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FACULTY OF TRANSPORTATION SCIENCES

# 20th Anniversary of the Faculty of Transportation Sciences Czech Technical University in Prague – Selected Papers

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## 20th Anniversary of the Faculty of Transportation Sciences, Czech Technical University in Prague

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## Selected Papers

Faculty of Transportation Sciences,
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**Dear colleagues,**

It is a great pleasure for me to address you concerning the occasion of the 20th anniversary celebration of the Faculty of Transportation Sciences that is an off-spring of the almost 305 years old Czech Technical University in Prague.

The Faculty of Transportation Sciences was founded in 1993 and has more than 1800 students, both undergraduate and postgraduate, while employing approximately 130 of academic staff. Due to the faculty's scientific and research activities that are applied in the industrial sphere, and in cooperation with universities all over the world, our graduates are sure to find a wide range of offers on the labour market.

All European regions face similar challenges in delivering sustainable transport solutions to meet their current and future mobility requirements. Transport authorities are aware of the real needs specific to their region but often find it difficult to gather sufficient information on relevant solutions that would bring about direct and tangible positive outcomes.

In my opinion, not only can transportation sciences contribute to the solution of the current transportation problems, but they may also become an instrument of further sustainable development of our society.

Referring to the papers presented herein, you can find that research results related to transportation are an excellent example of applied science in which understanding the intelligence in complex transport systems is an indespensable element of the given field.

I hope that our students and academic staff will always find the academic standards and the multidisciplinary environment of our faculty gratifying.

Let me express my most sincere wish that our faculty continues to prosper.

Yours,

**Miroslav Svítek**

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# DEPARTMENT OF APPLIED MATHEMATICS

# K611

The Department of Applied Mathematics was found in 1996. Since 1995 we have considerably contributed to curricula development in transportation sciences with emphasis on project oriented education which combines professional skill of academic staff and young would-be researchers. We understand this form of education can create a new spirit in all de-partments.

MISSION - Perform education of the Bachelor, Master and PhD. stu-dents in various mathematical disciplines with emphasis on analysis, geometry, probability, statistics, algebra, graph theory and discrete mathematics, and physics. Conduct fundamental research, and applied research in transportation sciences, recognised at European level. Cooperate with groups and departments of a similar orientation at the Czech Technical University.

RECENT IMPORTANT PROJECTS

- GACR P102/11/1795: Novel selective transforms for non-stationary signal processing
- GACR P108/10/P446 Multipurpose nanostructured carbon-based coatings for tribological applications
- TA 01030603 Novel control methods for urban traffic

RESEARCH ACTIVITY AND PROJECTS

1. Statistical methods and modelling of a large traffic system

The project deals with statistical pattern in modelling and controlling of a traffic network. Information about real system (urban traffic micro-area, motorway system, railway network) is obtained through the identification of the measured data. The traffic model is based on an opti-mal control synthesis which is carried out using Bayesian statistics methods.

2. Tribology of thin abrasion resistant coa-tings

Carbon-based coatings have significantly improved the working performance of the surfaces exposed to friction and wear in various environments. It has been showed that the driving effect of carbon-based coatings friction and wear is the third-body sliding interlayer formation. The aim of this project is to describe systematically friction, wear and the mechanisms leading to surface tribolayer formation. For this purpose, more carbon-based coating structures will be prepared. The research work is focused on interpretation of tribological measurements results obtained in ambient conditions, at elevated temperatures and also in vacuum environment. The main attention will be paid to deep analysis of surface tribolayer formation mechanisms, namelywear debris analysis, morphology, nucleation, growth, mechanical and thermal stability of surface tribolayer and its effect on tribological process.

3. Air Flow Visualisation using Infrared Camera

A technology to visualise air flow using infrared camera was developed. The main objective is to recognise laminar-to-turbulent transition and location of primary and secondary vortices over a wing. Results from flight tests which visualised surface flows using oil flow, tufts, or flow cones will be adjust to the infrared measurements.

4. Approximation, higher transcendental function for DSP and digital filter design

An innovative time-frequency transform has been devel-oped during the last 12 years of fundamental research in the field of function approximations and higher transcen-dental functions. In 1997 we discovered the algebraic form of Zolotarev polynomials refraining from a parametric representation, and developed an extremely efficient algorithm for evaluating them [10]. This method allows computation of expansion coefficients for Zolotarev polynomials of the first kind in terms of power series expansion and expansion into Chebyshev polynomials. In contrast to power series representation, the Chebyshev polynomial approach leads to coefficients valued in an astonishingly small range. The algorithm is of linear complexity with respect to the polynomial order and is robust enough to easily generate tens of thousands of degree polynomials. Since 1999 we have used Zolotarev polynomials for notch FIR filter design [2] – [4], [6], [8], [9]. Recently, (R. Spetik: The Discrete Zolotarev Transform, PhD. Thesis, FEE CTU, 2009), we have devel-oped the same algorithm for the Zolotarev polynomial of the second kind, which completes the set of functions generalizing a complex exponential. This marks the birth of a fundamentally new spectral transform of non-stationary signals. The method is based on signal decomposition of a 1D signal into a set of vectors related to Zolotarev polynomials of the first and second kind. We have named the novel method the Zolotarev Transform in honour of E.I. Zolotarev, who proposed and solved the approximation problems leading to these polynomials.

State-of-the-art, and beyond As the application of Zolo-tarev polynomials to the analysis of non-stationary signals came to us recently it needs further development beyond the state-of-the-art. The transform that we have developed is naturally reversible, with excellent time-frequency resolution. Moreover, the Zolotarev Transform is signal adaptive and therefore its time-frequency resolution can be continuously matched to the input signal for optimal representation. We have not yet published the algorithms for the selective sine function and selective exponential function, nor have we published the organisation of our transform and its reversibility. All these items are considered as central for our future study, development and potential applications.

There are several approaches available for addressing non-stationary signals, including the Short Time Fourier Transform (STFT), the Wavelet Transform (WT), and the Hilbert-Huang Transform (HHT). A large group of non-linear multiresolution transforms is also available. However, these approaches suffer from being difficult to interpret. STFT, WT, and HHT are therefore the most frequently used tools for non-stationary signal analysis. Researchers have devoted enormous efforts to the Wavelet Transform and Short Time Fourier Transform. The number of relevant publications confirms that this has been a field of considerable interest for decades. For example, a simple request on Web of Knowledge for "Wavelet Transform" reveals close to 570 publications in 2009. We are aware of a substantial number of these publications, but we will quote only a few selected references in formulating our project. We point out that our work is pioneering research, and the available references to other researchers in related fields do not reflect the efforts that we are proposing for our project.

5. History of mathematics

The objective of¨ the research is to enlarge students inter-est in mathematics in untraditional way, to show them historical-mathematical and technical relations and contribute to the cultivation of their technological thinking.

# How to Drive a Car Inexpensively and Safely

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**Abstract**

This paper deals with an automatic vehicle control system that on condition of adhering to safety rules and road laws minimizes fuel consumption. The proposal is based on a model of the following quantities: 'consumption' and 'speed' and the control quantities 'gas', 'brake' and 'gear'. The control is calculated in order to minimize fuel consumption with regards to approximate adherence to given recommended speed. This control is subordinated by a 'logic block' which specifically helps to adhere to road safety and road laws.

**Keywords:** control, system, model, fuel consumption, car driver system,

## 1. INTRODUCTION

The time period we live in is characterized by a huge increase in technology and automation. Man, as a living creature, and therefore relatively fragile being, is threatened by this growth of techniques. To solve this problem, there are two ways. The first one is to abandon the technique and to return to a natural life. We are not first who thought about this way. However, its implications for the modern man are so drastic that this way was not accepted by the most of society. The second way is based on consistent use of the technical and scientific progress and its utilization for man to help and protect him. Even this way is not entirely new and has previously been mentioned. "... something to shine and warm" (Čapek: Krakatit).

The aforementioned problem with all its consequences is particularly noticeable in traffic. Wagons with horses were replaced by cars and it meant progress. There was still no air pollution, gasoline was inexpensive and cars drove at a reasonable speed and a reasonable amount so that there was not a serious danger of accidents. However, this situation was not sustainable for a long time. It was transformed to the situation that we all know now: practically everybody has one or possibly two cars and he uses his car everywhere even to the places which can be comfortably reached on foot or by public transportation. This "development" is innate to humanity and it cannot be avoided. "Civilized man refused to adapt to their surroundings. Instead, he adapted the surroundings to him… However, somehow he did not realize when to stop " (Movie: The gods must be crazy).

The first mentioned solution means to give up cars at all. This solution is nowadays impassable. The latter one suggests ways how to use all the new technical possibilities and scientific potential in our benefit to minimize the negative impact of motoring. To this way, the research presented in this thesis also tries to contribute.

The aim of this research is to advise the driver in a driven car to go so that his ride was safe and efficient. The basis of the proposed solution is a model of driver-car system and a control design, build on this model, optimizing a compromise between minimum consumption and driving with a recommended speed. The recommended speed is proposed with regard to safety considerations and traffic laws.

The approach to this problem is outlined in the presented work. Chapter 2 deals with the problem description. Chapter 3 describes the model used and discussed. Chapters 4 and 5 are devoted to the control synthesis and Chapter 6 shows some preliminary simulation results.

## 2. THE PROBLEM OF INEXPENSIVE AND SAFE DRIVING

The approach used to solve selected problems is data dependent. For a description of our driver-car system, a regression model is used, estimated from measured data. A possibility of measuring the data and their specific selection for the model are therefore paramount.

Data, that can be used for modeling, are received from the company Škoda Auto CO. At a specially equipped vehicle Škoda Octavia, during driving, a number of variables were measured.

These variables are of three types:

- First modeled (output) variables - that is, those variables that we want and influence,
- Second control variables – i.e. variables which we can set an which influence the system,
- Other variables - which we cannot directly influence, but which have influence on the modeled values.

The group 1 includes variables that interest us from the viewpoint of their control. These are the variables "consumption" and "speed".

The group 2 contains the variables "gas", "brake" and "gear". Through these variables, the car is directly controlled and the driver manages them. However, at a reasonable (cost-conscious) riding the brake is practically not in use, and when used, then only to stop the car. But that is not a subject to optimization, but only a deterministic action necessary in the circumstances or the end of the ride. Therefore, only "gas" and "gear" remain in this group.

The group 3 contains "torque" produced by gas and having a direct impact on consumption, "engine speed", which is closely related to the selected gear and the "distance traveled", which is very closely tied to the speed of the car (which, otherwise, is quite difficult for modeling). These variables cannot be controlled directly, but have a significant impact on the modeled values.

The aim of the work is to synthesize optimal control realized by the variables "gas" and "gear" that minimizes deviations of the modeled variables from their set-points. They are zero value or some specified minimum for consumption and recommended velocity. Due to a stability of the solution, the method of dynamic programming on a finite horizon is used for the control synthesis. The set-point values on the whole control horizon are considered to be known in advance. Its future values are used for control at the current time – so called control with pre-programming. To be able to use the method of dynamic programming, we first need to model the controlled system.

## 3. MODEL OF THE CAR-DRIVER SYSTEM

For the reasons of modeling, we consider the variables in the form of random processes in the discrete time. We denote: $y_t$ - system output at time t (formed by the consumption and speed), $u_t$ - control variable at time t (gas and gear) a $v_t$ - external variables at time t (torque, revs and path). By $d_t = \{y_t, u_t, v_t\}$ we denote all data at time t and symbol $d(t) = \{d_0, d_1, ..., d_t\}$ represents all data from the beginning of modeling up to now including the prior information denoted by $d_0$.

As a model structure we choose normal linear regression model

$$y_t = b_0 u_t + c_0 v_t + \sum_{i=1}^{n} \left( a_i y_{t-i} + b_i u_{t-i} + c_i v_{t-i} \right) + k + e_t \,,$$

where $n$ is the model order, $e_t$ is random sequence with normal distribution, zero expectation and constant variance $r$ and $k$ is an offset of the model.

The parameters $a_i, b_i, c_i$ and $r$ are estimated from the measured data [1]. First of all it is necessary to determine suitable model order (so called structure estimation). It can be determined from the prior data sample (measured before the beginning of estimation). Very simple and reliable method is to normalize all data so, that they have zero expectation and variance equal to one. Then to perform model estimation (e.g. by the least squares method) and compare the absolute values of the estimated coefficients. Very small coefficients testify of the fact that the corresponding variable has only small or even no influence to the modeled one. So, we take into the model only those variables whose coefficients are in absolute value bigger than some level.

## 4. INEXPENSIVE AND SAFE DRIVING

With the model which is now designed and pre-set from the prior data, we can start the control synthesis. It is designed so that to minimize an expectation of the quadratic criterion $Q$

$$Q = \min_{U \in U^*} E\left[\sum_{t=1}^{N} Q_t \middle| d_0\right],$$

$$Q_t = (y_t - s_t)' \omega (y_t - s_t) + (u_t - u_{t-1})' \lambda (u_t - u_{t-1}),$$

where $N$ is control horizon, $U = \{u_1, u_2, ..., u_N\}$ is control in the interval $t = 1,2,..., N$, $U^*$ is a set of all possible values of the control variable and $s_t$ is the set-point for the output variable $y_t$ (i.e. for the speed and consumption). The second term in the expression $Q_t$ is a penalization of the control increments. This term is important to damp permanent variations of the control, e.g. permanent changes of the gear. $\omega$ and $\lambda$ are diagonal matrices with positive numbers on diagonals. Their specific choice determines the penalization of individual controlled variables, i.e. how much the control algorithm will adhere to minimization of the consumption or to maintaining the prescribed speed. The prior data $d_0$ is necessary for the start of the control algorithm at the beginning of the control.

The control on the finite horizon is considered because there are well known troubles with the stability of the so called one-step-ahead control. This method optimizes only for the next step of the control. It tries to reach its goal as quickly as possible and thus generates very large control actions. They are so large, that they can excite the system so much that it cannot be stabilized later on. Another advantage of the method of finite horizon is a possibility of using the pre-programmed set-points. Due to this, the control algorithm has information e.g. about the curve which is approaching and can take it into account. It can gradually slow down to save the petrol.

The optimization is based on the compromise between a inexpensive driving and short travelling time. On condition of requiring only the inexpensive driving, we would obtain trivial solution – not to drive, at all.

As we want to go, we must also imbed this condition into the criterion. We can do it by determining a recommended speed at which the car should go during the way. In our previous considerations, the recommended speed was constructed expertly from the map of the planned route. In further research, this speed should be modeled and designed in the basis of the data, which are taken from the navigation system. Then, the control algorithm for minimization of the chosen criterion optimizes the control variable so that the car moves as close as possible to the recommended speed and wherever it is possible and convenient it also saves fuel. The main savings while driving may be (i) gradual slowing when a curve is approaching, (ii) gradual taking speed after passing a curve, (iii) taking higher revs before an ascend, (iv) gas-free driving downhill. These main principles of low-cost driving are generally know. Nevertheless, we believe that such situation in which it is possible to save is much more and that they will be discovered and exploited by the optimization algorithm.

As we already mentioned, the model used for the synthesis must be a priori pre-set. However, nothing excludes a possibility of its further estimation during the driving. In that case, we tackle the task of simultaneous estimation and control which is the task of dual programming. It is known that this task has no feasible solution. That is reason, why we use the suboptimal method of the receding horizon. According to this method, we proceed as follows: (i) at the present time instant we compute the point estimates of the model parameters and (ii) compute the control synthesis for the whole control interval starting at its end and going against the time to its beginning. From the whole set of computed control laws we use only the last one for the actual time instant. After application of the actual control, we measure new output variable and with the new data pair we can do a new step of estimation and receive new point estimates of parameters. The control interval is moved one step ahead. This procedure is then repeated [2,3].

For realization of the adaptive control algorithm, the method of iterations spread in time is used. In this method, the calculation of the optimal control does not start according to the theory from zero initial conditions in the control interval but from the results of the previous time instant. Thus, even if the control law does not reach the steady state within a single control interval, it stabilizes in the following time periods and this is how the method got its name. The advantage of this method is that we can choose very short control interval which saves computational time and allows the control in real time tasks.

The computation of the optimal control on a finite horizon runs according to the following algorithm:

$$\varphi^*_{N+1} = 0$$
$$for\ t = N, N-1, \ldots, 1$$
$$\varphi_t = E\left[\varphi^*_{t+1} + Q_t \middle| u_t, d(t-1)\right]$$
$$\varphi^*_t = \min_{u_t} \varphi_t, \quad u^*_t = \arg\min_{u_t} \varphi_t$$
$$end$$

where $\varphi_t$ is so called Bellman function, that represents the value of the optimized criterion at time t, and $\varphi^*_t$ is the value of the criterion after.

As indicated, the computations go from the end of the control horizon. The optimal control is computed at each step. However, it cannot be applied immediately as the data needed is not at disposal at the moment. Even, when we come to the beginning of the control interval, we have the necessary data and we can compute and implement the control. The core of the algorithm is the expectation and subsequent minimization. These two steps are permanently repeated on the control interval.

## 5. LOGICAL BLOCK OF CONTROL

Optimal control is what we want, however, if the optimal speed is 55 km/h and the maximum allowed is 50 km/h, we will have to respect the lower speed even at the cost of higher consumption. That is why we have to construct a superordinate block of logical control that supervises the automatic control and checks the safety and traffic rules of the driving. In addition to controlling speed limit, this block checks also that is going downhill is gas-free, or signaling a pedestrian crossing or controlled intersections.

## 6. RESULTS OF SIMULATION EXPERIMENTS

Experiments with the proposed control algorithm were implemented for data measured on the chosen test circuit with the length approximately 40 km, which is located near Mladá Boleslav. This path leads first along the highway continues along the road of first class and the last part of the road leads second class. It also passes through several villages. Thus the measured data include all major types of riding which guarantees the representativeness of the sample. This sample includes data from eight trips through the circuit starting with a quiet ride (cost-saving) up to rather wild ride (sport-like). This data serves as both a prior data and to a comparison with the results obtained with automatic driving. According to these data and with the help of experts, the recommended speed for the test circuit was also constructed.

For testing purposes of the control algorithm, a software simulator of the car consumption has been designed. This simulator is built on basic physical relations between variables which affect the consumption of a car. The simulator has been tested on real data and its quality was more than good. Of course, the final results can be confirmed through the tests on a real car, only. This verification has not been performed, yet. However, this test is under preparation.

For the experiments, we used the second order regression model. This model has been off-line pre-set using the sample a priori data of 1000 measurements. The rate of data sampling is 5 times per second. The sample of prior data thus takes approximately 3.3 minutes. An important characteristic of the control are penalty coefficients used in the control criteria. Deviations of the modeled variables consumption and speed from of their required courses are penalized as well as variations of control variables gas and gear. Penalties for outcomes were the same and equal to one. Penalties of control variations were chosen 1000. This great penalty is to prevent abrupt changes in the values of the control variables. As it is a penalization of the variation only, it does not lead to permanent offset in the modeled variables. The control horizon was chosen with the length 5. It is permitted by the use of the method of iterations spread in time. Time of calculation procedures for 750000 samples is 8 seconds.

Figure 6.1, in the left part shows the controlled variable "consumption" (solid red line) and at the same time the consumption, which was achieved under the same conditions when during the measurement rides (blue dotted line). For information, the course of the desired consumption is plotted, too (green dashed line). It is equal to 85% of the consumption of the average value of this variable from the prior data sample. In the right hand side of Figure 6.1, the variable “speed” is displayed by the same type of lines. This is the speed controlled (red) reached during measurement (blue) and reference (green). The figures show part of the journey of the 1,000 samples (i.e. again about 3.3 minutes) of driving. A longer segment of driving produces unclear graphs. The selected section shows the essential characteristics of the control. From the graphs, it is clear, that the main savings when driving are obtained by reducing peaks in consumption, which is achieved by gentle handling of the gas and by a little slower driving.

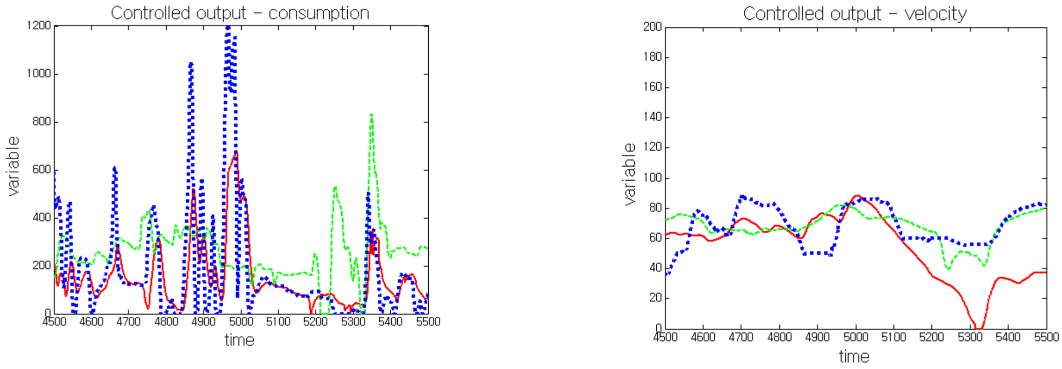


Figure 6.1 – Controlled output – consumption (left), speed (right)

Interestingly, Figure 6.2 shows the control variables on the same road segment that is shown in the previous graph. The blue line is the variable "gas" (the percentage of compression of the gas pedal) and "gear" (ten times a gear - for visibility graph along with the gas). We see that the car mostly goes to the sixth grade. It is allowed by the considerable power of the engine Škoda Octavia.

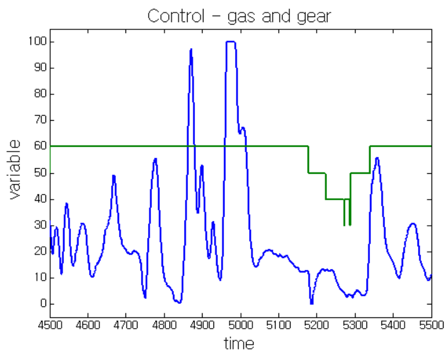


Figure 6.2 – Control – gas and gear

## 7. Conclusions

The paper introduces an adaptive software control system, generating as control variables the ratio of pressing the gas pedal and the gear used for driving. The generated control ensures minimal consumption during driving on condition of maintaining, as far as possible, the prescribed recommended speed. Automatic control is dominated by the logic control block whose job is to ensure driving safety and compliance with traffic rules.

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# Data reduction of traffic detectors

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**Abstract**

The complicated traffic situation in Prague is not only due to a rise the number of cars in the last few years, but also due to historical formed streets which are not able to fully satisfy present traffic performances. Also the ratio of motorization is higher here than, for example, in Vienna or Cologne. Using standard methods cannot solve the enormous traffic problems - a new approach should be used.
The traffic control in an area of Prague discussed in this paper is based on an adaptive control MOTION. Often, the level of service (LOS) in this area is on the threshold of saturation when the control system cannot significantly improve the situation. For this reason it has to be supported by another system, which provides information about the current traffic conditions to drivers and together create a hybrid traffic management system. Variable message signs (VMS) are used to distribute this information. This paper describes the way how information about LOS can be collected from the induct loops and distributed to the VMS. Most attention is paid to an automated mining of data from detectors. The algorithm used is based on clustering using genetic algorithms.

**Keywords:** traffic sensors, inductive loops, clusters, reduction, control

## 1. INTRODUCTION

Most of modern cities have similar problem - an excessive amount of traffic. Building of new infrastructure or improving the control of intersections is one of the solutions. It cannot be used everywhere. Prague, the capital of Czech Republic, is an example of a historical town in which not many new roads can be built and the control algorithms are pretty sophisticated already. One of the solutions how to decrease congestions is by navigation drivers via alternate roads. This advance vehicle navigation can be done using GPS and navigation services, or using so called variable message signs (VMS). VMS are usually located at critical points of the network and are supposed to deliver to drivers information about traffic situation and possible recommend them some better way to their destination. However, both of these systems do need quite large amount of accurate traffic situation. Their reaction must be fast. This information can be obtained from a city traffic management office, from the police or some random sources (such as drivers passing through critical parts of the system) or from traffic detectors.

Probably the most common detectors in most cities are so called induct loops. The data on each detector are collected in regular time intervals and their amount is really huge. In many cases, the data are collected but no algorithm is known to determine which data are significant and how they can be used.

In this paper, we would like to suggest a solution on how to choose relevant information from these detectors. We will provide an overview of the steps that must be accomplished in order to extract data from induct loops. Usually the VMS display information about the level of service (LOS) or about travel time. In this paper we focus on methodology on how to determine the level of service.

### *1.1. Study area*

The data used in this paper are from one particular area of Prague, particularly its left bank (Prague 5) that is known for problems with congestions. However this area has quite sophisticated control already - an adaptive control algorithm MOTION.. There are 64 intersections controlled by this algorithm. In order to provide data for the MOTION, many induct loops detectors are installed in the area.

Some are located about 50 meters from the stop lines and provide information for the local dynamics of the intersections. Others so called strategic detectors are located farther from the detectors and are supposed to help to determine the overall situation in the network. Both types of detectors and their position in the study area are depicted in Fig. 1.

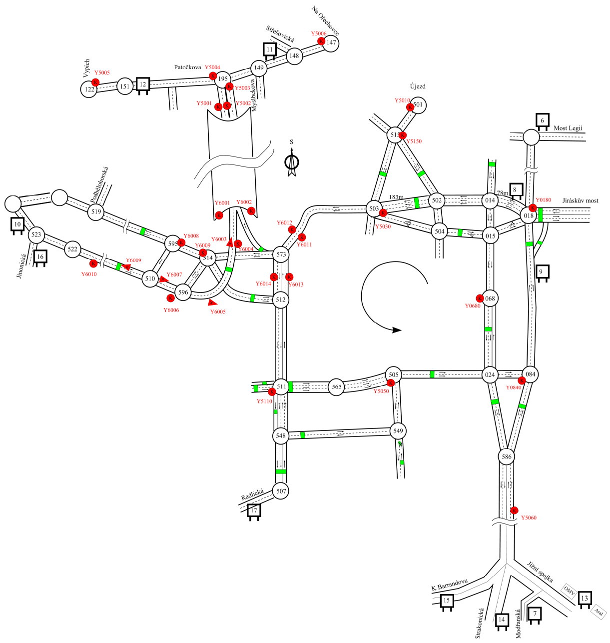

Fig 1: The controlled area.

It is possible to see also the VMS located usually at the entrance to the area in this figure (black squares).

## 2. ALGORITHM IN BRIEF

The proposed methodology for determining the LOS that could be used for the VMS consists of three steps.

First, the data from detectors must be filtered in order to get rid of random fluctuation and to have data that really describe given traffic situation. Since there is too much redundancy in the data, only relevant data or relevant detectors must be chosen in the second step. And finally, some automated classification of the data must be performed to determine LOS.

All three steps will be briefly discussed in this paper, however the objective of this paper is to introduce a new algorithm for data reduction (the second step) so the most attention will be paid to this step.

### *2.1. Filtering of data*

The raw data measured on the detectors are not well suitable for the purpose of LOS determination because of their large fluctuation (see for example Figure 2). It is given by the random character of traffic flow, influence of slow moving vehicles, or for example the impact of signal control. These random effects should be removed from the signal. This step is usually referred to as *data pre-processing*.

Several different techniques can be used for filtering. Probably the most common method is called *exponential smoothing*. This filtering is based on the following equation:

$$\overline{D}_t = \overline{D}_{t-1} + \alpha \cdot (D_t - \overline{D}_{t-1}) \qquad (1)$$

where $\overline{D}_t$ denotes the current filtered value of the time series, $\overline{D}_{t-1}$ the previous filtered value, $D_t$, is the current observed value, and α is the smoothing factor. The factor alpha determines the level of filtering. The higher the alpha, the more fluctuation is persisted in the filtered signal. In our preliminary studies, several different values of alpha have been tested in ref. [5]. An example of the results is presented in Fig. 2. The best results were obtained for so called exponential smoothing with variable coefficient alpha. The coefficient is computed in every time step based on the trend of the time series. Since it is not the focus of this paper, we recommend you to see ref. [5] for more details. A simple exponential smoothing with fixed coefficient alpha (for example set to 0,2) could be sufficient for any experiments.

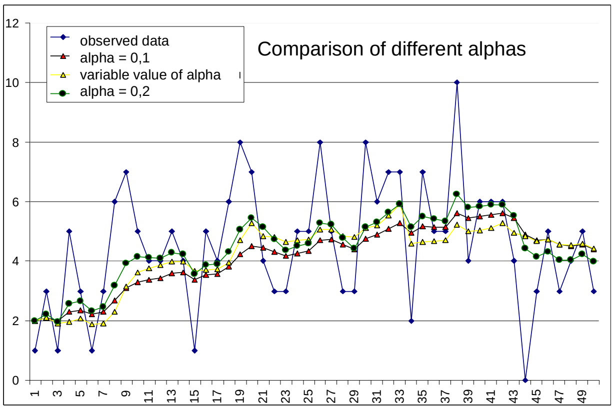


Figure 2: The effect of the coefficient alpha in exponential smoothing

### *2.2. Data reduction*

The amount of data collected from induct loops is really huge. Every detector provides the value of traffic flow and occupancy of the detector in aggregated values every 90 seconds in the centre of Prague. Considering the amount of traffic detectors (several at every intersection), detectors, the resulting number is really too big for processing. An important fact also is, that the detectors are often placed on several intersections in one line, so that their output is similar. An example of the data from two detectors placed two consecutive intersections from a city of Prague is provided in Fig. 3. We can see that these time series have similar trend and values only slightly delayed at the intersection downstream.

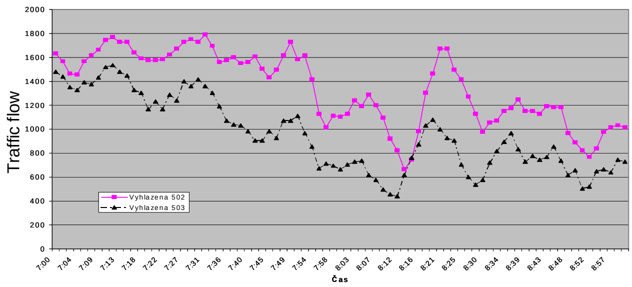


Fig. 3: Comparison of filtered data from two consecutive detectors in Prague.

For this reason, before we provide the data to an automated classifier, a selection from the set of detectors should be performed. The cluster analysis is recommended and used within this paper. The details of the algorithm are provided below. First we shortly describe the third step of the analysis – automated classification of LOS.

### *2.3. Automated classification of LOS*

At this phase, the resulting data are used for an automated classification of traffic. There are several algorithms that can be used. The classification in used in this paper is based on Fuzzy linguistic rules applied to flow and occupancy. The main effort was to concentrate on determination of fuzzy rules and consequently to verify it. The sequences of typical traffic situations in the Prague were recorded and a group of experts (mainly police) filled in special questioners oriented to description of traffic and to human classification. Thirty-two fuzzy linguistic rules were elaborated on this basis. This step will not be described in more details in this paper since it is not its main focus, but you can see ref. [7] for more details on the algorithm.

## 3. CLUSTER ANALYSIS FOR DATA REDUCTION

### *3.1. K-Medoids clustering*

There is a large number of well-known clustering algorithms, such as hierarchical clustering, or k-means clustering (which belong to the class of partitioning algorithm). This paper approaches the medoids-based formulation of clustering problem using genetic algorithms (GAs), a probabilistic search algorithm that simulates natural evolution. The method in this paper is based on so called *k-medoid clustering*, ref. [4].

Consider a set $S=\{S_1, \ldots, S_N\}$ of $N$ objects (in our case activity patterns). Each object $S_i$ is a vector, containing of $L$ integer values describing an activity type at particular time instant. Our objective is to find $K$ objects, $m_1, \ldots, m_K$, which represent all objects in the data set. The remaining objects are then assigned to the nearest representative object, using a given dissimilarity measure.

Mathematically, we are looking for a set of $K$ objects, $K<<N$, that minimizes the following *objective function*, $F_K$:

$$F_K = \sum_{i=1}^{N} \min_{t=1,\ldots,K} d(S_i, m_t) \tag{2}$$

In this equation, $F_K$ is the sum of dissimilarities of all objects $S_i$ to their nearest medoid.

An advantage of this method is also in the fact that it uses only a dissimilarity matrix and not the original data. This implies that this method can be used for any type of data as long as we know how to measure dissimilarities among objects in the dataset.

The developed algorithm requires the number of clusters, $K$, to be known. In order to find the optimal number of clusters, the algorithm will be repeated for different numbers of clusters. The optimal number will be chosen off-line, after the clustering problem for different $K$ will be performed. So called *silhouette width* are used to automatically determine the optimal number of clusters. The method was also first designed and described by [4] and you should see their work for more details.

### *3.2. GA-based implementation of K-medoids*

In order to avoid some limitations of the algorithm such as finding only local extremes, genetic algorithms are used for implementing the problem. The most common clustering techniques mentioned in the previous section, such as partitioning methods are so-called greedy algorithms, i.e. they look for the biggest improvement at each step. This does not ensure finding the global optima. Also their performance is very sensitive to the initial partitioning, that is in most cases done randomly. Using a genetic algorithm also does not ensure reaching the global optimum. The result depends mostly on the setting of its parameters, for example the selection mechanism, probability and type of recombination. However, the existing literature demonstrates that genetic algorithms are well suited for clustering and with the right parameter setting outperform standard clustering.

In this study, an algorithm developed in ref. [5] is used. It implements partitioning around medoids using genetic algorithms. The algorithm is rather robust and not too sensitive to its parameter settings, which is its significant advantage.

## 4. DATA REDUCTION – AN EXAMPLE OF IMPLEMENTATION

In order to demonstrate the functionality of the algorithm in a clear matter, the results from a small experiment are presented in this section. A subpart of the study area equipped with eighteen detectors was chosen. The data from one day (Wednesday, September) were collected a the k-medoids clustering was performed. This small-size experiment has the advantage that the results can be visually verified. The study area together with marked induct loops is depicted in Fig. 4.

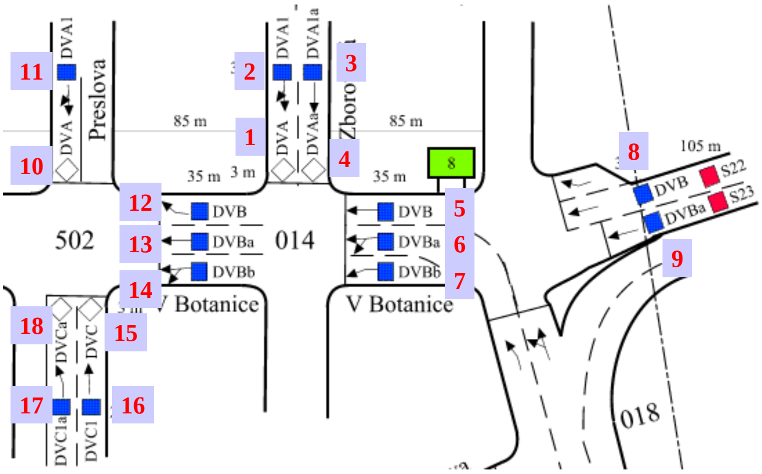

Fig. 4: The study area

The dissimilarities among the time series collected on particular detectors are the important input for the cluster algorithm. They can be computed in different manners and will affect the result of the algorithm. Based on preliminary tests, a dissimilarity measure based on the coefficient of correlation between the time series measured on the detectors is used. The value of dissimilarity is computed according to the following equation.

$$d(x,y) = 1 - |r_{xy}| \quad (3)$$

where $d(x,y)$ is the dissimilarity between objects $x$ and $y$, and $r_{xy}$ is the corresponding coefficient of correlation. The resulting matrix for our example is graphically depicted in Fig. 5. The darker the area, the smaller the dissimilarities.

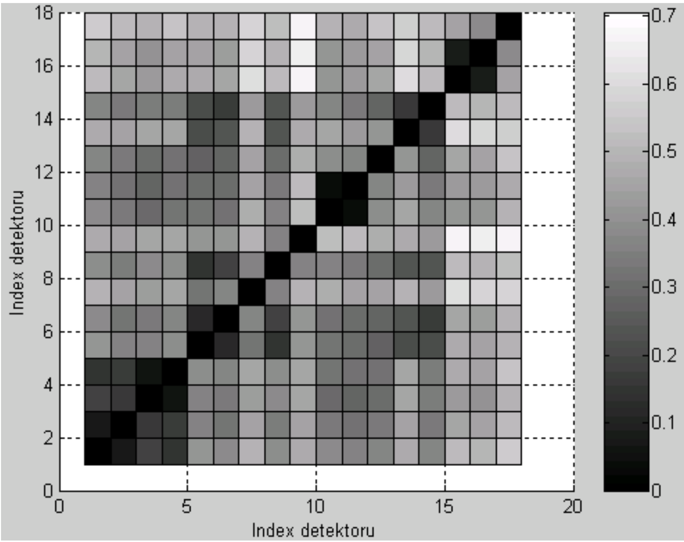


Fig. 5: The dissimilarities among detectors in the area

This matrix was used as an input to the algorithm. Since we do not know the optimal number of clusters, K, the algorithm must be performed several times, once for every K. the K was chosen from interval {2,…, 8}. The silhouette width was computed for every run and it is depicted in Fig. 6. The maximum silhouette width was obtained for five clusters, which is then the optimal number of clusters.

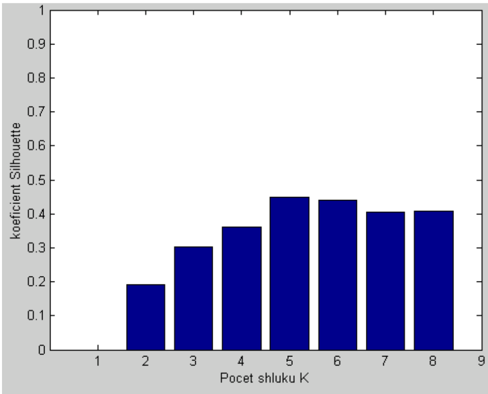


Figure 6: The dependence of the silhouette width on the number of clusters K.

The results of the analysis are provided in the following list, which shows assignment of particular detectors into clusters. The medoids (by other words, the most representative detectors) are stressed in bold:

Cluster 1: detector 1, 2, **3**, 4
Cluster 2: detector **5**, 6 ,7, 8, 9, 12, 13, 14
Cluster 3: detector 10, **11**
Cluster 4: detector 15, **16**
Cluster 5: detector **17**, 18

These results are also shown graphically in Fig. 7. If we look carefully at the study are, the results will not be too surprising. The advantage is that all this has been done automatically without deep knowledge of the study area. The algorithm determines the optimal number of clusters and finds detectors that carry the most significant information about the traffic situation in study area.

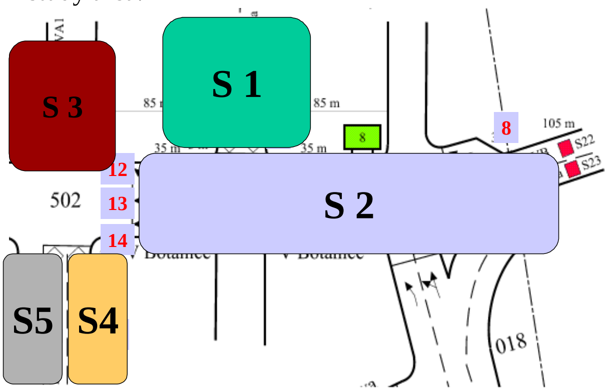


Figure 7: The results of cluster analysis

*4.1. Verification of the system*

The theoretical steps described in this paper were practically implemented and evaluated on a sample area in Prague. For one week (13-19.5.2003), the system generated automated messages on the information displays. The police supervised the entire system using CCTV cameras in the Main Traffic Control Centre. Their expert opinion was compared to the values generated by the automated system every 15 minutes, from 6am to 10pm, ref. [7]. Ten information displays located at the entrances to the tested area were wirelessly controlled by the algorithm described above. Finally, we should mention that there are five categories of LOS in the Czech Republic. Fig. 8 implies that the performance of the system is quite acceptable. The example displays automatically generated LOS and LOS suggested by experts (police) for a VMS at the south entrance to the investigated area. The figure shows that maximum difference between expert and automatic evaluation is one level. Due to the stochastic character of traffic flow this result seems to be quite sufficient. Only in few cases for specific configuration of sensors the computed value had to be manually calibrated by constant drift in plus or minus direction in accordance to expert decisions.

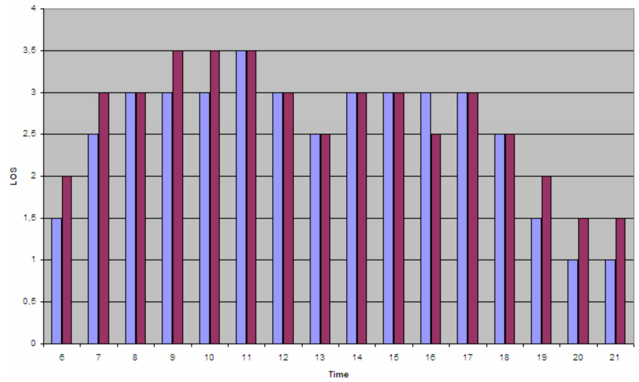


Figure 8: The automatically generated LOS (purple) compared to the expert decisions (blue)

## 5. CONCLUSIONS

Main objective of this paper is to gain information from traffic detectors and distribute it to the drtivers. It is an essential task for any automated management system in urban areas. There is a large amount of data that are similar in absolute values or trends. Their information value is for this reason weak. Only those detectors that provide the most information are used as an input to any automated system for classification or other telematics task.

In this paper, the methodology for an automated LOS determination was described. Examples of implementation were shown and the result of the entire algorithm was presented. Overall, the algorithm proved its usage and the results are satisfactory. Further testing and its use in practice should be considered.

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# Time-Frequency Stamp of a Moving Vehicle and Its Applications

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**Abstract**

The paper is dedicated to traffic sound analysis. The main objective of the research is aimed at traffic flow parameter – velocity. The second important objective is vehicle sound stamp. The recordings imply from sound coming from usual city vehicles - personal cars, tramways, buses and lorries. All these sounds were carefully recorded in different cities, under different weather conditions. Here we examine the recorded data from the view of sound signal magnitude and signal frequency spectrum. The tool used for the spectral analysis of non-stationary signals is Short-Time Fourier Transform (STFT) with its time-frequency output – spectrogram. According to the sound, we present an approach to identify respective vehicle type, car, tram or bus (lorry). The final analysis is intended to estimate velocity of a personal car with stress on measurement in one point of vehicle trajectory. The speed is computed by tracking the declination of overall signal magnitude.

**Keywords:** Fourier Transform, signal analysis, vehicle sound, Zolotarev Transform, spectrogram, windowing

## 1. Introduction

We can distinguish two main categories of signals. First, it is stationary signal. Its parameters are not time-dependent; they are usually called the time-invariant parameters. The output repeats regularly in time, there are the same values in different time instants. On the opposite side, we have non-stationary signal. Its parameters are time-dependent, their definition changes in almost each time instant. For instance, revolution change when a vehicle accelerates is a typical non-stationary signal.

Vehicle sound signal is also a non-stationary signal. In practise, to analyze a signal, we need to segment signal into smaller parts called windows. A signal segment can look like a stationary one and we can apply Fourier Transform. The length of window is crucial for appropriate results and can differ with source of the sound. For example, if we deal with human speech, a usual length of window is 20 ms. In our case, the window length was 11,6 ms.

The thesis was structured in accordance with concept of the data processing (data acquisition, signal pre-processing, digital signal processing and interpretation).

The part dealing with the data acquisition is devoted to real experience with sound recording, weather and vicinity conditions. Then, following device data sheet, general technical parameters are mentioned. It includes sampling rate, frequency range and sensitivity adjustment. Next chapter describes data pre-processing (segmentation, search for relevant data, avoiding the noise) and proper data processing (Fourier Transform, summation, maxima, gradient, peak representation). The final part is dealing with data interpretation which can provide knowledge and understanding of the data sets.

The frequency stamp of a vehicle is one part of the research. According to the sound, we present an approach to identify respective vehicle type, car, tram or bus (lorry). There are several scientists, who dealt with frequency stamp of a vehicle. Vehicle sound signature recognition by frequency vector principal component analysis was introduced by collective Wu, Siegel, Khosla [7]. Waveletbased acoustic detection of moving vehicles was processed by collective Zheludev, Averbuch, Hulata, Kozlov, Rabin, Schclar [8, 9]. In comparison to these studies, we propose an approach based only on time-frequency signal behaviour represented by spectrogram.

## 2. Data acquisition process

The goal of this section is to introduce measurement process. We have performed the acoustic measurement. Actually we have recorded the street sounds, and seldom taken video records as well. Video records are not directly used for computations in the thesis, they state as a verification of results. The second very important role of video records is that they significantly helped to tune the program for speed measurement, when estimating the vehicle speed only in one point.

The data acquisition was performed with remarkable help of student colleagues and friends, who witnessed and took additional records and notes. Thanks to them, a database of different means of transportation was made easier and much faster.

We describe several points, which have the greatest effect on measurement quality and consequently, on results. They are:

- kind of devices used
- close vicinity of measurement place - the location
- the weather conditions
- road surface

## 3. Data files for processing

This part deals with data itself, from obtaining data up to the results. First of all, we would like to give a frame to the task how to get appropriate outputs. The system is described as a virtual system of vehicle recognition.

In the beginning, there are sounds which we want to analyze. The point is in recording such amount of data, which on one hand correctly represent the event, but on the other hand are not useless, redundant or too long for software processing. There are two possibilities, how to reduce amount of data. Either we can change sampling rate of recorder to lower frequency or we can change length of the sound record. In fact, we look for a compromise between long enough and short enough in time domain, because change of sampling rate evokes loss of information necessary for frequency analysis.

Consequently, we chose to change the length of sound signal. It was a requirement from Matlab software, because of difficulty of computational task. If we want to do spectral analysis of any signal, we must deal with large amount of data because of windowing and overlapping. For instance, let the sampling rate to be 44,1 kHz. If we consider a record longer than 30 seconds, there are at least 1,323 millions of samples to be processed in Matlab. Then we store basic conditions to window length and overlapping, which raises number of computational tasks, extremely. Experimentally, in our case, when a record was longer than 30 seconds, there was a Matlab alert of exceeding memory dispositions. So we concentrated on shorter signal segments, cut manually by Marantz professional software, or later cut automatically by Matlab (auto segmentation).

### *3.1. Vehicle count*

Let us count the peaks and we obtain number of vehicles passed by, directly (printscreen in the figure 1). It is because only a loud continuous sound source can produce such a significant audible signal, which is identified as a vehicle, correctly. If we sum up all the peaks higher than 5 times average noise, we get number 6 - representing number of vehicle recorded. There exists a danger of incorrect identification of through pass. It is the case of two vehicles driving in opposite direction and meeting the recording point in the same or nearly the same moment. Then, only one vehicle is identified and the peaks of both vehicles are too close to be distinguished.

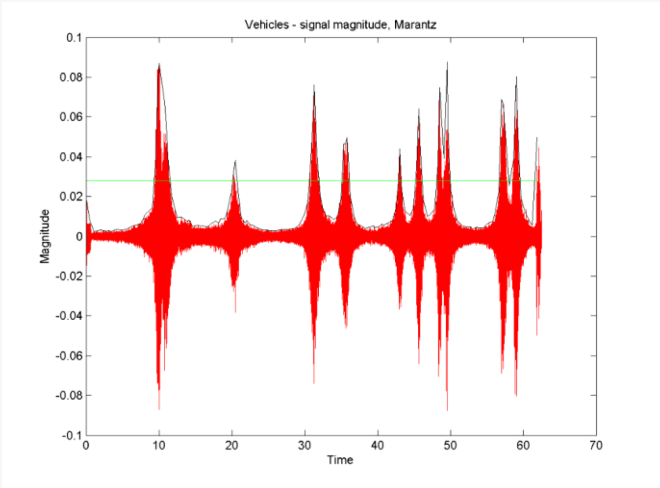


Fig. 1. Peaks of signal, threshold value

## 4. Detailed sound analysis

This chapter demonstrates the steps of sound analysis, with the goal to understand signal behaviour and find differences between various types of vehicles. Reasonably, there are similarities between two car records, although taken in unlike places. There are four main identification fields, which we use:

- Magnitude of the signal
- Frequency spectrum of the signal
- Signal spectrogram
- Analysis of one frequency behaviour in time domain

First of all, we plot magnitude of the signal, which is usually higher than average noise. Plot of magnitude, or simply signal behaviour, represents time domain.

Another issue is to use Fourier Transform to get frequency spectrum, in other words a state of frequency domain. The merge of both is well done in spectrogram - a powerful tool, which reveals frequency domain changing in time. The last identifier is created from spectrogram, when we get time behaviour of single frequency.

## 5. Results

Two main goals of the document are stamp of vehicle and car speed measurement.

They are connected very closely, because if we want to determine vehicle speed, we need to know what type it is. It is a necessary condition, because we considered only passenger cars. The length of car is equal to 5 m in the computations.

The length of a car changes widely through the car type spectrum driving in Czech Republic. So we took the value 5 m, used also in inductive loop detection with reference to traffic flow parameters.

### *5.1. Stamp of vehicle*

Central idea of vehicle stamp is in identification of specified frequencies. We distinguish three types of vehicles, which are usually available in Prague - car, tramway and bus (lorry). Each of them has its own expression because of:

- type of surface it moves - railway (tramway) or road surface (bus, lorry, car, pick-ups), adhesiveness and friction

- engine construction and revolutions - combustion engine, electricity as a power supply, low or high revolutions, sound intensity of engine
- aerodynamic resistance
- additional sounds - air conditioning, brakes, compressors

The best visual perception of changing frequencies is undoubtedly in spectrogram.

This is the starting point. We compared spectrograms of the same vehicle type and then looked for the difference between the classes. There are some features, characteristic only for one group, which are written in autonomous sections.

The stamp was created by just a few rules, evolved from spectrograms observations. So, all the rules are copying eye perception of colours and shapes.

First of all, we try to identify some periodicity of peaks created in spectrogram - acting partly as independent peaks. Human eye does is by perceiving yellow colour on blue background. Yellow colour in spectrogram refers to approximately one half of damping (one half of maximum amplitude), while blue one is colour of significantly high damping (low amplitude). We enquire time behaviour of higher frequency (9000 Hz), because this frequency appears only if vehicle is truly present. Then we sum up the peaks. Longer transportation means (a tramway) have their axles further than a passenger car. To compare with lorry, a lorry has the axles further too, but produces one continuous peak. If traction gears are truly more than 5 meters distant, more peaks can emerge in the signal spectrogram (example: 3 peaks, tramway in figure 2).

Rule states if there are more than two peaks, sort a sound as a tram. Otherwise judge next conditions. Next identification rule was done from shapes occurrence, precisely curves and lines. They are clearly visible in higher frequency band, from 6000 up to 15000 Hz, if the records are not noisy. This concerns only buses, lorries and railway vehicles (trams). We compute gradient (first derivation) through the frequency spectrum for each time instant. Then, a curve or a line is localized and points belonging to curve are picked up. We fit a line into and get a tangent - first parameter of line (parameter a)

$$y = ax + b$$

which tells about line declination.

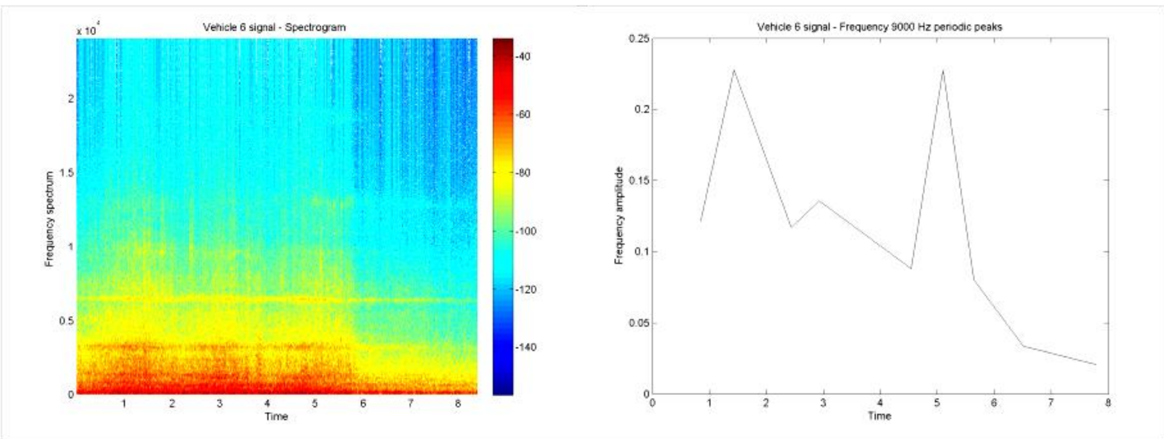


Fig. 2. (a) Tramway - spectrogram; (b) Tramway - rule one, peaks on 9000 Hz

If a line is nearly horizontal, the tangent is small, if the tangent is really horizontal then the tangent is equal to 0. If there was a steep curve and is fitted by a line, the line is steep, too. So the tangent reaches greater values (figure 3). The second rule is set up in program experimentally, if the parameter is lower than 150, claim sort of tramway, otherwise check next condition.

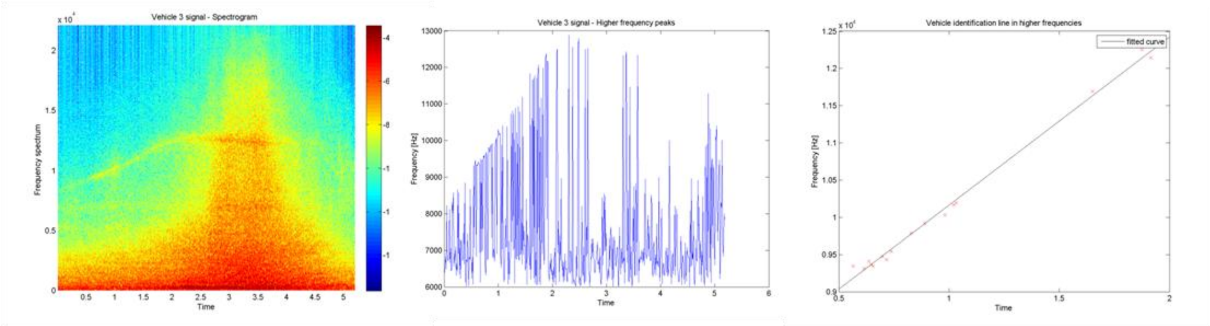


Fig. 3. (a) Bus / Lorry spectrogram; (b) frequency curve detail; (c) curve approximated by line and its tangent

A passenger car spectrogram is a nearly symmetric hill with no outstanding lines or gaps. This assumption counts for all the records of passenger cars we have recorded. First of all, application of rule two is necessary, because if system evaluates that no curves or lines are detected, it implies car type. No line fit is done, because no real curve exists in spectrogram in higher frequencies.

*5.2. Speed measurement*

One point speed measurement is done hand in hand with signal magnitude analysis. The first option is to fit signal magnitude points with a line. The points are local maxima (among defined number of samples) of absolute value of original signal. The tangent computed as a result after fitting the points is used for speed evaluation. The equation

$$v = 535 * p1 + 25$$

was derived experimentally, where p1 is the tangent. The tangent is supported only with those points, which are located before global maximum (the highest value of magnitude, when a car was closest and gave the loudest sound), figure 4.

The final stage is two point speed measurement, when two devices were at disposal (one professional recording device, the second one a mobile phone). By matching both data sets we are able to compute the time differences in signal magnitude peaks. The distance between the two measurement points is 10 m and so we can easily compute the velocity of a car passing by. The final results are in the figure 5.

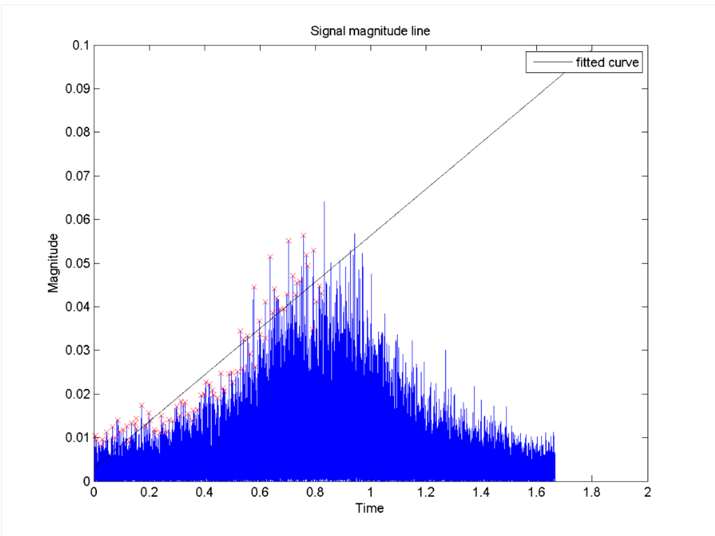


Fig. 4. Magnitude analysis and tangent line

| RECORD | MAGNITUDE ANALYSIS [km/h] | RADAR DEVICE [km/h] | TWO RECORDS [km/h] |
|---|---|---|---|
| hs 2 | 36 | 45 | 41 |
| hs 6 | 41 | 39 | 43 |
| hs 7 | 54 | 38 | 40 |
| hs 8 | 54 | 43 | 49 |
| hs 9 | 32 | 42 | 59 |
| hs 10 | 50 | 50 | 39 |
| hs 11 | 59 | 45 | 52 |

Fig. 5. Results of the speed measurement

## 6. Conclusion

We have tried several approaches to speed measurement and a part of the results are very close to reference value observed on RADAR device installed nearby. In our opinion, there is a huge potential in sound signal analysis for traffic purposes. The sound-based devices (microphones, sensors, arrays) do not depend on day time or on visibility conditions. They are non-intrusive, what means that they do not disrupt road surface. Every vehicle has its own representative sound demonstration and this may be the proper identifier serving in future traffic data collection and recognition.

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# General relativity in the Institute of applied Mathematics

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**Abstract**

In this contribution we present the research in the area of general relativity. Without entering the details and calculations, we motivate the study of mathematical physics and then focus on two selected problems: helical symmetry and the problem of energy in GR. We present our recent results.

**Keywords:** general relativity, helical symmetry, binary systems, spinors, conformal techniques, twistor eqaution, quasi-local quantities

## 1. INTRODUCTION

Mathematics is often referred to as „the Queen of the Sciences“. It is customary to distinguish the *pure* mathematics and the *applied* mathematics. The former branch is not a priori interested in potential applications and its purpose is to formulate deep and beautiful theorems about the abstract notions without direct relation to the (material) reality. The latter branch, on the other hand, is concerned with particular practical problems which emerge in the other disciplines. The scope of applied mathematics is amazing: physics, economy, traffic, engineering, sociology, and many others.

We believe that the most striking applications of both pure and applied mathematics are those in the area of theoretical and mathematical physics. Applied mathematics provide us with powerful analytical and numerical methods for solving differential equations by which we describe realistic physical phenomena. But what is even more fascinating is that Nature seems to talk to us in mathematical language. Although the theorems of pure mathematics were formulated without any reference to a true, physical world, it turns out that those extremely abstract notions and entities of pure mathematics represent an appropriate setting for describing the ultimate laws of Nature.

It turns out that the entire variety of the phenomena being observed in Nature are the consequences of merely four fundamental interactions: gravitational force, electromagnetic forces and weak and strong nuclear forces. Gravitational force is appropriately described by Einstein's general theory of relativity (GR), while the other three forces have been successfully described in so-called gauge quantum field theories. The unified framework encompassing all phenomena not involving gravitation is called the *Standard Model* of particle physics. Both GR and the Standard Model have been experimentally verified to a fantastic degree of precision. The last great success of the Standard Model is the discovery of the Higgs boson in the Large Hadron Collider in CERN, Switzerland. GR has been tested recently under the extreme conditions in the pulsar PSR J0348 0432.

Thus, both theories describe fundamental forces in a perfect agreement with the experiment. However, these great theories are genuinely incompatible. The sangreal of contemporary physics is the discovery of the theory which would unify both theories into a single framework. Such theory would be relevant for the study of the Bing Bang or in the singularities of black holes where we expect both quantum and gravitational effect to be significant.

Unfortunately, during last 30 years, no real success in formulating such a theory of quantum gravity has been made. The reason is in the fundamental difference between the geometric nature of general relativity and the rest of physics. There are many arguments that the presence of gravitational fields forces us to revisit the very basic notions of physics, like the entropy or energy.

Hence, in our research we focus on selected problems in classical GR which we believe could have the relevance to these fundamental and fascinating questions. We collaborate with several domestic and foreign institutions: Institute of theoretical physics of Charles University in Prague, Mathematical institute of University of Oxford, Hungarian Academy of sciences in Budapest and Max Planck Institute in Golm near Berlin.

In this contribution we present the motivation and some of our results regarding the problem of *helical symmetry* and the problem of *quasi-local quantities* in GR. The former is related to the problem of detection of gravitational radiation, the latter is connected with the aforementioned problem of the energy in GR.

## 2. Helical symmetry

According to general relativity, moving bodies emit the gravitational radiation and therefore lose their energy. The existence of gravitational radiation (or gravitational waves) has been confirmed indirectly by measuring the period of binary pulsars. Since the pulsars lose the energy by radiation, the radii of the orbits of the constituents of the pulsar decrease, the stars approach each other and finally they form a single neutron star or black hole. Such pulsars have been observed and the decrease of their period is in perfect accordance with the prediction of Einstein's theory.

Nevertheless, the gravitational radiation is extremely weak and it has been never detected directly. The reason why it is important to be able to detect this radiation is twofold. First, it would be a direct verification of Einstein's theory and, second, it would allow us to gather much more information about the structure of the Universe than we have today. Because gravitational waves are so weak, they almost do not interact with the bodies in the space and therefore they can carry information about the early Universe, about the formation of galactic structures, etc. Presently there are several huge gravitational wave detectors like VIRGO or LISA under construction which should be sensitive enough to detect gravitational radiation. Consequently, there is a lot of interest in the properties of gravitational waves in the relativistic community, both among the experimenters and the theorists.

Binary systems comprised of two neutron stars or black holes are the most promising source of gravitational waves. As we have already explained, GR predicts the inspiral of such binary systems and it is expected that in the final stage of the coalescence, the gravitational radiation should be strong enough to be detectable by terrestrial detectors.

One of the most promising approaches to simulate the inspiral is based on the notion of *helical symmetry*. Helically symmetric space-times describe the sources in time-periodic circular motion. In the beginning of the simulation it is assumed that the components of binary system (black holes, neutron stars) are moving along circular trajectories in a quasi-periodic way. At this stage, corresponding space-time exhibits helical symmetry. As soon as the black hole reaches the innermost stable circular orbit (ISCO), the rapid inspiral follows.

However, no exact helically symmetric solution of Einstein's equations is known so far. It turns out that even the notion of helical symmetry is not clearly defined in general curved space-time. The main problem is that although any continuous symmetry is generated locally by an appropriate Killing vector field, periodicity requires that the object returns to the initial position at some later time; this is a non-local property. For a given foliation of the space-time by space-like hypersurfaces, there is no canonical way how to identify points lying on different slices and hence it is impossible to say that the object returned to the initial position.

Thus, we focus on the problem of helical symmetry. In papers [1] and [2] we have shown that there are no asymptotically flat space-times which are periodic in time and analytic at null infinity. Hence, isolated gravitating systems cannot move in a periodic way. Next we have constructed an exact helically symmetric solution of linearized Einstein's equations. In this case, the notion of helical symmetry is well-defined because of the presence of the flat background metric. The geodesics in these space-times have been analyzed in the bachelor thesis of M. Tomášik [5]. Mathematical techniques related to the topic have been discussed in the review paper [4] and, more exhaustively, in the monograph [3] by M. Scholtz.

In these works we have found that a two-particle solution of linearized Einstein's equations exists only for special values of the parameters describing the system. However, in order to prevent the loss of the energy by radiation it is necessary to employ a symmetric combination of retarded and advanced solutions of the Einstein equations which effectively means the introduction of incoming radiation coming from infinity which compensates the energy loss. We considered two particles, called particle A and particle B, in circular periodic motion with constant angular velocity. In the units we use, the radius of the orbit of particle A is $a=1$, the angular velocity $\omega$ of both particles is encoded in dimensionless parameter $\alpha = \omega\, a/c$ and the radius of the orbit of particle B is $b$. For given $b \neq 1$ there is a unique value of $\alpha$ such that the system is in equilibrium. For $b=1$, when the radii of both orbits coincide, the value of angular velocity can be chosen arbitrarily and the mass $m$ of each particle can be calculated, see **Chyba! Nenalezen zdroj odkazů.**.

In the case of the linearized theory on the flat background, one can split the full metric tensor into the flat Minkowski part and a small perturbation,

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu,} \quad |h_{\mu\nu}| \ll 1.$$

In the de Donder gauge, the linearized Einstein's equations read

$$\eta^{\mu\nu}\nabla_\mu\nabla_\nu \bar{h}_{\alpha\beta} = -16\,\pi\, T_{\alpha\beta},$$

where $\bar{h}_{\alpha\beta}$ is the trace-reversed perturbation and $T_{\alpha\beta}$ is the energy-momentum tensor for a point particle. Using standard Green functions of the d'Alembert operator, the explicit solution of linearized Einstein's equations with helical symmetry in the co-rotating cylindrical frame has been derived:

$$h^{\pm}_{00} = -\frac{4\,m_A\,\gamma}{\rho_\pm}\,(1-\,\omega^2\,a\,r\cos\theta_\pm), \qquad h^{\pm}_{01} = -\frac{4\,m_A\,\gamma}{\rho_\pm}\,(1-\,\omega^2\,a\,r\cos\theta_\pm)\,\omega\,a\sin\theta_\pm,$$

$$h^{\pm}_{02} = \frac{4\,m_A\,\gamma}{\rho_\pm}\,(1-\,\omega^2\,a\,r\cos\theta_\pm)\,\omega\,a\,r\cos\theta_\pm, \qquad h^{\pm}_{11} = -\frac{4\,m_A\,\gamma}{\rho_\pm}\,\omega^2 a^2\,\sin^2\theta_\pm,$$

$$h^{\pm}_{12} = -\frac{4\,m_A\,\gamma}{\rho_\pm}\,\omega^2 a^2 r\,\sin\theta_\pm\cos\theta_\pm, \qquad h^{\pm}_{22} = -\frac{4\,m_A\,\gamma}{\rho_\pm}\,\omega^2 a^2 r^{\,2}\cos^2\theta_\pm.$$

Retarded solution is denoted with the sign +, advanced solution corresponds to the choice of the sign -. Functions $\rho_\pm$ and $\theta_\pm$ are given implicitly by the set of transcendent equations. We will see the expression for the latter later.

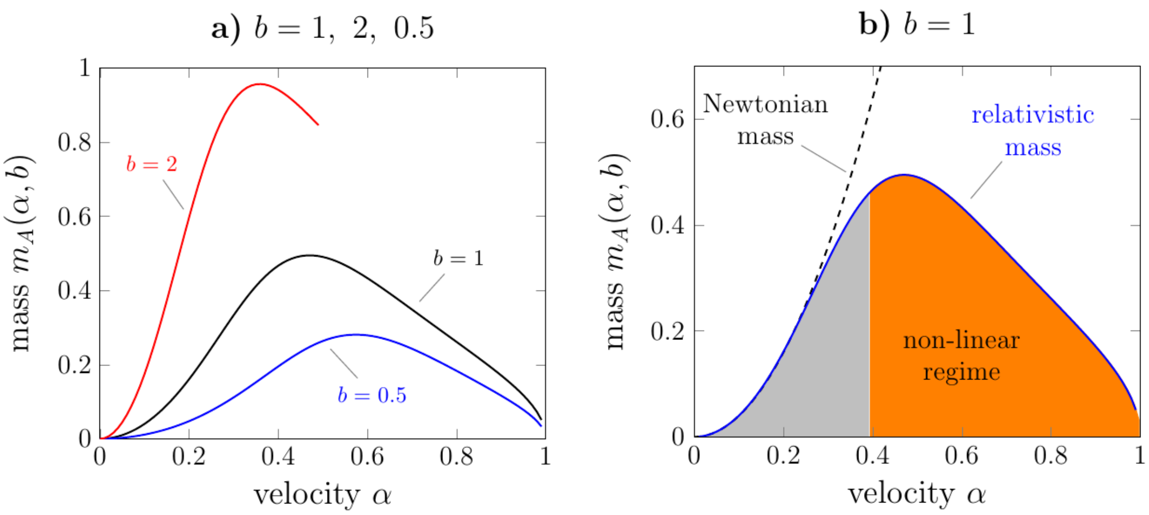


Figure 1. Mass of particle A.

Once we have established the existence of helically symmetric configurations, we could analyze the asymptotic properties of these solutions. In asymptotically flat spacetimes there is a well-known peeling theorem which asserts that the Newman-Penrose components of the Weyl spinor satisfy the fall-off given by $\Psi_n = O(\Omega^{5-n})$, where $n = 0,1,..4$ and $\Omega$ is the conformal factor in terms of which the asymptotically flat spacetime can be compactified. In particular, the $\Psi_4$ component describes the radiative part of gravitational field.

It turns out that in helically symmetric case (being not asymptotically flat) the retarded and advance parts of the solution exhibit different properties. For example, the radiative part of gravitational field is asymptotically given by relation

$$\Psi_4^{\pm} = \frac{m\,\alpha^4\,\gamma}{2\,r\,(1+\,\alpha\sin\theta_\pm)}(10\,\alpha^2 +\,15\,\alpha\sin\theta_\pm -\,\sin 3\theta_\pm + (2\,\alpha^2 - 8)\cos 2\theta_\pm) +\,O\left(\frac{1}{r^2}\right),$$

where the signs + and – represent the retarded and the advanced part of the solution, respectively. The retarded deficit angle is defined by $\theta_+ = \,\alpha\cos\theta_+ +\,\alpha\,u,$ where $u$ is the retarded time, $u = t - r$. On the other hand, the advanced deficit angle is given by

$$\theta_- = \,\alpha\,(u+r) +\,\alpha\sqrt{1+r^2 -\,2\,r\cos\theta_-}$$

and hence it is a rapidly oscillating function which is not well-defined at null infinity, i.e. in the limit $r \to \infty$. The difference between retarded and advanced solution is depicted in figure 2. Finally, we have investigated the behaviour of geodesics in helically symmetric space-times by the method of the Lyapunov exponents. That is, we have generated a family of the pairs of geodesics starting at two nearby points. All pairs start at the same points but they differ by the initial velocity. For each pair we have computed the Lyapunov exponent as the limit of the distance of geodesics in the limit of infinite proper time. The map of Lyapunov exponents in the parametric space is shown in figure 3 and strongly indicates the chaotic behaviour.

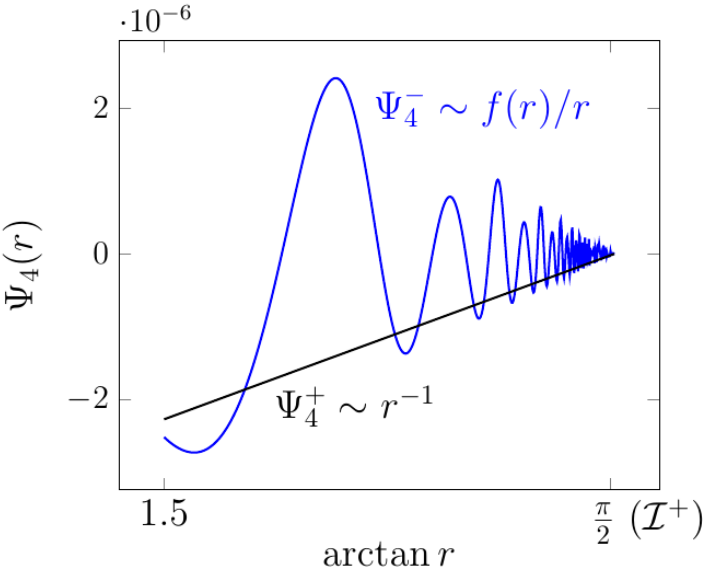


Figure 2. Retarded (+) and advanced (-) radiative parts of gravitational field near null infinity.

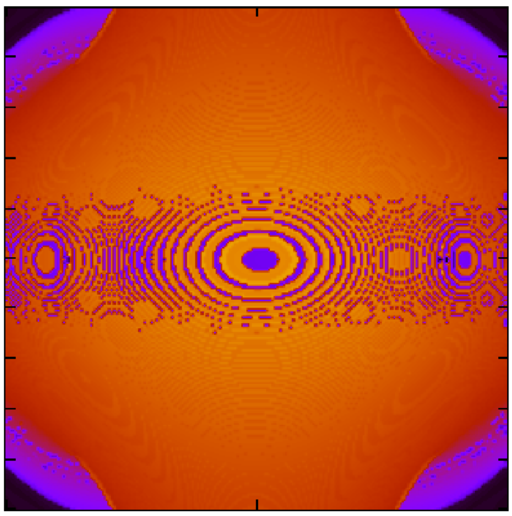

Figure 3. The map of the Lyapunov exponents.

### 3. Energy and momentum in general relativity

Among the all of the long-standing problems in GR, the problem of energy is perhaps the most frustrating one. The notions of energy, momentum and angular momentum belong to the most useful quantities not only in classical physics, but also in special relativity and quantum mechanics. The deeper understanding of what the energy is was brought by the celebrated Noether theorems. According to these theorems, if the system possesses any kind of continuous symmetry, i.e. if there is a Lie group of transformations under which the system is invariant, there is a conserved quantity associated with any continuous symmetry. In particular, the homogeneity of time implies the conservation of the quantity called energy. Homogeneity of the space and the isotropy of the space then give rise to the conservation of the momentum and the angular momentum.

Nevertheless, the Noether theorems show that the notion of conserved quantities is intimately related to the symmetries of the system, in particular the spacetime symmetries. Flat Minkowski space possesses 10 Killing vectors and hence 10 conserved quantities: energy, three components of the momentum and six components of relativistic angular momentum. In general curved spacetime which is a solution to Einstein's equations

$$R_{\mu\nu} - \frac{1}{2}\, R\, g_{\mu\nu} = \,-8\,\pi\, T_{\mu\nu}$$

there are no Killing vectors and hence there is no canonical way how to construct conserved quantities. There are many special but still important examples of spacetimes, which admit a Killing vector and one can define associated conserved quantity, e.g. in stationary spacetimes with the timelike Killing vector there is a well-defined Komar mass.

In asymptotically flat spacetimes, on the other hand, there is a well-defined notion of the global mass associated with the entire spacetime. The reason is that in such spacetimes the curvature tends to zero far from the source and in the infinity the symmetries of the Minkowski spacetime are recovered. However, resulting group is larger than the Poincare group of the Minkowski spacetime and is known as the Bondi-Metzner-Sachs group. BMS group is a semidirect sum of the Lorentz group and the group of supertranslations. The mass (energy) of the spacetime emerging from the construction based on the BMS group is known as the Bondi mass.

The most striking property of the Bondi mass is the following. Suppose there is an asymptotically flat spacetime containing a gravitating source with the compact support. For some reason, this systems suddenly emits a burst of gravitational (or other) radiation. Intuitively we expect that this radiation carries the energy and hence the energy of the source must have decreased by the emission. Unlike the timelike geodesics, which have their endpoints at the future/past timelike infinity, and unlike the spacelike geodesics having their endpoints at the spacelike infinity, null geodesics along which the radiation propagates can have endpoint anywhere at the null infinity. Hence, if we want to measure the decrease of the mass of the system, we can choose a spacelike surface which is asymptotically null, so that it never intersects the geodesics of emitted radiation. The energy measured at this surface at null infinity will be therefore diminished by the energy carried by the radiation. To conclude, the Bondi mass of the spacetime is a non-increasing function of time and it decreases whenever the system radiates any form of radiation (gravitational, electromagnetic, scalar).

We have employed the spinorial methods together with conformal techniques developed by Penrose in order to calculate the Bondi mass of spacetimes with interacting electro-scalar sources. The Lagrangian of interacting scalar and electromagnetic fields reads

$$L = \,(D_a\phi)(D^a\bar{\phi}) - \frac{1}{2}\, m^2\, \phi\, \bar{\phi} - \frac{1}{4}\, F_{ab}\, F^{ab},$$

where the gauge covariant derivative acting on the scalar field carrying the charge $e$ is given by

$$D_a\phi = \,\nabla_a\phi + i\; e\; A_a\phi, \quad D_a\bar{\phi} = \,\nabla_a\bar{\phi} - i\; e\; A_a\bar{\phi}.$$

From this Lagrangian, the spinorial equations of motion can be derived. In particular, the Einstein equations acquire the form

$$\Phi_{ABA'B'} = \left(D_{(A(A'}\phi\right)\left(D_{B')B)}\bar{\phi}\right) + \,\phi_{AB}\bar{\phi}_{A'B'}, \quad \Lambda = \frac{1}{12}\,[-(D_a\phi)(D^a\bar{\phi}) + \,2\, m^2\, \phi\, \bar{\phi}].$$

Having derived the Einstein's equations, one can introduce an appropriate tetrad similar to that of Bičák, Scholtz, Tod [1, 2], but in the physical spacetime, and expand all geometrical and gravitational quantities into the series in the conformal factor near the null infinity. In this procedure we assume the analyticity of the solution. In this way we obtain asymptotic expansions of the spin coefficients, the components of the Weyl and the Ricci spinorand the scalar curvature. Similarly we obtain asymptotic expansions of electromagnetic and scalar fields.

The Bondi mass appears through the solution of the asymptotic twistor equation

$$\nabla^{A'(A}\,\omega^{B)} = 0.$$

This equation has non-trivial solutions only in the flat spacetime. The Penrose suggestion is therefore to restrict this equation to a space tangent to the 2-surface which yields the 2-surface twistor equation. The Atyiah-Singer index theorem then guarantees that the 2-surface twistor equation has, in generic case, four linearly independent solutions which can be identified with the components of the four-momentum of the finite region. This construction is known as the Penrose quasi-local mass.

In our case, we are interested in a global, not quasi-local energy, so we restrict this equation to the null infinity. Using the aforementioned asymptotic expansions and inserting them into the restricted twistor equation, we find that the leading terms of the components of the spinor $\omega^A$ are

$$\omega_0^0 = 0, \quad \omega_0^1 = a\,Y_{\frac{1}{2},\frac{1}{2},-\frac{1}{2}} + b Y_{\frac{1}{2},\frac{1}{2},\frac{1}{2}},$$

where $Y_{s,\,l\,m}$ are the spin-weighted spherical harmonics.

Using the solutions of asymptotic twistor equation we have found that the Bondi mass of electro-scalar spacetimes is given by relation

$$M_B = -\frac{1}{2\sqrt{\pi}} \oint \left(\Psi_2 + \sigma\,\dot{\bar{\sigma}} + \frac{1}{3}\,\partial_u(\phi\,\bar{\phi})\right) \mathrm{d}S,$$

where $\sigma$ is the asymptotic shear of Newman and Penrose. Corresponding mass-loss formula reads

$$\dot{M}_B = -\frac{1}{2\sqrt{\pi}} \oint \left(\bar{\sigma}\,\dot{\bar{\sigma}} + \phi_2\,\bar{\phi}_2 + (D_u\phi)(D_u\,\bar{\phi})\right) \mathrm{d}S,$$

These results show that the Bondi mass is positive and strictly decreasing for spacetime containing gravitational, electromagnetic or scalar radiation. Calculations presented in this section comprise the main part of the diploma thesis [6] and corresponding paper has been submitted to General Relativity and Gravitation journal recently.

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# Rôle of differential equations in transport applications

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**Abstract**

In this contribution, we present the work of the students interested in applied mathematics and, in particular, in the modelling of real-world phenomena by differential equations. Although the topics to be presented are quite different, the unifying idea behind them is the use of differential equations, their qualitative analysis and finally the numerical solution. The topics include the traffic models, aerodynamics and the analysis of delayed differential equations.

**Keywords:** ordinary differential equations, partial differential equations, delay differential equations, aerodynamics, traffic models

## 1. INTRODUCTION

Since the discovery of the differential and integral calculus by Newton and Leibniz, these techniques became the standard tool of mathematics and of all sciences based on mathematics. The extraordinary power of the calculus rests in its ability to describe the processes. Unlike algebraic equations, which are basically just relations between *numbers*, differential equations are relations between the *functions* and their derivatives. This is exactly what we need in order to describe the real phenomena.

For example, consider simple Newton's law of motion, which is traditionally written in the form $F = m\,a$, where $F$ is the force exerted on a body, $m$ is the mass of a body and $a$ is its acceleration. Of course, ultimately we are interested in a precise trajectory of a body: where and when it will be. However, the answer is not that easy to find in terms of algebraic relations. In algebra it is usual that, having $n$ equations for $n$ variables, there exists one solution or more solutions (as in the case of quadratic equation), but they are all completely fixed by the system of equations to be solved. On the other hand, the precise motion of moving body depends not only on the force exerted on a body, but also on its initial velocity and position, but these quantities do not at all enter the Newton law! In other words, the equation $F = m\,a$ itself will not tell us what the motion of a body will be, unless we provide it with particular initial conditions we are interested in.

The reason for this different behaviour of algebraic and differential equation rests in the fact that differential equations describe how the quantities of interest *change* rather than what the values of these quantities *are*. Newton's law of force does not tell how the body actually moves, but how any force will *affect* its motion. Yet the result depends on the motion of the body before the force started to act.

The theory of differential equations deals with the methods of solving differential equations (how to reconstruct entire motion when we know the initial conditions and the law of motion), but also formulates beautiful questions (and often even answers) about the existence and the uniqueness of the solution, about well-possedness of the initial value problem, about topological aspects of differential equations, and many others.

Which physical laws and which processes can be described by differential equations? So far as we know, all of them. All fundamental physical laws are written in terms of differential equations, the processes in economics, traffic, they are all described by differential equations. Hence, it is a powerful tool not only for mathematicians, but also for all applications of mathematics in the physics and engineering.

In the work to be presented in this contribution, we do not address the aforementioned deep questions. Rather we concentrate on selected problems in the areas of the traffic modelling and aerodynamics and briefly present some properties of the so-called *delay differential equations*. In the following sections, we always introduce the particular problem, present the equations describing the situation and present the solution. Topics covered in the contribution are subject to bachelor theses of students Miroslav Vaniš and Petr Veselý.

## 2. Traffic models

Miroslav Vaniš, the bachelor student of Martin Scholtz, is interested in numerical and analytical methods in the theory of the traffic flow. This part of our research is perhaps the most closely related to the research performed by other projects running on our faculty. Our point of view is somewhat different, however. While the other research groups mostly rely on the existing computational software or standard libraries, our goal is the *development* of such software. Hence, we study the traffic models and their basic principles and implement them in appropriate programming language. Primarily we use Mathematica and Java environments.

Essentially, the traffic models can be divided into two large categories: macroscopic and microscopic. Macroscopic models are inspired by continuum mechanics and thermodynamics in the physics. Instead of examining the individual cars, macroscopic models deal with average characteristics of the traffic flow, which is regarded as a continuum distribution of vehicles. There are numerous analogies between the fluids (subject to continuum mechanics) and the traffic flow. For example, the distribution of the mass of the fluid is described by the mass density $\rho = \mathrm{d}m/\mathrm{d}V$, which gives the mass per unit volume. Analogously, the distribution of cars is described by function $\rho = \mathrm{d}N/\mathrm{d}x$ giving the number of cars per unit length. The flow of the mass (in fact the momentum density) is described by vector quantity $\boldsymbol{j} = \rho\, \boldsymbol{v}$ satisfying the equation of continuity $\partial_t \rho + \nabla . \boldsymbol{j}$. This equation is mathematical formulation of the law of the conservation of the mass and states that the mass can be neither created nor destroyed and any change of the mass in a given region is due to flow of the fluid throw the boundary of this region. In the traffic flow, it is the number of cars that is conserved and the car density obeys exactly the same equation of continuity. Thus, because of these analogies, one can employ the apparatus of the continuum mechanics and the theory of partial differential equations to the traffic flow, provided this flow is dense enough.

The so-called microscopic models for the second class of the models and in the thesis to be presented we have focused on them exclusively. The microscopic models have roots in the statistics, statistical physics and molecular simulations. In this approach, each participant of the traffic is described by the individual set of parameters, e.g. position, velocity, acceleration, and these parameters are governed by ordinary differential equations, which are specific to particular model.

There have been many attempts to describe the behaviour of the traffic flow by differential equations on the microscopic level and many models have been suggested. “Classical” family of models have been formulated by General Motors Company. More recently, the so-called Intelligent Driver Model (IDM) has been proposed which adequately describes the driver’s own preferences and his interaction with nearby vehicles. The motion of a car in IDM model is governed by the equations

$$\dot{x}_n = v_n, \;\; \dot{v}_n = a \left( 1 - \left( \frac{v_n}{v_{free}} \right)^{\delta} \right) + a_{int} \; .$$

The first of these equations is, from the physical point of view, merely a definition of the velocity. From the mathematical point of view, it is an auxiliary equation, the purpose of which is to rewrite the second order differential equation formally as the pair of the first order differential equations. In physics, this procedure is known as the Legendre transformation and converts the second order Lagrange equations into the set of first order Hamilton equations.

The true dynamical equation, however, is the equation for the acceleration. The acceleration is composed of two terms, the so called *free acceleration* and the interaction term $a_{\mathrm{int}}$. The former describes desired acceleration of the driver who is moving on the free highway (with no other cars) with the speed $v_n$, while his own preferred speed is $v_{\mathrm{free}}$. Hence, the free acceleration is positive, if the actual speed is smaller than the desired one and vice versa. If the actual speed happens to be equal to the desired speed, the free acceleration is zero. Parameter $a$ is equal to the acceleration of the car with zero initial velocity.

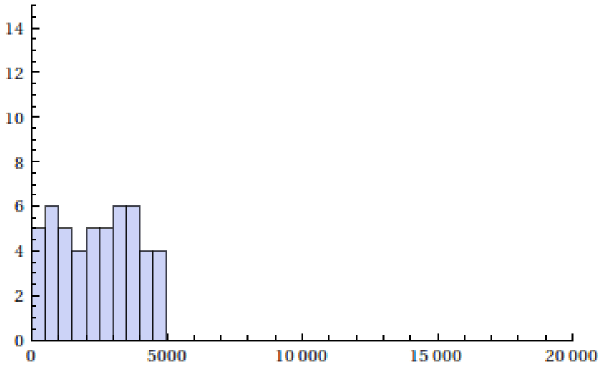
Non-linear term $a_{\mathrm{int}}$ describes the interaction of the driver with the car in front of him (called leading car) and is given by relation

$$a_{int} = \frac{a}{s_n^2} \left[ s_0 + v_n\, T - \left( \frac{v_n (v_{n-1} - v_n)}{2\sqrt{a\, b}} \right)^2 \right] \; .$$

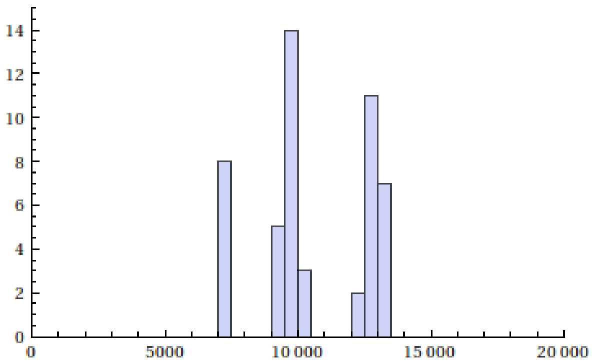
Here, $s_n$ is the actual distance between the two cars, $v_{n-1}$ is the actual speed of the leading vehicle, $s_0$ is the minimal required distance between the cars in the congestion and $T$ is a safe time headway.

We have implemented the IDM model in Java and extended it by lane-changing model MOBIL. It is based on the two criteria, safety and motivation. The decision whether particular vehicle will change the lane or not is a result of inequality $b_r + a_2 - a_1 > p\,\left(a_2' - a_1'\right) a_{\mathrm{thr}}$ , where $a_1$ is the actual acceleration of the car in the current lane, $a_2$ is the acceleration after possible change of lane. The difference $a_2$ -$a_1$ is a measure of the motivation for changing the lane. Primed accelerations refer to car in the next lane, which would eventually become the following car. Thus, $a'_2$ - $a'_2$ measures the disadvantage of the following car caused by the overtaking car and the politeness factor $p$ determines the strength of this criterion. Term $b_r$ expresses the bias of the driver for the right lane so that the left and the right lanes are not treated in a symmetric way. Finally, $a_{\mathrm{thr}}$ represents the threshold value of the acceleration, so the marginal advantages are neglected. Once the motivation criterion is satisfied, the inequality $a_2' > -b$ is checked, where $b$ is safe braking deceleration.

As an example, we present simulation in which the vehicles were initially randomly distributed, with random preferred and actual velocities. The simulation shows that after certain transient period, three groups of cars have emerged having the same velocity. These groups are far enough from each other so that their mutual interaction can be neglected. Hence, a stationary state has emerged.

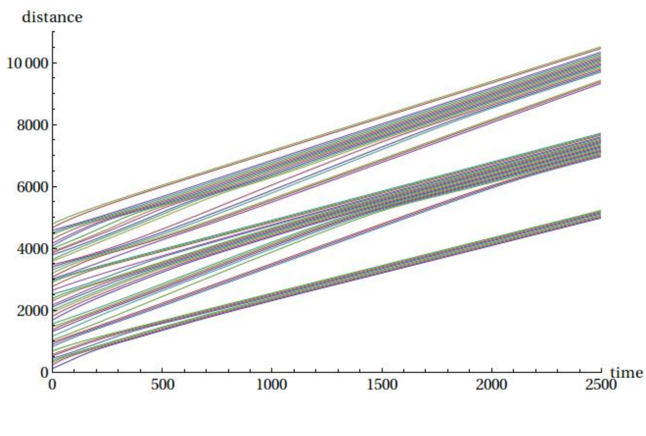



Initial distribution

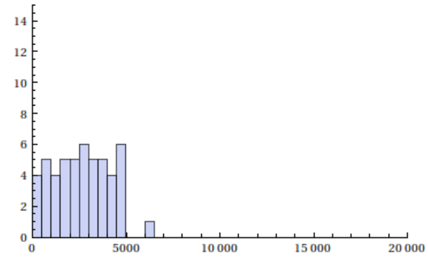



Final stationary distribution

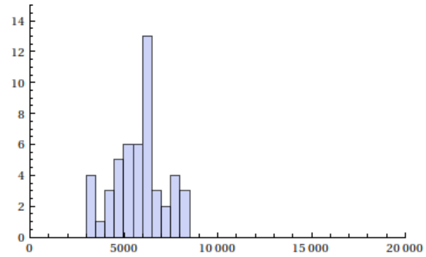
In these figures, the horizontal axis represents the position on the highway. The height of each bar represents the number of cars per 500 m. These graphs are discrete approximations of the density function. Positions of individual cars as functions of time are plotted in the next figure. In this simulation, overtaking has not been allowed.



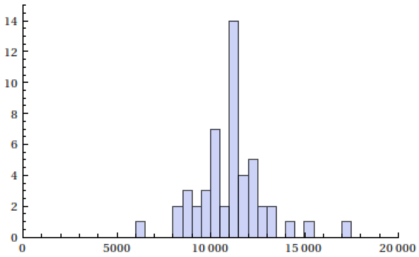

In the next simulation we studied the (artificial) situation when the initially cars were more-less uniformly distributed, but the single car was placed at the distance 1 km in front of the initial group of the cars. The velocity of this car has been set to zero and overtaking has been allowed.




Initial distribution




Peak near the standing car




Peak does not decay

In the figures above, we observe an interesting phenomenon. At the beginning, we can see the initial group approaching the standing car, which is represented by a single bar at position 6000 m. As the group of cars meets the standing car, it must slow down and overtake the car, which results in a sharp peak of the distribution. An interesting feature is that the peak does not decay when entire group leaves the standing car and exhibits a soliton-like character even if the group of the cars is relatively far from the standing car. Such behaviour is typical for non-linear systems with dispersion, i.e. when the individual constituents of the system are propagating with different speeds.

In the near future, we plan to investigate more realistic traffic models and use more advanced mathematical methods to investigate them. The bachelor thesis [1] containing full discussion of the aforementioned traffic model has been successfully defended in 2013 at Faculty of transportation sciences, CTU in Prague.

## 3. Aerodynamics

In this branch of our research we study selected problems of computational fluid dynamics (CFD). Ultimately we are interested in applications of CFD in the aerodynamics, i.e. in the simulations of real turbulent flow in the neighbourhood of bodies, namely the aircrafts. These problems were investigated by Petr Veselý in the framework of his bachelor thesis [2] supervised by Martin Scholtz.

It is often being said that the turbulence is the last unsolved problem of classical physics. Its overwhelming complexity is due to the non-linearity of the Navier-Stokes (NS) equations, which are believed to describe realistic flows properly. Only very few exact solutions of NS equations are known and they altogether represent only highly idealized situations of little practical importance. Moreover, these equations exhibit extreme sensitivity to the initial conditions, which are always known to a certain degree of accuracy. Hence, the behaviour of the flow becomes unpredictable, chaotic. The analysis of the flow is therefore an interdisciplinary topic and requires the techniques of the theory of differential equations, the functional analysis, numerical mathematics, the statistics and stochastic dynamics and the chaos theory. The research in this area is permanently stimulated by experimental data, e.g. from the wind tunnels. Because of this complexity and because of the lack of advanced mathematical background provided by our faculty, we have decided to start our research with investigation of simpler problems in CFD.

The purpose of the thesis to be presented in this contribution is to get familiar with analytical and numerical methods in the theory of the two-dimensional inviscid and incompressible flow and apply them to the problem of the flow past the airfoil.

In the previous section we have seen that microscopic traffic models are formulated in terms of ordinary differential equations. The equations of fluids, on the other hand, are partial differential equations. The basic equation is the celebrated Navier-Stokes equation, which is usually written in the vector form

$$\frac{\partial \boldsymbol{v}}{\partial t} + \boldsymbol{v} . \nabla \boldsymbol{v} = -\frac{1}{\rho} \nabla P + \nu \, \Delta \, \boldsymbol{v},$$

where $\boldsymbol{v}$ is the velocity field of the fluid, $\rho$ is the mass density and $\nu$ is the kinematical viscosity of the fluid. Solving this equation is a formidable task and has not been fulfilled yet. Even the numerical simulations based on this equation are highly imprecise and need enormous computational capacity.

For this reason we have decided to investigate simpler problem of two-dimensional inviscid flow. In that case, the flow is fully determined by the equation of continuity

$$\frac{\partial \rho}{\partial t} + \nabla . (\rho \, \boldsymbol{v}) = 0.$$

When the flow is irrotational at every point (up to a set of zero measure), the velocity field $\boldsymbol{v}$ can be written as the gradient of the potential $\varphi$ satisfying the Laplace equation

$$\Delta\varphi = 0.$$

Similarly, one can introduce vector $\boldsymbol{\psi} = (0, 0, \psi)$, where the scalar $\psi$ is called the streamfunction, so that the velocity is given by the curl of this vector:

$$\boldsymbol{v} = \nabla \times \boldsymbol{\psi}.$$

It is interesting that the potential and the stream function can be combined into a single complex function, called *complex potential*, given by

$$F = \varphi + i\,\psi.$$

This function is holomorphic (satisfies the Cauchy-Riemann conditions) and hence the apparatus of the holomorphic functions can be applied. If the function is assumed to be meromorphic everywhere except for the origin of the complex plane, it can be expanded into the Laurent series

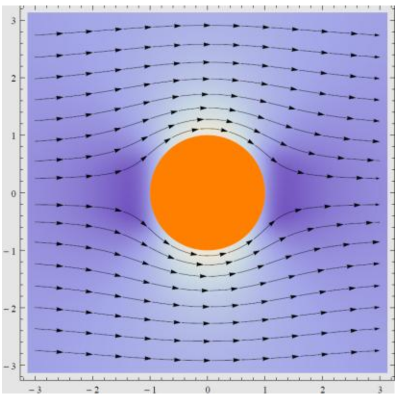
$$F = \sum_{n=0}^{\infty} \frac{a_n}{z^n},$$

where $a_n$ are unknown coefficients and $z = x + i\,y$ is the complex variable. Any function of this type automatically solves the Laplace equation for both potential and the stream function and hence represents a flow of the fluid. In order to find the solution representing the flow for a given situation, one has to impose the boundary conditions and find their implications, i.e. find the coefficients $a_n$.

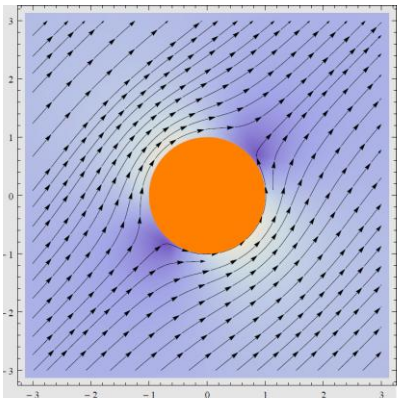
We started with the problem of the flow past the cylinder, which admits exact solution represented by the complex potential

$$F(z) = \bar{v}_\infty\, z + (v_\infty - u)\frac{R^2}{z} + \frac{\Gamma}{2\,\pi\, i}\log z.$$

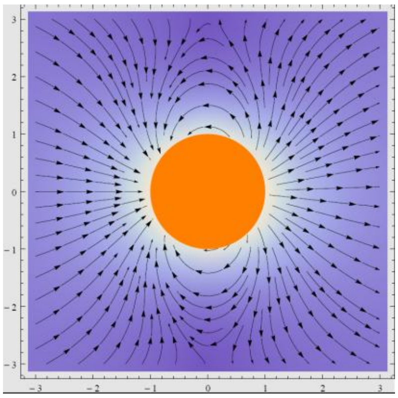
Here, $v_\infty$ denotes the velocity of the flow at infinity, $R$ is the radius of the cylinder, $\Gamma$ is the total circulation around the cylinder, $z$ is the complex variable and bar denotes complex conjugation. Parameter $u$ is the magnitude of the normal component of the velocity at the boundary of the cylinder. In the following figures, we plot the flows around the cylinder for selected values of these parameters.



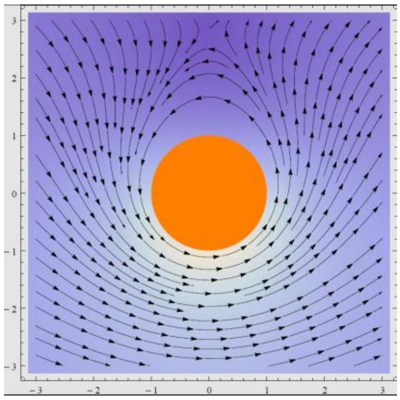
$v_\infty = 1, \quad u = 0, \quad \Gamma = 0$



$v_\infty = 1 + i, \quad u = 0, \quad \Gamma = 0$



$v_\infty = 1, \quad u = 10, \quad \Gamma = 0$



$v_\infty = 1, \quad u = 0, \quad \Gamma = 20$

In order to calculate the flow past an arbitrary airfoil shape we have employed the method of vortex panels. Vortex panel is a continuum of point vortices distributed along a line segment. In general, the density of vortex lines strength can vary arbitrarily along the line segment but we have chosen vortex panels with linearly varying densities. If $\gamma$ is the vortex density along the panel, the velocity generated by this panel is given by relations

$$v_x(\boldsymbol{r}) = -\frac{1}{2\pi}\int \gamma(\boldsymbol{r}')\frac{y-y'}{|\boldsymbol{r}-\boldsymbol{r}'|}\,\mathrm{d}r', \qquad v_y(\boldsymbol{r}) = \frac{1}{2\pi}\int \gamma(\boldsymbol{r}')\frac{x-x'}{|\boldsymbol{r}-\boldsymbol{r}'|}\,\mathrm{d}r'.$$

The airfoil is then approximated by the sequence of vortex panels. Densities of these panels are chosen to satisfy the "no penetration condition", i.e. the condition that the normal component of the velocity must vanish on the boundary of the airfoil. The unique solution is then obtained by imposing the Joukowski-Kutta condition: the circulation of the velocity field must vanish at the trailing edge of the airfoil.

We have developed a program in Mathematica software, which is capable of calculating the velocity field past an arbitrary airfoil. We present a series of figures plotted by our program in order to illustrate its functionality. For this purpose, we have chosen a modern profile signed nlf 0115 designed for general-aviation aircrafts, i.e. aircrafts with maximum takeoff weight greater than 5200 kg. This profile exhibits high values of the lift force and small values of the drag force exerted on the wings. In the figures below, we plot the flow past the profile for angle of attack equal to 5°. The blue lines represent the streamlines of the flow, while the profile itself is depicted in brown. The dashed red curves represent dimensionless pressure coefficients defined by

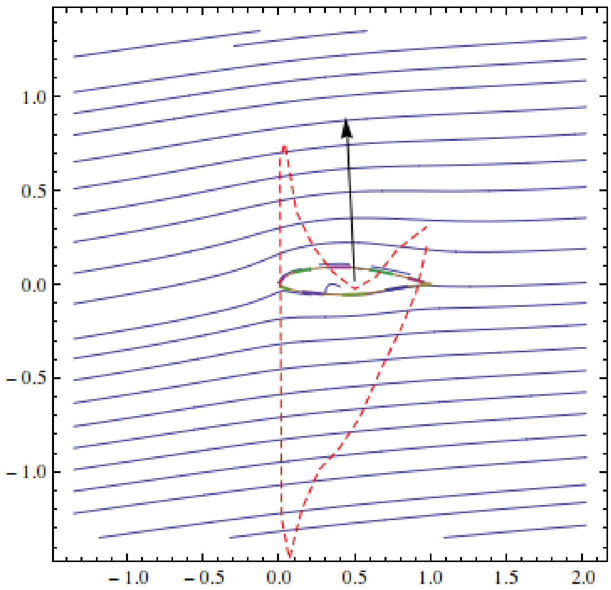
$$c_p = \frac{P-P_\infty}{\frac{1}{2}\,\rho\, v_\infty^2} = 1 - \left(\frac{v}{v_\infty}\right)^2.$$

Upper red curve models value of $c_p$ on the upper surface of the wing, similarly for the lower curve. Finally, the arrow represents (dimensionless) overall force exerted on the wing given by

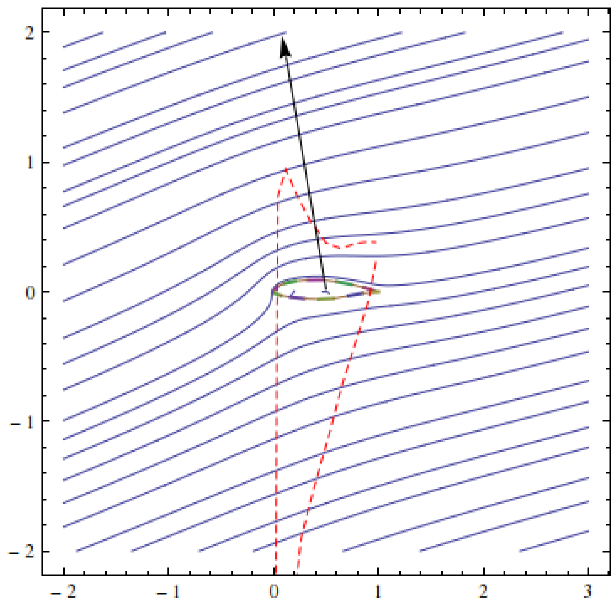
$$\boldsymbol{F} = -\oint P\,\boldsymbol{n}\,.\,\mathrm{d}\boldsymbol{r}.$$

Its normal part, referred to as the *lift force*, by the Joukowski-Kutta theorem, has value $L$=-2Γ/$U$ = 0,883696, where Γ is total circulation around the airfoil and $U$ is the velocity at infinity.

The same calculation has been repeated for the angle of attack equal to 15°. In the latter case, the lift force turns out to be L = 2,07224. For segmentation of the airfoil into 40 vortex panels, the relative error of numerical calculation was about δ = 0,6%.




Angle of attack 5°




Angle of attack 15°

In the near future, we plan to perform the analysis of a wide class of profiles and compare our numerical simulations to real experimental data. Moreover, we wish to extend the algorithms to the case of the flow past three-dimensional bodies and investigate methods available for turbulent flow.

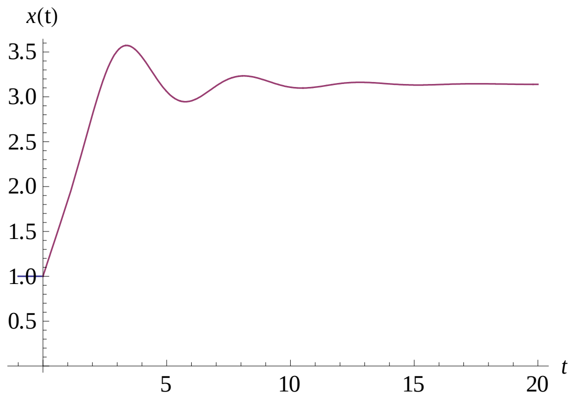
**4. Delay differential equations**

In this last section we sketch some properties of *delay differential equations* which are studied by Pavel Matějka. Since he started his research in this area only recently, we restrict ourselves to brief explanation of what these equations are, without presenting any new results.

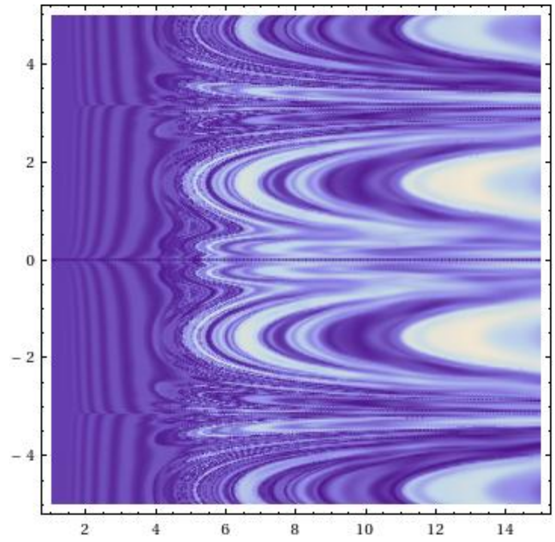
Delay differential equation is an ordinary differential equation (i.e. not involving partial derivatives) in which the derivative of the function depends not only on the values at a given time, but also on the values of unknown function (or its derivatives) at some later time. Such equations describe realistic systems in which the reaction of the system is not immediate but delayed. As an example we take equation

$$\dot{x}(t) = \sin x_\tau,$$

where $x(t)$ is the unknown function at time $t$, $x_\tau = x(t-\tau)$ is the value of the unknown function at the earlier time and $\tau$ is the time delay. In order to solve this equation one has to specify not only the value $x(0)$ at the initial time, but infinitely many values of $x(t)$ for $t \in (-\tau, 0)$. Thus, any function defined on this interval plays the rôle of the initial conditions. Since in the cases discussed here the character of this initial function does not change the behaviour qualitatively, we choose for simplicity $x(t)=\theta$ = constant for $t < 0$. The solution is plotted in the following figure.

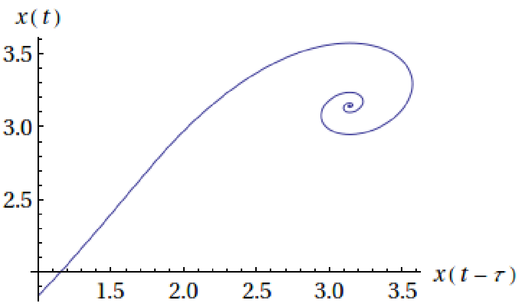



The solution for initial condition *x(t < 0) = 1*

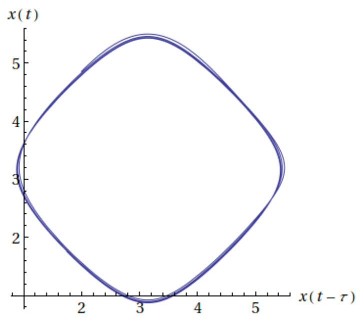



The map of the Lyapunov exponents

The behaviour of the system can be better visualized by plotting the value *x(t)* against retarded value *x(t-τ)*. In the following figures, we show two solutions for different values of the time delay and parameter *θ*.




Point attractor, $\tau = 1, \ \theta = 1$




Limit cycle, $\tau = 5, \ \theta = 2$

In the first case, the solution is being attracted to a single point called stable focus. In the second case however, the solution exhibits the so-called limit cycle, a kind of quasi-periodic behaviour. In order to investigate the behaviour of solutions for different values of parameter we have used the method of the Lyapunov exponents. In the figure above we present the map of the Lyapunov exponents in the parametric space with coordinates (*τ, θ*).

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# DEPARTMENT OF TRANSPORTATION SYSTEMS

# K612

The Department of Transportation Systems is a profiling department of the study field of Transporting Systems and Technology with all its levels of education. It also provides an education in subjects common to more branches of the study. In all bachelor studies subjects of the whole faculty graduates acquire a comprehensive knowledge of the transport infrastructure of rail and road traffic. Specialized compulsory and optional subjects are focused on construction, projecting, layouting and security of traffic roads for all kinds of transport, as well as on organization and management, on optimal transport service of regions of various sizes, on transport and spatial planning and on relationship between transport and environment. The focus of student projects, which fall into the gestion of the Department of Transporting Systems, covers a wide area of optimalization range and quality of transport infrastructure of railways, urban rails, roads, cycle paths, river ports and airports. There are also student projects focused on cooperation between various transport occupations in passenger and freight transport, environmental aspects of transport, transport impacts on spatial planning, development of settlements and on traffic accidents.

Targets of scientific activities of the Department of Transporting Systems are optimalization of area transport services and transition linkages of public mass transportation, planning and evaluating the effectiveness of intelligent transportation systems, evaluation methods, qualitative and quantitative risk analysis, safety analysis and auditing services in terms of infrastructure. This is further done by tracing liner buildings, traffic calming on roads, traffic modelling, integration of transport systems and the relationship between transport and environment.

The Department of Transporting Systems for both private and public bodies provides census surveys and census of traffic, assessment of speed and structure of road vehicles, concept design and assessment of public transport within a defined territory (including the assessment of vehicles and terminals in terms of connecting links and passenger requirements), assessment of transport measures and structures in terms of environmental impact, noise and vibration measurements in the transportation and the safety audits of roads. Furthermore, it includes a design or assessment of traffic calming on roads, traffic signs, road traffic management and intelligent transport systems and processing of other studies and reports from field of transport systems (including a comprehensive assessment and selection of the optimal design).

The department also holds regular seminars, designed especially for staff and students.

# Comparison of Roundabout Accident Prediction Models: Challenges of Data Collection, Analysis and Interpretation

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**Abstract**

The paper presents methods of accident studies and introduces an analysis based on prediction models. In an example, roundabout accident prediction models are compared. To this end available Czech data sets have been used; a comparison with several models from abroad was conducted as well. In addition to methodology and example description a number of challenges are stressed, including data collection, analysis and interpretation. Various ways to overcoming these challenges are mentioned, including pros and cons of specific alternatives.

**Keywords:** accident prediction model, roundabout, methodology, data

## 1. INTRODUCTION

Road safety and traffic engineering experts have traditionally been interested in accidents on intersections. Various levels of accident analysis are available. Three of them will be described in the following paragraphs.

### *1.1. National traffic police accident statistics*

Data from annual Czech traffic police reviews [12] may be used for this "macro" analysis. Among others they report national numbers divided between 3-arm intersections, 4-arm intersections, intersections with 5 and more arms and roundabouts. The following graph (Fig. 1) shows the number of all reported accidents from last 5 available reviews (2007 – 2011).

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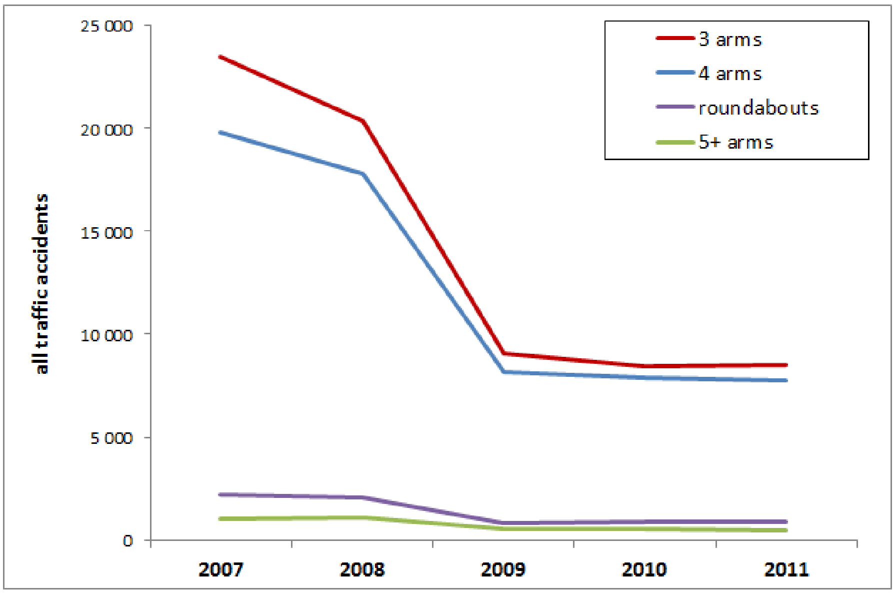


Fig. 1. Number of all accidents on specific intersection types [12]

The graph shows a significant change in 2009 – it is due to an increased change of accident reporting threshold which caused higher underreporting (for more information see e.g. [5]). Since this change influenced mainly the number of property damage only accidents, its impact may be reduced by considering just injury accidents. Fig. 2 shows that underreporting is lower in the case of these accidents and their numbers are relatively stable.

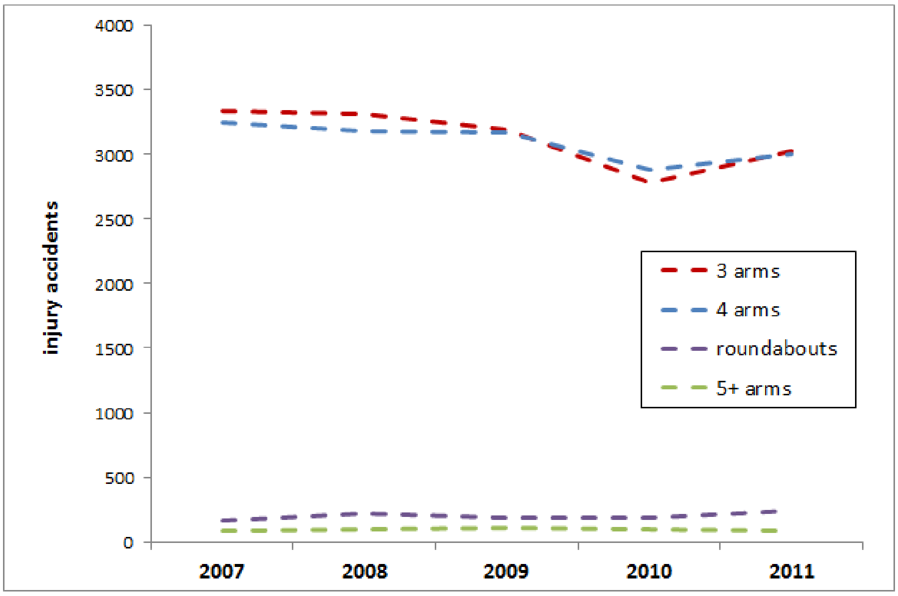


Fig. 2. Number of injury accidents on specific intersection types [12]

Nevertheless, disadvantage of this statistics is that the specific numbers do not allow comparisons of intersection types: this is because the numbers represent total numbers which reflect uneven distribution of intersection types on the Czech road network. Since the police statistics do not comprise the number of intersections, the values cannot be equalized and compared. What is more, traffic volumes on specific intersections are not reported, as well as signalization etc.

### *1.2. Accident analysis of selected intersections*

The second level of analysis is based on a data set, representing selected intersections of specific types. Such analysis was conducted for example in a research project BESIDIDO, which will be mentioned in chapter 3. Graph in Fig. 3 presents some of its results: it compares the average annual accident frequency for each intersection type.

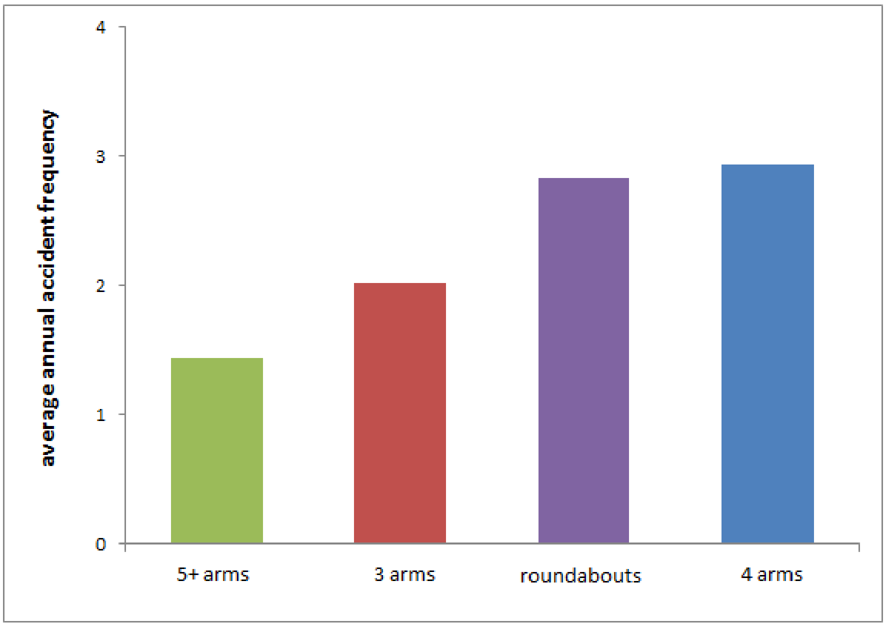


Fig. 3. Average annual accident frequency on specific intersection types [18]

Compared to the first method of analysis, the results are already equalized and may thus be used to compare the safety of intersection types. However, the explanatory power is limited by the size of a used sample.

### *1.3. Analysis with accident prediction models*

The third level analysis employs accident prediction models, created from larger data sets. While previous methods use a retrospective analysis, prediction models enable to forecast the potential future state, i.e. prospective analysis. With a prediction model it is possible to not only compare each represented type, but also to study the impact of specific explanatory variables on accidents. The example is shown in Fig. 4: it compares accident prediction models of unsignalized 3- and 4-arm intersections in Prague [25]. The graph shows the predicted (expected) annual accidents versus traffic volume (AADT) in terms of total daily number of incoming vehicles.

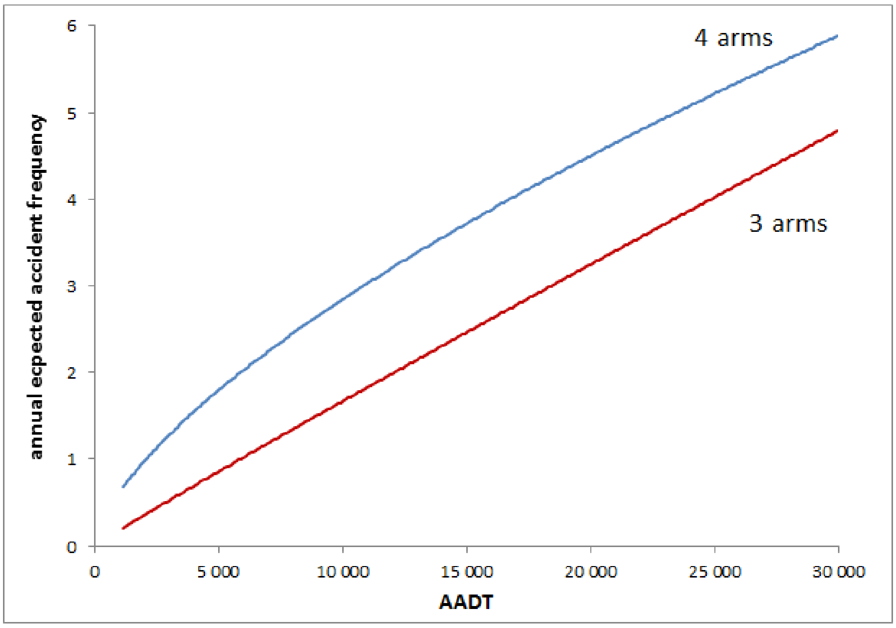


Fig. 4. Comparison of annual expected accident frequency on unsignalized 3- and 4-arm intersections in Prague [25]

Given the three mentioned accident analysis methods, the third way offers apparently the most details. This is why this method was selected for the presented paper. It aims to compare roundabout accident prediction models. Data from several research projects were used and the results were compared with some models developed in the world. These comparisons also bring a number of challenges, which will be summarized in the end, together with alternatives of possible solutions.

## 2. ACCIDENT PREDICTION METHODOLOGY

Prediction methodology consists of several steps which are briefly described next, for the case of intersections. For more information see for example recent Czech guidelines for the identification of hazardous road locations [8].

### *2.1. Selection of variables and data collection*

Data availability is the main limitation: area-wide databases (secondary data) or own data collection (primary data) may be used. Data should contain the most significant variables which impact and explain accident frequency (according to previous research), are available and are not excessively correlated with each other. These explanatory variables, describing the intersection characteristics, are the independent variables (predictors). Dependent variable is accident frequency in a specific time period.

### *2.2. Selection of model form*

The recommended function form is $E(\lambda) = \alpha \cdot AADT^{\beta} \cdot e^{\sum \gamma_i x_i}$, where $E(\lambda)$ is the expected accident frequency is a function of AADT and further explanatory variables $x_i$. The objective of modelling is to estimate the values of regression parameters $\alpha, \beta, \gamma$.

### *2.3. Accident modelling*

Modelling comprises selection of statistically significant explanatory variables and the estimation of values of their regression parameters. Since the accident frequency is a discrete variable with non-normal probability distribution, ordinary linear regression may not be used. Models are thus developed using generalized linear modelling. This procedure is available in a number of statistical software packages; it also allows to choose between various probability distributions of residuals and develop multivariate models.

*2.4. Model quality assessment*

Model quality may be assessed by several ways, e.g. checking the distribution of residuals (they should fluctuate randomly around zero), comparing information criteria (the smaller, the better), etc.

The frequency of reported accidents, which is subject to various biases, such as the mentioned underreporting, should be substituted by the expected accident frequency estimated with prediction models (see e.g. [3, 5]).

These procedures have been known world-wide for a number of decades; however this is not the case in the Czech Republic. One may ask: Does it mean that Czech studies up to now are not usable? In search for an answer to this question, the following study was produced.

## 3. COMPARISON OF CZECH MODELS

There have been several Czech research projects dealing with roundabout safety and accidents. The authors of the paper had three following data sets available:

- data on conversions from 4-arm intersections to roundabouts from a project of Czech Technical University in Prague, Faculty of Civil Engineering (GAČR [18, 19])
- data on other roundabout conversions from a project of Transport Research Centre (Centrum dopravního výzkumu, v.v.i.) and Czech Technical University in Prague, Faculty of Transportation Sciences (BESIDIDO [15])
- data on roundabout safety from a project of Transport Research Centre (VEOBEZ [20, 21,22])

Models have been developed according to the mentioned steps. However considering the heterogeneity of data sets, only one explanatory variable was used (AADT). Therefore, the models have a general form $E(\lambda) = \alpha \cdot AADT^{\beta}$.

Available roundabout data sets had the following sizes:

- 88 roundabout conversions (GAČR)
- 58 roundabout conversions (BESIDIDO)
- VEOBEZ data set is being enlarged [11], currently 200 roundabouts are described in detail

In order to have comparable models, only 4-arm roundabouts with 1 lane, as a typical Czech roundabout design type, were selected. It limited the data sets to 76 (GAČR), 35 (BESIDIDO) and 120 (VEOBEZ) cases.

In the course of the analysis it became apparent that BESIDIDO data set is not sufficient for the estimation of statistically significant regression parameters; thus only two data sets were used for subsequent analyses. These are the data set GAČR, labelled as “CTU” (Czech Technical University) and the data set VEOBEZ, labelled as “CDV” (Centrum dopravního výzkumu, v.v.i.). The annual frequency of accidents of all severities was chosen as a dependent variable.

The first result is in Fig. 5: CTU is in blue, CDV in red; points are accident frequency data points, curves show expected accident frequency, i.e. prediction models.

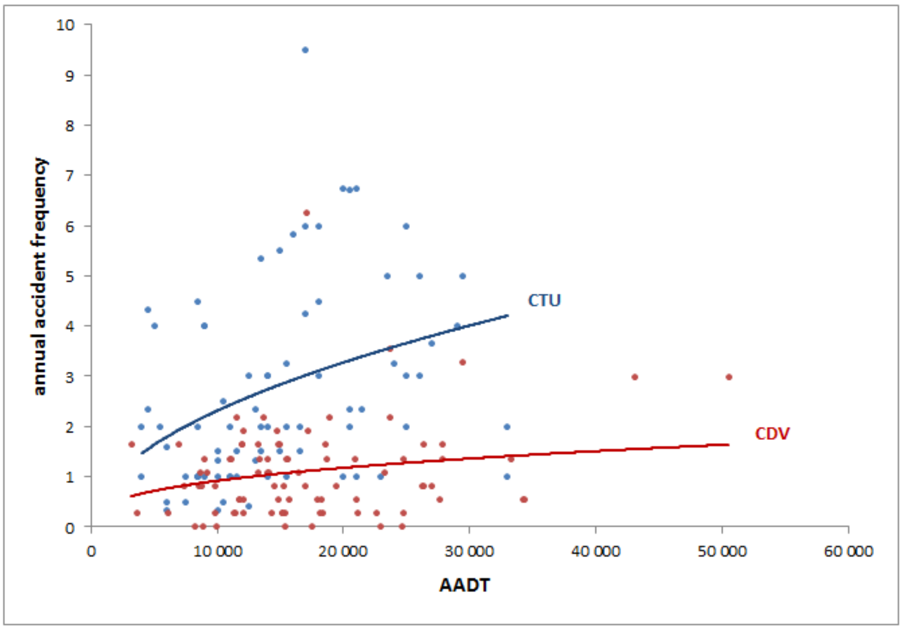


Fig. 5. Comparison of annual accident frequency on roundabouts in CTU and CDV data sets

The models are significantly different. The reason may concern time periods related to the collected data: CTU data are from 1995 – 2003, CDV data are from 2009 – 2012. Within this range several changes of underreporting took place.

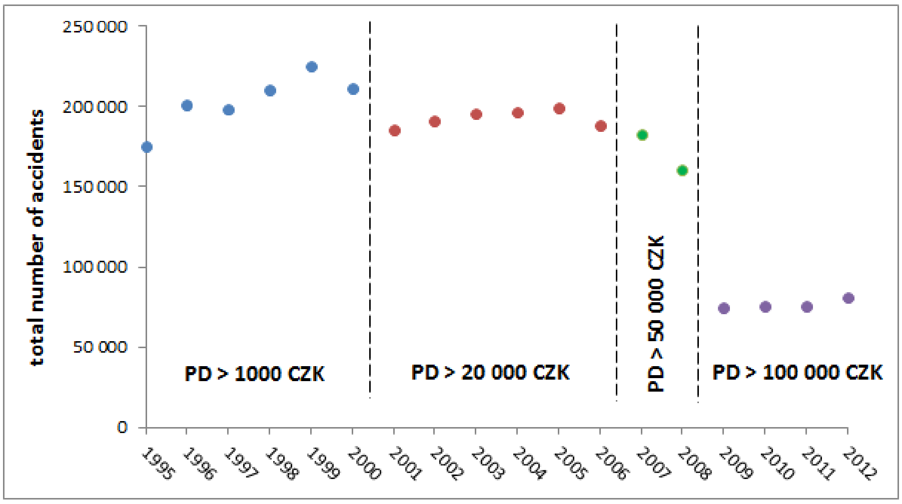


Fig. 6. Number of all reported accidents in four periods with different accident reporting thresholds based on limit of property damage (PD) in Czech crowns (CZK) [12]

Fig. 6 shows the total number of reported accidents in the Czech Republic divided into four time periods with different accident reporting thresholds (different limits of property damage). Since CTU data are from the first period and CDV data from the fourth, a relation between these periods was determined. It was calculated as a ratio of average values of numbers in these periods – the value was 2.6. Subsequently, CDV numbers were adjusted by multiplying by 2.6 in order to be comparable with CTU data. Fig. 7 shows the prediction models after this adjustment (only the central area with AADT below 30 000 vehicles per day is displayed).

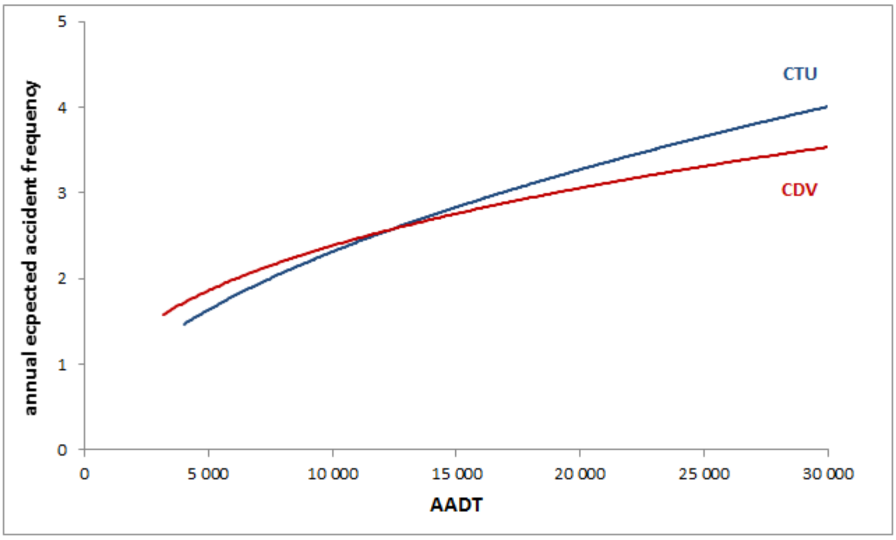


Fig. 7. Adjusted roundabout accident prediction models for CTU and CDV data sets

After the adjustment, both curves are relatively similar. One may speculate about the small differences. One of the reasons may be the fact that CTU data are from the roundabout conversions, i.e. the intersections with generally lower safety, which may be caused not only by the geometry. In contrast, CDV data were selected on an area-wide basis and are thus not influenced by this potential bias.

Nevertheless, there may be a host of influences towards the differences of both data sets safety performance. In order to illustrate them more widely a comparison with several international models was conducted and described in the following chapter.

## 4. COMPARISON WITH INTERNATIONAL MODELS

The above shown Czech prediction models were compared with several other models which are used abroad and were retrieved from the literature [6, 9, 13, 14, 23, 24]. They include some European examples (Belgium, France, Italy, Sweden, United Kingdom) as well as United States, Canada and New Zealand – see Fig. 8. The range of AADT values are limited between 10 000 and 30 000 vehicles per day.

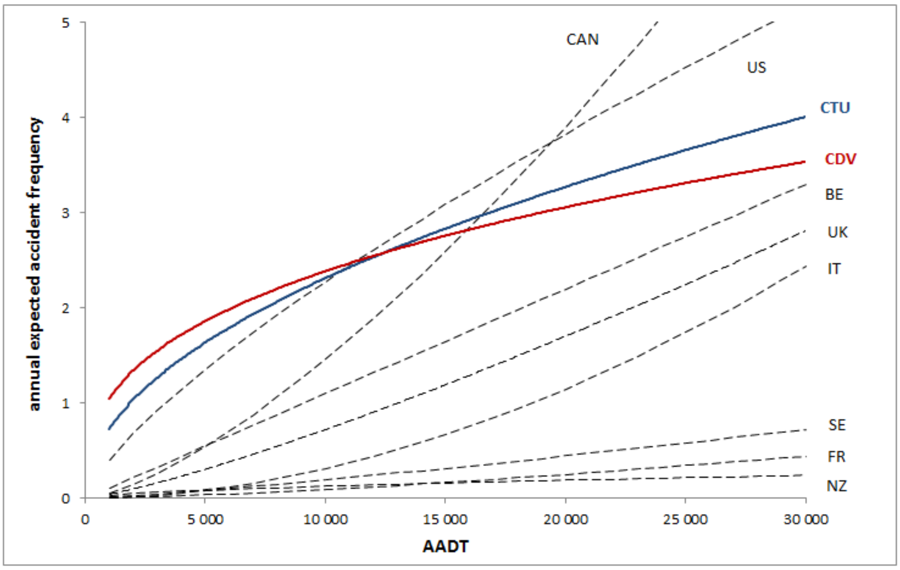


Fig. 8. Comparison of Czech roundabout accident prediction models with several international models (BE – Belgium, CAN – Canada, FR – France, IT – Italy, NZ – New Zealand, UK – United Kingdom, US – United States, SE – Sweden)

Considering the shape of curves, several conclusions may be made:

- Traditionally safe countries (Sweden, New Zealand) have the lowest expected accident frequencies.
- North American countries (United States and Canada) have similar shapes on the other side of the range.
- Most European countries (Belgium, United Kingdom, Italy) have values between those two thresholds.

However the reasons to the differences may be numerous; some of them will be listed (for more see [24]):

### *4.1. Various accident reporting practices*

Most countries report just injury accidents and data in graph reflect this fact. They should have therefore lower values compared to the Czech models, which utilized also property damage only accidents. However there are differences with accident reporting among specific countries as well: for example in Sweden and New Zealand approximately 40% of injury accidents are reported, while in United States it is 70% and even 100% in Italy.

### *4.2. Definition of intersection crashes*

There is no uniform criterion used for assigning an accident to an intersection. For example Belgian practice is to consider all accidents within an area of 100 m (the same holds for CDV data). However, in Canada 20 m limit is used, 30 m in Sweden and 50 m in New Zealand.

### *4.3. Design and traffic differences*

For example roundabouts in France have a long tradition; what is more, they were built there primarily for safety reasons. On the contrary, the United States and the United Kingdom use roundabouts mainly because of capacity. These underlying concepts dictate the roundabout design, e.g. the diameter. There are also international differences in the age of roundabouts and the data sets do not cover the same time periods or rural/urban areas. Also speed characteristics and climate conditions may be significantly different.

## 5. SUMMARY AND DISCUSSION

The objective of the study was to compare roundabout accident prediction models. Data from Czech research projects have been used, as well as some international models. A number of challenges which result from the text will be summarized.

### *5.1. Availability of accident data*

The availability of Czech accident data has been known for a long time; for a common user area-wide facilities are very limited. There is a public database JDVM, however, it serves mainly for basic statistical purposes and the details are not sufficient for safety analyses [1].

Increasing degree of underreporting is another challenge. The paper showed a potential way to its adjustment, however it is apparently only an approximation. It is possible to consider injury accidents only, however, it cuts the sample size needed for modelling. This fact is particularly severe with roundabouts: property damage only accidents comprised almost 80% of all accidents in presented data sets. The sample size may be extended by larger number of cases or prolongation of a time period: however, it is significantly time and resource demanding, apart from mentioning the instability of traffic characteristics.

A radical alternative is to substitute accidents with surrogate data, which do not depend on the mentioned databases. These may be the safety performance indicators, such as traffic conflicts. These data may even give a more complex picture of traffic and safety at the observed intersections, free from underreporting. Czech guidelines for the standardized traffic conflict observation and assessment is currently under development [4]; nevertheless, these data are very specific and are thus usually seen as a complement to accident data, not its substitute.

### *5.2. Availability of traffic engineering data*

Also, Czech traffic engineering data (i.e. traffic data and road data) have been known to be an issue [1]; nevertheless, their condition is improving, e.g. with publicly available detailed results of National Traffic Census

2010. It would be also suitable to publish data from automatic traffic counters or other traffic surveys, e.g. on local roads. There are still parts of the road network which are not subjected to the national census. This is why various research activities had to cut their sample sizes, since intersections without known traffic volume data are useless. For example in a Transport Research Centre's study [11], more than 40% roundabouts were situated on such local roads and therefore could not be included into a prediction model. What is more, traffic and road data (and accident data as well) exist separately, which impedes data searching and syntheses.

As stated before [1], a short term solution is to update and extend the outputs from currently used systems. A long term solution could be a change in data delivery systems; however it is in a collision with legal conditions.

Thus the alternative is to collect own primary data, as has been done for example in BESIDIDO project. It is however obvious that it is a demanding task with small coverage; it was also the reason why BESIDIDO data did not suffice in the presented study.

### *5.3. Availability of research data*

Research data are outputs of accumulated data of previous research projects. The acquisition of data sets used in this study was possible only due to the cooperation between Transport Research Centre and Czech Technical University in Prague. On the other hand, data from a similar project conducted at Technical University in Ostrava were not acquired (107 roundabouts, according to [10]).

The solution would be a set-up of public database of research data. It could improve sample sizes and thus the quality of studies. It would also enable independent assessments and replications with published data.

### *5.4. Different methodologies*

As mentioned in the introduction, accident data are non-normally distributed and linear regression and correlation techniques are thus not applicable. Even accident rate, which erroneously treats accident frequency as being in a linear relationship with traffic volume, should not be used (see more in [2]). These facts have been known abroad for a long time and they were also applied in the Czech Republic [16], however, not always with success [7]; nevertheless, they are still not a part of Czech road safety/traffic engineering knowledge.

To alleviate these methodological constraints, generalized linear modelling techniques are suggested. These procedures are routinely applied abroad and so were in this study. The most significant explanatory variable is AADT, however there are many others, as was apparent from presented Czech and international data sets. Multivariate modelling is thus a necessary further step. For example, using detailed data on 200 roundabouts [11], the following relation for annual expected accident frequency was found:

$$E(\lambda) = 0{,}0002 \cdot AADT^{0{,}576} \cdot D^{1{,}245} \cdot \Delta^{-0{,}377}$$

where $D$ is roundabout diameter and $\Delta$ is deflection angle. The exponent signs confirm logical facts (the larger the diameter, the more accidents and the opposite for a deflection angle) and also enables to quantify their effects. Such models may then be used in studies related to safe roundabout design parameters.

## 6. CONCLUSIONS

The paper presented methods of accident studies and introduced analyses based on accident prediction models. The example focused on a comparison of roundabout prediction models; in addition specific challenges related to data collection, analysis and interpretation have been mentioned. Nevertheless these challenges have solutions; several of them were described in the previous text and they are summarized in the Table 1.

Table 1. Summary of challenges, their descriptions and solutions

| Challenge | Description | Solution |
|---|---|---|
| Data collection | Insufficient quality and/or quantity of accident, traffic and road data | Data controls, updates, combination of databases<br>Extension of samples in space and/or time<br>Alternatively own survey, safety performance indicators/surrogate measures collection |
| Data analysis | Non-linear relationships, discrete data, non-normal probability distribution | Generalized linear modelling |
| Data interpretation | Multivariate relationships | More explanatory variables in prediction models |

Proposed solutions have been known abroad, in the Czech Republic this is still not the case. Reasons may include a lack of knowledge, but also elaborateness, demanding thorough data preparation. As early as 10 years ago, it was stated that this approach is maximalist and nonstandard [17]; nevertheless, it is inevitable, as confirmed by international experience.

## Acknowledgements

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# Planning of parking spaces according to the Czech legislation

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**Abstract**

The requirement for parking spaces is a necessary part of each project documentation, from which a new investment plan will be made. Determination of needs for parking spaces is also part of any land–use plan. The reason is, that needs for parking are an important point in urbanization and town development. The number of parking spaces is important not only for planning of a new construction or development plans, but also for existing territories and objects such as assessment of existing buildings after modernization, … etc. The total number of parking spaces is sequentially specified from the input parameters and coefficients set in the technical standards, which are either partially inaccurate, or does not correspond to the real requirements for parking and parking spaces in general.

**Keywords:** project, parking, legislation, urban roads, school, catering, restaurant

## 1. Introduction

For more regional and supra–regional units is typical, that needs for parking spaces are not calculated according to the standard ČSN 73 6110 "Design of urban roads", but these needs for parking are determined according to their own regulatory measures as they try to adapt to local conditions (e.g. Public notice No. 26/1999 of the Collection of Prague).

The reason for creating these ordinances is that we can find different characters of local areas (historical center, peri–urban areas, etc.), the size of the territory, the nature of public transport and other services.

But even despite of these differences is the basic document, on which are based the regional or local documents, the above mentioned standard ČSN 73 6110 "Design of urban roads". Strict compliance with the prescribed procedure, how to obtain the required number of overall parking spaces, is determined by tracing individual factors such as availability index, walking distance, the coefficient of reliability, coefficient of line frequency, the coefficient of reduction of number of parking spaces, etc.

## 2. Coefficient of walking distance to stop

Through all the stages and the monitoring indexes closely, we can find, that in the current standard of calculation of the total number of parking spaces is most likely a mistake. This is a paragraph within the walking distance. The calculation is used mainly for calculation in "difficult conditions" for each zone or buildings, that are located in areas with good public transport connections, but in the total this calculation may have a large impact on the total number of parking spaces.

The calculation of “the index of availability” is as follows (According to standard ČSN 73 6110 “Design of urban roads”):

- Index of availability

$$A_D = \sum A_F \tag{1}$$

$A_F$...............................line frequency
$\sum A_F$ ..........................the sum of all line frequencies of all stops that are reachable in the area

- The unit of the metric line frequency

$$A_F = \frac{60}{A_N} \tag{2}$$

$A_N$...............................coefficient of entering time

- Coefficient of entering time

$$A_N = A_Z + A_C \tag{3}$$

$A_Z$...............................time needed to reach the bus stop
$A_C$...............................the average waiting time for the arrival of public transport vehicle

- Time needed to reach the bus stop

$$A_Z = l \bullet v \text{ [s]} \tag{4}$$

$l$.................................distance [m]
$v$................................speed [considered 1,4 m/s]

$$A_Z = \frac{l \bullet v}{60} \text{ [min]} \tag{5}$$

The goal is to find the determination of average time needed to reach the stop. We can consider the average walking speed of *v = 1,4 m/s* for an uniform movement, which is one of the basic patterns of mechanics, where mechanics is one of the oldest parts of physics.

In the available documents (for example mathematical or physical tables) are laid down two basic formulas of the movement. This is a calculation of the trajectory and speed within the harmonic motion.

$$s = v \bullet t \tag{6}$$

$s$ ................................trajectory [m]
$t$.................................time [s]

or rather

$$v = \frac{s}{t} \tag{7}$$

By modification of the basic formulas (4), (5), (6) and (7) we can set the time needed to reach the stop:

$$t(A_Z) = \frac{s}{v} \text{ [s]} \tag{8}$$

or

$$A_Z = \frac{(s/v)}{60} = \frac{s}{60 \bullet v} \text{ [min]} \tag{9}$$

It is clearly seen, that the input quantities entering both established formulas for the calculation of the time *t* (according to mathematical – physical numbers and the calculation of the walking time to the station according to standard ČSN 73 6110 “Design of urban roads”), are identical and the error is given by the mathematical operators “times” and “divided by”.

By comparing the results is evident, that contrary to the physical properties leads to inaccurate calculations of the total number of parking spaces, which is higher than it should be properly determined.

In the current text of standard ČSN 73 6110 “Design of urban roads” including the Change of standard “ČSN 73 6110 Change Z1 (Change 02/2010)” this inaccuracy not only affects the time needed to reach the bus stop $A_Z$, which is always significantly higher than the one using the modified formula (9), but also, at the same time reduces the availability index and level of availability of the territory.

From these calculations is then determined the coefficient of number of reduction of parking spaces, which will be higher and as demand of this multiplication there will increase the total number of parking spaces. The inaccuracy was also already mentioned in one of the Bachelor's thesis at the Faculty of Transportation Sciences (CTU in Prague).

An adjustment of this formula (9) will bring more precision and accuracy of the result, but doesn´t work with the global decision–making aspects. Those are for example – the attractiveness of the territory, kind of city transport or public transport etc. It would also be appropriate to deal with the territory as a whole and not just as one particular part.

It would be desirable to replace the length to the bus stop by the distance – circle showing us the same distances from different parts of the area to the bus stop. With this technical parameter, such as distance – circles, or the availability of the bus stop, is determined the position of a new bus stop. The variable should be the default measure for the availability of the territory.

## 3. Determination of parking spaces according to the functional units

According to character of the landscape and territorial plan are nowadays also designed and planed large mixed – use objects with a predominantly residential character, but also with another use as administrative spaces or cafes. These services are primarily designed to meet the needs of local residents, or residents of a nearby area, which are in a relatively acceptable walking distance. Uses for persons from a border area are then minimum and for this reason there are not as far as so much set demands on parking spaces.

In opposite to the needs (with reference to the standard ČSN 73 6110 “Design of urban roads”, Change of standard “ČSN 73 6110 Change Z1 (Change 02/2010)”) the requirements of parking spaces are neglected. The numbers of parking spaces are decided by the developers, but as these buildings include non–residential spaces, the developers do not set the correct numbers of parking spaces. For this reason, the reference vehicles of the people working in the administrative areas are parked for a period of non–use in the available parking spaces and therefore reduce the capacity of the parking spaces that are designed for other purposes, for example to visit the housing section.

Functional breakdown of the areas of the non–residential character are divided in the table No. 34 of the standard ČSN 73 6110 “Design of urban roads” and the relevant Change of standard “ČSN 73 6110 Change Z1 (Change 02/2010)”, where the individual “pointers” are further divided into subgroups with the relevant criteria of the required number of parking spaces. The area of public restaurants or catering has become the exception of this subsequent subdivision in the Change of standard “ČSN 73 6110 Change Z1 (Change 02/2010)”. This area has been provided for only one subgroup – the “restaurant”, which in its original form (01/2006) of the standard ČSN 73 6110 “Design of urban roads” was divided into 4 groups (please see Table 1.).

Table 1. A modified part of the table No. 34 of the standard ČSN 73 6110 “Design of urban roads” – Featured basic indicators of all parking and parking spaces from the Change of standard “ČSN 73 6110 Change Z1 (Change 02/2010)”

| Type of structure | Specific unit | The number of special purpose units to 1 parking | The number of parking spaces | |
|---|---|---|---|---|
| PARKING SPACE | | | The short-term [%] | The short-term [%] |
| Catering – restaurant | Area for guests in $m^2$ | 4 to 6 | 70 | 30 |

By distribution to only one subgroup “restaurants” are disadvantaged smaller areas of business, such as Cafe, where are not usually served main courses, and the delay of serving the customers is not as long due to the preparation and consumption of main courses in these smaller devices.

These Cafes are most commonly placed in the multi–purpose objects. The subsequent calculation of parking spaces generates for these smaller food services facilities a necessary number of parking spaces. It would be appropriate to divide this area into 2 subgroups as for example restaurants and cafes.

It would also be good to prove the individual coefficients, also the ones in other areas of calculation of parking spaces in the following table (table No. 34 of the standard ČSN 73 6110 “Design of urban roads” – Featured basic indicators of all parking and parking spaces from the Change of standard “ČSN 73 6110 Change Z1 (Change 02/2010)”) where a good example can be taken education.

When a standard elementary school, which has 2 classes for each level of schooling (2 × 9 classes) and an average number of 20 students per class, the is taken as example, the required number of parking spaces is 72 with 58 parking places for short–term parking and approximately 14 parking spaces for the long–term parking spaces.

Without any long considerations it is evident that the needed number cannot be realistically achieved in the existing buildings, but cannot also be achieved in the new buildings, where it is counted with higher number of parking spaces.

The main request for parking is only in the morning, when the parents take their children to school. In the afternoon, this request decreases significantly due to dispersion of class hours in other time zones for each class. The pupils at this age don´t have any claims to the parking space, and therefore it is important to propose a sufficient number of long-term parking spaces and parking spaces of the K+R type “Kiss and Ride” according to local conditions of placement of the school.

One of the possibilities would be using these parking spaces in specified times (afternoon / night) for people living in the area.

## 4. Conclusion

The achievement of traffic sources and destinations and, consequently, requests for parking are created by a lot of aspects in these days. It is determined not only by the density and capacity of the transport networks, time course of the day, capacity of the parking areas, but it is also affected by the quality of public transport, the availability for cyclists or walking to the source or target etc.

Therefore, the parameters for the calculation of the total number of needed parking spaces should be made more accurate, that the proposed number of parking areas can match the real request. For this reason, this article only draws attention to the inaccuracies that are valid in the current standards. In the future there will be found such parameters, which can be subsequently integrated into the regulations and standards related to designing of communications.

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[2] Standard ČSN 73 6110 “Design of urban roads” (01/2006)
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# Road safety education for young drivers in relationship to decreasing of car accidents caused by young drivers

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**Abstract**

Number of car accidents caused by young drivers has been a very actual topic within the last few years. Many accidents, where young people die, are caused by drivers of age 18 – 24 years. The statistics show us, that behavior of young drivers is very unpredictable and most of tragic car crashes are caused because by non–experienced young drivers. This problem can be caused by many reasons and it is highly necessary to find a border, when a young driver sees his / her skills and possibilities. There are many questions that need to be answered - like additional education of young drivers and especially training in avoiding dangerous situations that can be met by all drivers every day on the roads.

**Keywords:** car accidents, education, young driver

## 1. Introduction

Every young driver gets the basic education for driving car usually in the age 18 – 20. In many cases, driving license is a necessary step to modern society. But many times are young drivers a potential danger to other drivers. In the last 3 years there were many studies focused on behavior of young drivers. Most of these studies were made in Germany, where this topic is very actual because of increasing number of tragic accidents. After getting the driving license, there is no additional control of young drivers' skills. There are a few possibilities to upgrade skills, like special driving lessons focused on driving in the city or school of braking, but all these activities are voluntary and the common knowledge of these possibilities is very low.

### *1.1. Road safety education from nursery school to driving school*

The proper general road safety education starts by young drivers in the driving school, where the future young drivers first meet the bad aspects of their behavior behind the steering wheel. Before the driving school the children are taught about road safety only rarely. The first knowledge can get the child already in the nursery school. There gets the child information about aspects of traffic and car in common. Beside that is the child taught how to behave on the streets and in case the car is coming. In the Czech Republic is this basic educational system implemented in most of the nursery schools.

During the first 4 years of school (6 – 10 years) the children can take part in special lessons, where all participants get information about behaving as pedestrians and cyclists. But in most of the cases children have to take special lessons, because this kind of education is not compulsory in the schools. Today there are schools themselves interested in offering the children and their parents many volunteer activities, where children and young students can get information about the right behavior on the streets. This system has been already used in Germany, where the road safety education has stronger basement. The main program of many German schools is to make the topic “Safety way to school” attractive not only for children, but also for their parents. To effect as many children and parents as possible, created the German automobile club (ADAC) many brochures (please see Fig. 1.) and educational programs in the last 3 years where the schools don´t have to prepare anything. Every single school can order different educational programs. By these sessions children try to solve different problems connected to road safety that they can meet every day on their way to school. The common educational program prepares future drivers. The main goal of this education is to let children and young students find their own relationship to traffic themselves. Children of 8 – 10 years are taught, how to behave on the streets and how to ride a bike in a safe way.


Fig. 1. The educational brochure for children of age 6 – 10 years in Germany (source: www.adac.de)

For older students (10 – 15 years) ADAC created a higher level of “traffic” education. The youngsters can fluently continue in their activity in level 2 education, where they learn (please see Table 1.), how to go alone throw the city and they learn the basic traffic rules for riding bike with other traffic (cars, public transport, … etc.).

Table 1. Road safety education for children and youngster under 15 years in Germany

| Age | Point of education |
|---|---|
| under 5 | How to behave by walking with parents |
| 5 – 10 | Behavior by walking, basic lessons of riding bike |
| 10 – 15 | Behavior by riding bike, traffic rules |

This kind of education is still missing in the Czech schools. One of the possibilities was to take part in lessons for future drivers, that was offered within high schools, but this possibility disappeared very fast and the Czech drivers has to learn everything in the driving schools.

*1.2. Statistics of car accidents caused by young drivers*

As one of the main causes by car accidents of young drivers is poor knowledge of traffic and its principles in the basic row. For a young driver there are almost no borders. Having driving license is a necessary social step and the young drivers do not think about the demands of their behavior on the roads.

According to the national statistics for the year 2011, 9 286 of 41 408 (total) car accidents were caused by drivers of age 18 – 24 years (please see Fig. 2.). That is 22,4 % of all car accidents in the Czech Republic in the year 2011. In the same year died 120 youngsters by these car accidents. That´s 17 % of all persons killed by the car accidents (taken all age groups). In comparison to other countries in EU (please see Fig. 3.), the Czech Republic has an opportunity in decreasing the number of deaths on the roads.

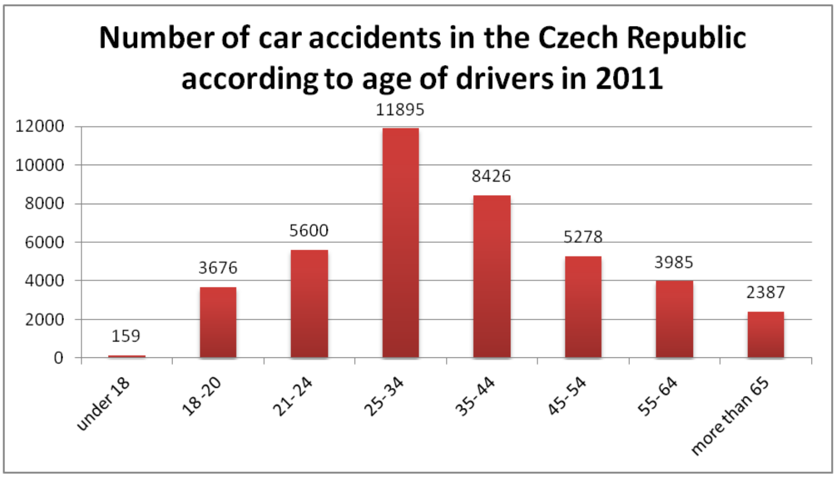


Fig. 2. Number of car accidents in the Czech Republic according to age of drivers in 2011 (source: www.zavolantem.cz)

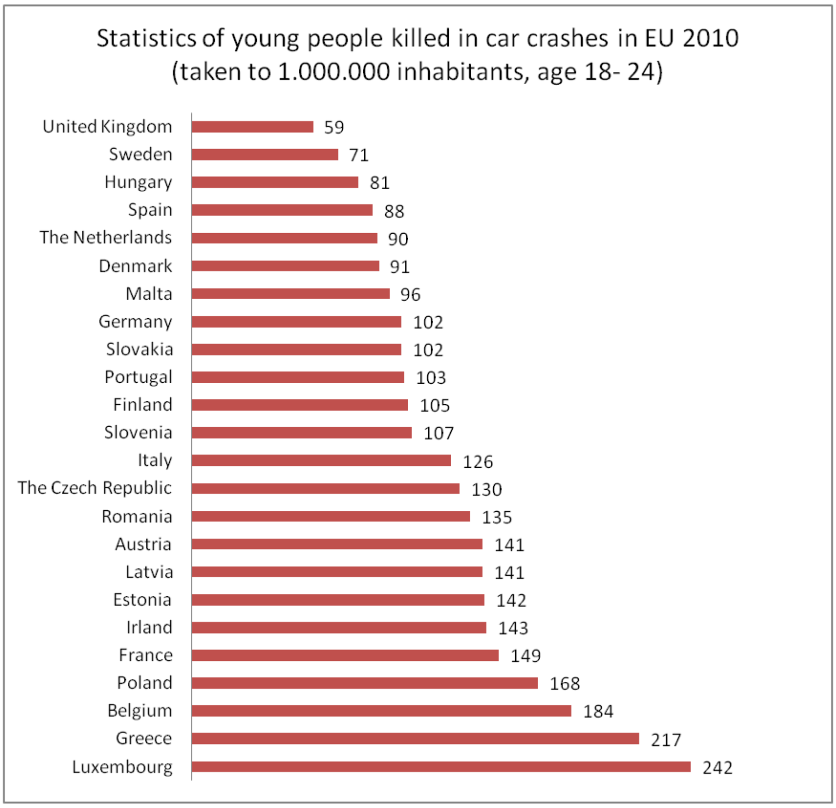


Fig. 3. Statistics of people killed by car accidents in EU in 2010 (source: www.adac.de)

The main causes by car accidents are in Germany in year 2012 (and are very similar to the Czech Republic, please see Fig. 4. and Fig. 5.):

- ride off the road according to high speed...... ca. 23,5 %
- ride off the road in curve – high speed ......... ca. 11,0 %
- overtaking off other cars................................ ca. 8,0 %
- turning left .................................................... ca. 8,0 %

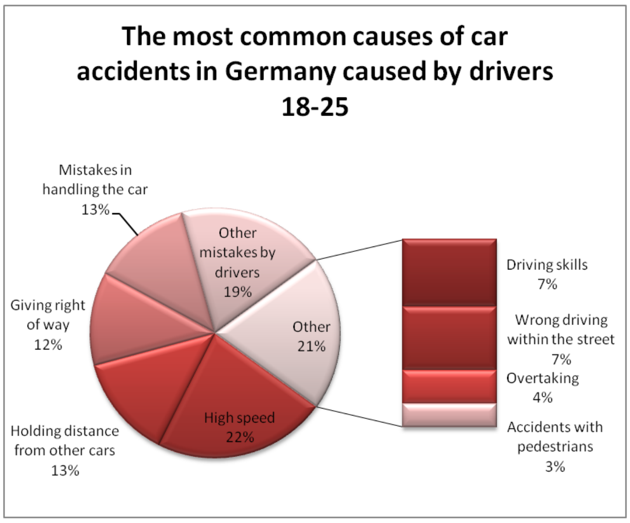


Fig. 4. The most common causes of car accidents in Germany caused by drivers of age 18 – 25 (source: www.adac.de)

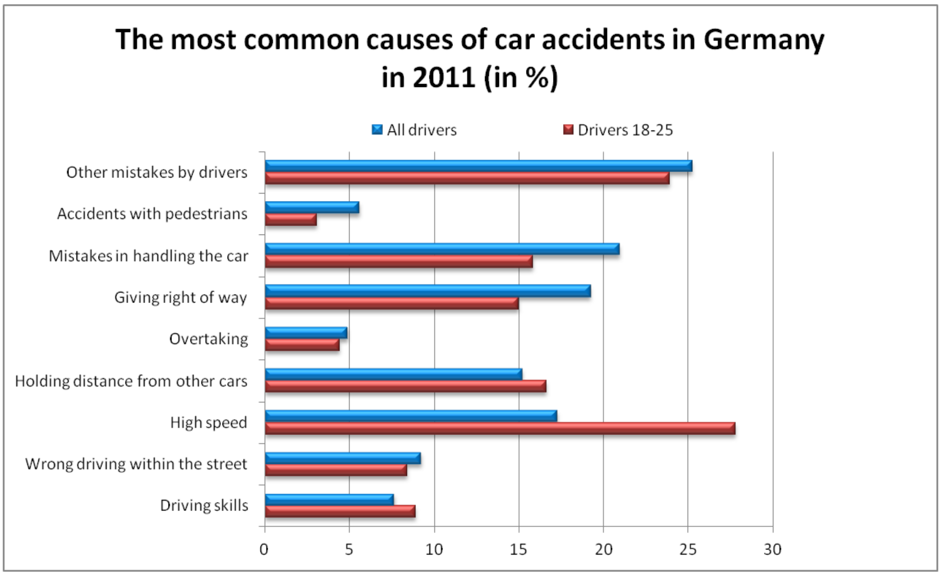


Fig. 5. The most common causes of car accidents in Germany in 2011 in % (source: www.adac.de)

Table 2. Tragic car accidents in the Czech Republic in April and May 2013 (source: www.idnes.cz)

| Date | Place | Age of driver | Cause | Killed | Seriously injured |
|---|---|---|---|---|---|
| 24.5.2013 | Uhelná na Jesenicku | 19 | High speed | 1 | 0 |
| 26.5.2013 | Kostelec nad Labem | 20 | High speed in curve | 1 | 2 |
| 21.5.2013 | Bělušice na Mostecku | 18 – 24 | Giving right of way | 2 | 1 |
| 17.5.2013 | Pluhův Žďár | 20 | High speed in curve | 1 | 0 |
| 10.5.2013 | Ostrožská Lhota | 24 | Ignoring of road marking | 0 | 2 |
| 30.4.2013 | Lichnov | 20 | High speed | 0 | 1 |
| 25.4.2013 | Turnov | 22 | High speed | 1 | 0 |
| 19.4.2013 | Praha | 18 | High speed | 1 | 0 |

Compared to all drivers, young drivers drive faster. This is usually based on their need to reach their own borders. Most of the accidents with tragic consequences are caused because of high speed. Only in the April and May 2013 died 7 young drivers and 6 were seriously injured. Most of the accidents were cause because of high speed (please see Table 2.).

## 2. Safe driving trainings – Research made by University in Regensburg and German automobile club (ADAC)

To find out the problematic of young drivers´ thinking, ADAC in cooperation with University in Regensburg tested 519 young drivers of age 18 – 24 years. The main goal was to find a solution that would allow setting a new driving education for young drivers and beside that to show up where the problem is.

Young drivers were split into groups of max. 15 persons and their tasks were to complete a full training of "Car Control and Recovery Exercise". The drivers filled a 100–questions questionnaire that was focused on car safety and drivers personal views of traffic in common sense and their driving skills. In this test took 201 female and 317 male part. All drivers used their own cars during the training. They filled the same questionnaire before the training itself, after the training and after 3 months per e–mail. 92 young drivers from the testing group and 24 drivers from the control group totally finished the research.

The results were quiet surprising. Immediately after the training many participants reported a visible improvement and agreed, that they didn´t have a clear view of risks they can meet on the roads. The whole testing brought many results not only for short term effect.

The most significant differences before the training and after were related to speed, behavior behind the steering wheel, driving competence and anticipatory driving. Just in case of speed was very significant gender split. At the question of handling speed limits the participants used "sporting style" of driving. That means to drive fast with an acceptable percent of risk. Women were more affected by the training and even after 3 months agreed, that the awareness of driving fast had still effect on their style of driving.

The test training had also effect on behavior of the drivers. During the training they were taught to take the right position, to have both hands on the steering wheel or to have right foot on the breaking pedal.

## 3. Goals of the study at the Faculty of Transportation Sciences (CTU in Prague)

The study in Germany showed, that after getting the driving license, additional training is highly recommended. According to the results the Czech Technical University in Prague (CTU in Prague) Faculty of Transportation Sciences, decided to use similar research model on young drivers in the Czech Republic. The research will be most focused on meanings before the driving school, after getting the driving license and then after 3 – 6 months. The control group will be made by young drivers that absolve an additional training focused on handling the car (braking, simulation of aquaplaning, … etc.).

The testing group awaits more than 1000 participants. Into the control group should be involved around 200 young drivers. Each participant will be asked to fill the questionnaire truly.

Table 3. Time plan of the research model on young drivers prepared by Faculty of Transportation Sciences (CTU in Prague)

| Time period | Goal |
|---|---|
| July – August 2013 | Getting the driving schools involved into research |
| September 2013 | Start of the research |
| December 2013 | End of 1st round |
| January – April 2014 | 2nd round (drivers fill the questionnaire after 3 months) |
| May – July 2014 | 3rd round (drivers fill the questionnaire after 6 months) |
| October 2014 | Evaluation of the research |

There will be asked as many driving schools in the Czech Republic in the first round of this research as possible. The target is to cover the whole Czech Republic, not only one region. The research will be started in September 2013 and will end in June 2014 (please see Table 3.). All involved young drivers will be asked automatically after 3 and 6 months after finishing the driving school. It´s awaited around 30 % of responses after 3 months and 15 % after 6 months. In this case there still should be sufficient amount of answers to set results that will be trustworthy.

The results will be compared with the control group and should help to find the point, where young driver has enough training, information and mainly experience to start driving in a safe way or at least to minimize the risks that are usually taken by young drivers in many situations on the roads.

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# Parameters of Passenger Facilities According to Railway Station Characteristics

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**Abstract**

The article presents ways and goals of categorization of railway stations and stops in the Czech railway network. The aim of this categorization is to classify railway stations (or stops) in the railway network according to a suite of entrance parameters (e.g. municipality population, transfer links, job opportunities, tourist attractiveness). On the basis of these parameters, railway stations and stops will be classified into several categories, which will be used to specify the conclusions for station equipment concerning ticket offices, commercial services, waiting rooms and other accessories. Research results can be used as a support for infrastructure managers and railway operators to optimise the scale of their services.

**Keywords:** railway station, stops, passenger facilities, categorization

## 1. Introduction

Equipment for passengers in railway stations and stops is one of the key parameters for both effective railway transport operation and passengers´ comfort. The range of needed accessory depends on many types of outer influence that may be stable or can be variable in time. By the station facilities we understand e.g. ticket offices, separate waiting areas, areas for short-time waiting, refreshment points, stores and shops and other supplementary commercial activities. The aim of this article is to introduce the methodology for a railway station categorization – the output then should be a recommendation for an optimal railway station or stop equipment, depending on demographical, economical, transport and other relevant influence. This methodology will be verified on certain examples that represent railway station of various parameters (traffic range and characteristics, parameters of the closest settlement etc.) – this will also serve for the calibration of the chosen parameters of the methodology. Later the importance of the single methodology parameters will be set by the authors.

## 2. Assumption and categorization principles

The target of this research is to create a methodology that could be used with no extra technical knowledge or expert assessment, based only on one-time parameter definition. Therefore all the parameters have specific values and if not, they have to allow to be set based only on a general judgement. All inputs can be represented by either definite numbers (population, number of trains etc.) or easily distinguishable groups (local, regional, international). The result should be represented by a methodology that can be used for railway station buildings adaptations and dimensioning, mainly by their administrators.

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In the categorization described in this article a set of input criteria is divided into a 100 point scale, what is also a maximum value a station can reach. The more points the station reaches, the higher is its importance concerning the passenger services. Based on the total score the final category of the station is chosen and it corresponds with a certain range of services. The categorization is designed as an open system, i.e. its parameters are based on the expert knowledge of the authors verified in real example application. All input values can be recalibrated in case of need, as well as for the output categories different conclusions can be set. Therefore the main target of the methodology is not to assign certain services to a railway station strictly, but to provide a guideline for railway station buildings administrators in the station importance classification, which would be based on unified and exactly set inputs.

The whole categorization is designed as a two-step process. The first step divides the maximum sum of 100 points into four basic general groups, which are further divided among concrete subsidiary segments. Each criterion has a certain share in the final score and also has a given range of its values. Criteria are set mainly exactly to prevent a subjective judgement of a user during the evaluation process. In real the categorization is represented by three charts. The first one is used for a general criteria calibration, the second allows the calibration of the subsidiary segments. As a result the third chart will compute the total score based on the input values for the chosen station. The total score is then used for the station categorization into one of the predefined categories.

During the calibration process the authors revealed, that in a small number of cases such situation may occure when e.g. a station with a high frequency of lower-class trains accompanied by a local attractivness scores more points in the final score than a station with higher-class train service with lower frequency. This, however, does not correspond with the presumption, that passengers of higher-level trains demand higher service level and spend more time within the station premises. To prevent from this discrepancy the authors decided to improve the next version of the categorization charts with new indicators, so the final equipment recommendation depends not only on the final score, but also on the transportation characteristics of the station and corresponing traffic.

## 3. Input parameters

### *3.1. General parameters*

General criteria in the categorization define the importance of four main groups of input parameters. A share of these criteria influences the further importance division of the subsidiary segments, where the maximum score of the subsidiary segments of a one group can reach only the share of the group within the general criteria. The general criteria are:

- importance of the station within the network
- importance of the station as a public transport change node
- settlement and a position of the station relatively to this settlement
- attractiveness of the station surrounds

Using these criteria we see, how importance is being divided among the position of the station within the railway network, its public transport inter-change operability (especially concerning integrated systems), position of the station respectively to the closest town or city together with its demography and also the presence of other transport sources and/or targets (job opportunities, sights, shopping etc.).

### *3.2. Subsidiary criteria*

The *Importance of the station within the railway network* criterion consists of segments defining transport characteristics of the station, given by a position of the station within the network as well as the structure and the intensity of the railway traffic. Due to the fact, that the range and structure of the traffic strongly influence passengers´ requirements on the station accessories, the biggest importance share belongs to this criterion within the decision model.

The *Railway traffic structure* segment represents the quality category of the trains, which stop in the station. It acquires four values rising with a category of the train – suburban trains with a peak interval shorter than 30 minutes, regional trains with a peak interval over 30 minutes, lower quality fast trains and higher quality fast trains (Ex, IC, EC). The highest stopping category is determining. This criterion assumes, that passengers travelling longer distances and those using higher quality trains require a higher level of services within the station buildings. On the other hand the daily passengers of suburban trains with short intervals usually require only minimum or even no facilities, as they are coming to the station only a short time before a train departure. If the interval is shorter than 15 minutes a part of the passengers even come to the station regardless the timetable, as they consider the longest waiting time still appropriate.

The *Number of incorporated directions* segment considers the fact that in a station, where more railway routes meet, a certain (hardly definable) part of the passengers only changes and does not use the station facilities at all. Therefore with the growing number of incorporated directions the segment score decreases. However, this effect depends on hardly describable parameters, such as platform configuration or timetable (waiting times for connections), therefore only a small importance share is assigned to this segment - it cannot be neglected, as the passengers´ service demands within the change node are undisputed. On the other hand with a good timetable configuration with short waiting times the importance of change-related services may plunge sharply, especially in the regional transport (e.g. Ostromer, Stara Paka). During the methodology functionality verification the authors found out, that in some cases this segment can even skew the total score of the station. The first countermeasure is therefore the low importance share, the next could be a separate coefficient, that would consider the ratio between transit and source/target passengers.

The *Number of stopping trains* in a peak hour segment evaluates the intensity of railway traffic in the station. It is a total sum of stopping trains not distinguishing among the train categories, as this quality has its own segment. The segment score rises with the number of stopping/ending trains. The peak hour is the hour between two :00 in which the highest number of trains stop in the station, usually in the morning or the afternoon rush hour.

Table 1. Dividing general criteria into segments and their importance (part 1)

| **Importance of the station within the network** | total importance (maximum) | 45 | already divided | 45 | to divide | 0 |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Railway traffic structure (the highest of the categories)** | importance (maximum) | 20 | given maximum | 20 | | |
| type of railway traffic | rating | | | | | |
| **suburban trains with a peak interval shorter than 30 minutes** | 5 | | | | | |
| **regional trains with a peak interval over 30 minutes** | 10 | | | | | |
| **lower quality fast trains (R)** | 15 | | | | | |
| **higher quality fast trains (EC, IC, Ex)** | 20 | | | | | |
| | | | | | | |
| **Number of incorporated directions** | importance (maximum) | 5 | given maximum | 5 | | |
| number of incorporated directions | rating | | | | | |
| **2** | 5 | | | | | |
| **3** | 4 | | | | | |
| **4** | 3 | | | | | |
| **5** | 2 | | | | | |
| **6 and more** | 1 | | | | | |
| | | | | | | |
| **Number of stopping trains in a peak hour** | importance (maximum) | 20 | given maximum | 20 | | |
| number of stopping trains in a peak hour | rating | | | | | |
| 1 or less | 3 | | | | | |
| 2-3 | 6 | | | | | |
| 4-5 | 10 | | | | | |
| 6-10 | 15 | | | | | |
| 11-20 | 18 | | | | | |
| more than 20 | 20 | | | | | |
| | | | | | | |
| **Importance of the station as a public transport change node** | total importance (maximum) | 15 | given maximum | 15 | | |
| importance of the station as a public transport change node | rating | explanation | | | | |
| **no importance (is not a public transport change node)** | 0 | - | | | | |
| **local change node** | 5 | only bus lines within the settlement | | | | |
| **small regional change node** | 8 | only regional bus lines/bus city transport | | | | |
| **large regional change node** | 12 | only regional bus lines/bus or tram city transport | | | | |
| **inter-regional change node** | 15 | regional and inter-regional bus lines/tram and bus city transport, metro | | | | |

The second group of segments – *Importance of the station as a public transport change node* – represents the importance of the station regarding the other modes of a public transport assuming that in optimal case all modes of public transport share the facilities placed preferably within the railway station. The criterion can score four grades – a local change node, a small regional change node, a large regional change node and inter-regional change node. All these types have also their analogy in a city public transport system where a similar division can be made using the means of city public transport.

The *Position of the station according to the settlement criterion* represents the relationship between the station and the settlement, for simplification represented only by a directly corresponding settlement – usually the town or city of the same name. The input parameter of this criterion is the population of the whole settlement. The score rises linearly with the population number. A correction of this score is provided by many coefficients that correct the actual score depending on the position of the station according to the settlement and also on the existence of other public transport systems nearby. The correction is used in case the station is difficult to reach from the settlement and it is further specified by an existence of another (easily reachable) change node / station. In such cases we assume that the passengers´ demand will be divided among more change nodes / stations or will be attracted to the more accessible one. A special case is represented by a station with a disadvantageous position according to the settlement, whereas there exists another more advantageous public transport change node / station with a similar range of services and similar transport directions. In such case the coefficient affects the total score of the station, because almost all demand will be attracted to the more advantageous change node / station.

The last *Attractivness of the station* surrounds criterion considers other influences that may induce transport demands of a permanent or random character. Mainly we are talking about concentration of job opportunities, shopping stores or tourist and recreational attractions, considering their range coverage (town, region, country).

Table 2. Dividing general criteria into segments and their importance (part 2)

| | | | |
|---|---|---|---|
| **Position of the station according to the settlement** | total importance (maximum) 25 | | |
| **population** | | | |
| for each 5 000 citizens 1 point | | | |
| i.e. over 125 000 citizens the same score | | | |
| **station position according to the settlement coefficient** | maximum coefficient value given 1 | | |
| **station position according to the settlement coefficient** | **coefficient value** | examples | remark |
| station reachable by foot from the whole settlement area | 1 | Stratov, Všenory, Poděbrady | |
| station within the area, reachable by foot or city transport from the whole settlement area, no comparable station/stop | 1 | Pardubice hl.n. | |
| station within the area, reachable by foot or city transport from the whole settlement area, there is a more advantageous station/stop | 0,25 | Nová Paka | ***reduces only "Position of the station according to the settlement"*** |
| station within the area, reachable by foot or city transport from the whole settlement area, there is a comparable station/stop | 0,5 | Ostrava-Svinov, Ostrava hl.n. | |
| station outside the area, reachable by city transport, no comparable station/stop | 0,5 | Dvůr Králové, Hořice | |
| station outside the area, reachable by city transport, there is a more advantageous station/stop | 0,1 | Golčův Jeníkov | ***reduces the total score of the station*** |

| | | |
|---|---|---|
| **Attractivness of the station surrounds** | total importance (maximum) 15 | given maximum 15 |
| attractivness of the station surrounds | rating | examples |
| **no attractiveness** | 0 | - |
| **tourist or recreational target - local** | 5 | Malá Skála, Hrusice, Zlenice |
| **tourist or recreational target - regional** | 10 | Máchovo jezero, Křivoklát |
| **tourist or recreational target - coutry** | 15 | Mariánské lázně, Kutná Hora, Karlštejn |
| **concentrated job opportunities within a walk range** | 5 | Jihlava - Bosh Diesel |
| **shopping store within a walk range** | 5 | - |

## 4. Output parameters

The final 100-point scale is divided into 5 groups that set a general category of the station and its passengers´ facilities. Below one of the possibilities is presented – the group description as well as the point range can be altered.

Based on application of the methodology on dozens of stations the authors suggest the following categorization:

A (100 – 86 pts.): large railway nodes in cities with population over 100 000, with higher quality trains stopping
B (85 – 61 pts.): important railway nodes with strong source/target traffic, partly with higher quality trains stopping
C (60 – 46 pts.): usually middle-sized stations in larger towns and city suburbs
D (45 – 26 pts.): usually stations and stops in smaller towns with regional traffic
E (25 and less pts.): stations and stops with minimum service demand caused by low transport demand or short time spent within the station facilities

Table 3. Facility recommendation according to the category

| | A | B | C | D | E |
|---|---|---|---|---|---|
| **Area layout** | | | | | |
| shelter | | | | | x |
| heated/tempered hall | x | x | x | x | |
| separate waiting area | x | x | x | | |
| separate higher-quality waiting area | x | x | | | |
| **Transport services** | | | | | |
| ticket booth/window | x | x | x | x[1)] | |
| check-in centre | x | x | | | |
| **Other services** | | | | | |
| supplementary services basic | x | | x | | |
| supplementary services extended | x | x | | | |
| supplementary services centre | x | | | | |
| bathroom | x | x | x | x | |

x[1]) … depending on turnover, can be combined with commercial activities

## 5. Conclusion

The main target of the above described methodology is to provide a guideline for railway infrastructure administrators, carriers, public administration or integrated transport system coordinators. Its goal is not to present a strict definition how a chosen station should be equipped, but to provide an order or a categorization according to exact criteria. Based on this categorization a decision concerning the station facilities can be made, the recommendation by the authors according to the final score was given.

The main advantage of the methodology is the possibility of its recalibration. This was used mainly during the first calibration on a few dozens of existing stations within the Czech railway network. The authors presume a further specification and development of the categorization to be able to provide an objective option how to evaluate an importance and an area potential for the passengers in the railway station buildings.

## Acknowledgements

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# The State of Vertical Traffic Signposting in the Capital City of Prague

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**Abstract**

The main purpose of this article is to highlight the present state of vertical traffic signposting in the capital city of Prague. The analysis is based on field inspection and it captures the most frequent faults committed in placing traffic signs in the road network.

**Keywords:** vertical traffic signs, traffic signs, traffic models, traffic excesses

## 1. INTRODUCTION

A faultless state of vertical traffic signposting is a vital prerequisite for a fluent and safe progress of traffic in the road network. It is fairly difficult to monitor its state and condition due to the excessive amount of traffic signposting; therefore, it is not uncommon for us as traffic participants to encounter instances of inconveniently located or neglected traffic signposting in numerous places.
Students are introduced to the problematic of traffic signposting within the framework of "Traffic Models and Excesses" course available as a part of the undergraduate programme at the Faculty of Transportation Sciences. After finishing the theoretical portion of the course it is mandatory for the students to carry out an inspection of traffic signposting in a selected area in order to successfully complete this course. While accomplishing the aforementioned assignment, students have an opportunity to apply their theoretical knowledge and confront it with real situations. In the ideal case scenario the inspection would result in a description of a faultless state of all traffic signposting; however, the reality often proves to be different.
An abundance of valuable data which allows the individual observer to save a considerable amount of time can be obtained from selected assignments. An analysis of the aforementioned data enables to identify the most frequently used traffic signposting type in the road network and simultaneously it makes it possible to detect the type of signposting displaying most faults.

## 2. METHODOLOGY

The first step to facilitate the students´ inspection is introducing them to the correct placing of street signs, be it from the construction (the correct direction and height placement) or traffic (using the correct type of signposting) points of view. Students are presented in detail with the problematic of relevant articles of legislative (technical conditions, Czech state norms, laws and regulations, especially TP 65 and TP 133 and regulation no. 30/2001). In the practical part of the course students are also introduced to the guidelines for safe movement on roads and also the importance of protective safety gear is stressed.
Any traffic signposting is deemed to be faulty if the sign does not meet the criteria of correct placement in relation to the road (side margin, height) or shows signs of damage (e.g. bended, plastered with papers, soiled by paint, etc.) Moreover, the sign must not be placed in inappropriate correlation with another sign and the total amount of signs allowed on one post must not be exceeded.

The result of the inspection is a report including a description of the selected area, an itinerary of all traffic signposting (including horizontal traffic signposting and light signals), a description of faulty traffic signposting as well as a conclusion in which possible means of rectification are suggested. The submitted assignment also includes a map of traffic signposting with highlighted examples of unsatisfactory signposting to enable quick and easy orientation and photo-documentation illustrating the identified faults. Any submitted assignment is checked and verified by a teacher. The underlying motivation is to teach students to embrace the project format required by an investor in practice and applying their theoretical knowledge at the same time. The fieldwork was carried out in autumn 2012.

Data from some of the most informative inspections carried out in the capital city of Prague have been used to draw general conclusions about the state of traffic signposting and to indicate the most serious faults.

## 3. OBTAINED RESULTS

Some of the best semester assignments examining the signposting in the capital city of Prague have been chosen. In total, 1600 vertical traffic signs were inspected in various areas (e.g. Jižní město, Stodůlky, Evropská Street, etc.); 350 signs were identified as faulty. The most frequently occurring sign is P02 (Main road), constituting 11,67% of all signs (it is followed by IP 06 Pedestrian crossing – 10,54% and IP12 Reserved Parking – 5,5%).

Table n. 1: Frequency of appearance

| rank | code | name | quantity | % |
|---|---|---|---|---|
| 1. | P02 | Main road | 187 | 11,67 |
| 2. | IP06 | Pedestrian crossing | 169 | 10,54 |
| 3. | E13 (resp. E12) | Text | 140 | 8,73 |
| 4. | IP12 | Parking management zone | 88 | 5,49 |
| 5. | B28 | No stopping | 73 | 4,55 |
| 6. | P04 | Give away | 65 | 4,05 |
| 7. | B24 (a+b) | No turn (left + right) | 56 | 3,49 |
| 8. | B20 (a+b) | Maximum speed (start + end) | 56 | 3,49 |
| 9. | C04 (a+b+c) | Turn right + left + ahead only | 52 | 3,24 |
| 10. | IS22 | Direction sign to local streets | 41 | 2,56 |

Taking into consideration the most problematic traffic signposting where the ratio of faulty signs in total constituted more than 1,5% (25 pieces) of all examined signs it is surprising that the worst examples included two warning signs – A11 Zebra crossing (50% faulty examples) and A12 Children crossing ahead (44, 83% faulty examples). This means that almost every other sign predominantly placed in schools´ surroundings and warning traffic participants against unexpected danger does not properly fulfil its function. In case of P02 (Main road) the ratio of faulty examples was 29%. This means that one traffic sign in four unambiguously indicating priority is unsatisfactory. In case of IP06 (Pedestrian Crossing) the ratio amounts to 28,4%. Further results are stated in the Table n. 2.


Fig. 1. You really can’t stop here. The problem of duplication traffic signs. [6]


Fig. 2. Invisible traffic signs. [6]


Fig. 3. A lot of traffic signs in one place. [7]


Fig. 4. Nature vs. traffic signs [6]

Table n. 2: Traffic signposting according to percentage of faulty signs. Only signs appearing at least 25 times have been considered.

| rank | code | name | quantity | faulty | % faulty |
|---|---|---|---|---|---|
| 1. | A11 | Zebra crossing | 28 | 14 | 50,00 |
| 2. | A12 | Children crossing ahead | 29 | 13 | 44,83 |
| 3. | B02 | No entry for vehicle traffic | 33 | 12 | 36,36 |
| 4. | B20 (a+b) | Maximum speed (start + end) | 56 | 18 | 32,14 |
| 5. | P02 | Main road | 187 | 55 | 29,41 |
| 6. | B28 | No stopping | 73 | 21 | 28,77 |
| 7. | IP06 | Pedestrian crossing | 169 | 48 | 28,40 |
| 8. | IP19 | Appropriate traffic lanes at junction ahead | 40 | 11 | 27,50 |
| 9. | IS04 | Direction sign to important local destinations | 36 | 9 | 25,00 |
| 10. | IJ04 | Bus stop | 26 | 6 | 23,08 |
| Σ | | | 1603 | 357 | 22,27 |

## 4. DISCUSSION

Road network development, increasing speed of motor vehicles and their growing number - these factors all represent reasons why it is vital to maintain traffic signposting in the best possible condition. Overlooking an important traffic sign may have fatal consequences. Modern vehicles nowadays are capable of distinguishing traffic signposting. To ensure the reliability of these systems it is crucial to preserve traffic signposting intact. Damaging, unprofessional manipulating, vandalism or neglected maintenance of these signs may result in a failure of the aforementioned system or the impossibility to spot an important traffic sign by sight and subsequent danger of accident possibly resulting in health and life threatening situations. The faults in warning and priority indicating signs are especially alarming.

## 5. CONCLUSION

After drawing a general conclusion it is necessary to state that almost one sign in four encountered by a traffic participant shows certain imperfections and may considerably influence the participant's perception of the traffic situation.

From the financial point of view, proper maintenance of traffic signposting is the least expensive way of contributing to traffic safety. As it has become evident from the above mentioned results, there are numerous possibilities to rectify the imperfections.

Placing traffic signs P02 and IP06 in immediate proximity of each other belongs to the most frequent faults together with traffic signs damaged due to their being placed in insufficient distance from the road margin or due to vandalism (plastering).

It would be advisable to offer selected well-executed assignments to transport committee representatives or board of transport members (not only in Prague) in the concerned city parts or municipalities for viewing and initiate cooperation of academic and state organs.

## 6. ACKNOWLEDGEMENTS

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# Layout Optimalization of Equipment for Personal Transport in Public Transport Change Nodes

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**Abstract**

The paper presents several key parameters of public transport change nodes, which is important for layout optimalization in them. First, based on surveys in chosen localities a real speed of getting on and off the board by passengers was ascertained depending on the height of a door edge and vehicle type and the platform access capacity and the speed of pedestrian current on the platform and on different types of access paths and on staircase were verified. A statistics of all railway station in the Czech Republic was processed to characterize existing stations in respect to their platform layout and parameters. Finally, a change nodes classification – which influences the transfer characteristics – is very important.

**Keywords:** public transport, change node, railway station, platform, pedestrian

## 1. Introduction

In connection with finalization of transit railway corridors in the Czech Republic the medium-term investment activities will be aimed at those railways which do not belong to the so-called European railway network, which means also at regional railways. Discussions are still being held about the optimal disposition, layout and parameters of railway stations, especially concerning the equipment of the stations for personal transport (platforms, access to the platforms, vestibules), but also about other problems connected with organization of public mass transport operation (range of information provided to the public, real transfer times).

## 2. Pedestrian Currents in Transfer Nodes

A transfer between lines of the same or different transport systems belongs to the basic attributes of regular public mass transport. At the same time an effort is spent to minimize the number of transfers in public mass transport as for passengers they represent a complication and a delay. Therefore an exact definition of the time needed to get on and off the vehicle as well as the walking speed of the passengers in the different areas of transfer nodes is a basic step to improve the situation. Based on this data we can not only set a real transfer time within the change node, but also design the layout of the change nodes to minimize the transfer time.

Two of the elements, which influences the total time of entering and exiting the railway vehicle, is the door width and the height difference between the platform and the vehicle board. A door profile capacity, i.e. the number of passengers that go through the door in one second, was surveyed using the vehicles, which are in operation in the Czech Republic. The measured value tells us the speed of change of the passengers when entering and exiting the

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vehicle and can be also used to compare the total time of getting on or off the vehicle when the type of the vehicle and the expected number of passengers are known.

The survey has validated the presumption that the low-floor vehicles with wide doors (In this case narrow doors are meant to be the doors of a classic-construction vehicles (the door width is 740 mm), wide doors are about twice the wide (for example the suburban units types 471) the are advantageous not only for physically disabled persons and passengers with prams or bicycles, but they also allow a faster change of passengers. The speed of change of the passengers is twice the high compared to the classic-construction vehicles. An interesting finding is that the height difference between the platform and the door edge does not play a significant role in influencing the speed of change of the passengers (when not concerning physically disabled persons and passengers with prams or bicycles). Survey results are presented in the table 1.

Table 1 – Doors capacity of railway vehicle

| series | height of platform edge above rail top | 200 mm | | 550 mm | |
|---|---|---|---|---|---|
| | clear doors width [m] | getting on [pers·s$^{-1}$] | getting off [pers·s$^{-1}$] | getting on [pers·s$^{-1}$] | getting off [pers·s$^{-1}$] |
| 471 | 1.34 | 1.09 (0.76) | 1.22 (1.00) | 1.25 (0.97) | 1.20 (1.17) |
| Bdmtee | 1.86 | 1.13 (1.20) | 0.83 (0.69) | 1.29 (0.91) | 1.13 (0.73) |
| B | 0.74 | 0.56 (0.52) | 0.50 (0.44) | 0.50 (0.49) | 0.67 (0.45) |

There are the highest values in the table, average values are in round brackets. Source: [3]

Another measured value was the real movement speed of the passengers depending on the use of different access paths. Walking speed on platform or when using a horizontal access path which does not cross the railway is set between 1.5 and 2.0 mps, i.e. around 6 kph. The speed seems to be surprisingly high, but for the persons leaving the train through level access railyard the speed is even higher. It could be explained by a psychological feeling of danger on the crossing, which motivates the passengers to walk to the safety as fast as possible. On the other hand the speed on a central crossing is up to 25 % lower (max. 1.5 mps, 1.2 mps in average), what we can explain by a relative feeling of safety on the wide access path from the semi-island platform towards the railway station building. Furthermore when walking on the central crossing the passengers in the centre stations look around to find their connecting train.

Table 2 – Walking speed

| movement type | walking speed [mps] | | | |
|---|---|---|---|---|
| | up | down | speed recalculated to horizontal line | |
| | | | up | down |
| staircase | 0.68 (0.57) | 1.30 (0.81) | 0.61 (0.52) | 1.18 (0.74) |
| escalator | 0.65 | 0.65 | 0.56 | 0.56 |

There are the highest values in the table, average values are in round brackets. Source: [2]

When comparing a solid staircase and an escalator a logical presumption is validated, that the movement down the stairs is faster than the movement up, whereas using escalator in both directions the speed is equal. On the way down a normally physically equipped person is faster than the escalator. The speed of the escalators was measured in the access paths from the railway station underpasses and the results are in compliance with the technical parameters given by the producers (0.27–0.75 mps). Results that arose from the measured values are presented in table 2. A horizontal speed of sloping paths is also given. It is not a real speed of movement on the sloping path, but a counted speed $v_p$ defined according to (1). This speed is meant for comparison of the movement retardation of the passenger, who surmounts a height difference compared to a passenger, who passes the same distance horizontally. During the survey the speed was measured within the whole staircase, which means that the speed is measured on the line, which connects the edge of the first step with the edge of the last step of the last stair segment, i.e. respecting the inserted landings. This line usually forms an angel $\alpha = 24°$ with the horizontal level. [2]

$$v_p = v_r \cdot \cos\alpha \qquad (1)$$

where: $v_p$ – recounted speed [mps]
$v_r$ – measured speed on the staircase with landings [mps]
$\alpha$ – an angle formed by a horizontal level and a line connecting the first and the last step of the staircase

Based on the recounted speed we can state that surmounting the lost-height drop leads to the retardation of the pedestrian current, decreasing the speed to one half for a solid staircase on the way down and to only one third when using escalators or a solid staircase on the way up.

When comparing the capacity of different types of access paths the surveys showed that the full saturation of a solid staircase is reached only when leaving the train, usually down the stairs to the underpass. Especially in terminal stations during the morning peak time the upper mouth of the staircase is clogged and the capacity of the staircase is then fully used. The escalators provide the highest capacity recounted to 1 metre of the width where shorter spaces were observed between the persons. Different access path capacities are presented in table 3.

Table 3 – Profile capacity for persons

| movement type | profile capacity [pers·min$^{-1}$·m$^{-1}$] | | |
|---|---|---|---|
| | up | down | horizontally |
| horizontal walking | - | - | 62.89 (46.91) |
| staircase | 45.45 (39.85) | 68.03 (36.73) | - |
| travelator | 93.33 (75.40) | 93.33 (75.40) | - |
| escalator | 142.46 (81.44) | 142.46 (81.44) | - |

There are the highest values in the table, average values are in round brackets.

## 3. Analysis of Platforms and Railway Stations in Czech Republic

From the passenger's point of view a platform is one of the most important parts of the traffic route. As a main element in the connection of the stationary and moving part of the transport system a platform influences significantly the comfort, speed and safety of getting on and off the vehicle board. Within this project 1,151 operating posts with have a status of a railway station or D3 operating post were explored. General summary of the analysis of the station types and platforms used in them are presented in table 5 [1, 4]. Explanation of the abbreviations of the Czech regions (NUTS 3 regions) used in the statistics overviews is introduced in table 4. If the edge height of the platform above the rail top is exactly 550 mm, within this survey it is marked as "high". Other platforms belong to the group "low". Bay platforms are also divided into two groups – "from platform" if they are directly connected to an island or outside platform and "from surface" if they are accessible from outside the railyard. When creating the database the following resources were used: book timetable for 2009/2010, SŽDC (Railway Infrastructure Administration) direction SR 70 and the Declaration on railways 2010 by SŽDC. The mapping of the station equipment was carried out by a combination of a personal on-site surveys and an analysis of the Train Traffic Schedule Aid 2009/2010. The statistics include all the passenger stations on all railways in the Czech Republic and was valid by the end of August 2010.

Table 4 – Regions abbreviations (to table 5)

| | | | | | |
|---|---|---|---|---|---|
| JHC | *Jihočeský kraj* | the South Bohemian Region | PHA | *Hlavní město Praha* | the Capital City of Prague |
| JHM | *Jihomoravský kraj* | the South Moravian Region | PLZ | *Plzeňský kraj* | the Plzeň Region |
| KHK | *Královéhradecký kraj* | the Hradec Králové Region | STC | *Středočeský kraj* | the Central Bohemia Region |
| KVK | *Karlovarský kraj* | the Karlovy Vary Region | UST | *Ústecký kraj* | the Ústí Region |
| LIB | *Liberecký kraj* | the Liberec Region | VYS | *Kraj Vysočina* | the Vysočina Region |
| MSK | *Moravskoslezský kraj* | the Moravian-Silesian Region | ZLK | *Zlínský kraj* | the Zlín Region |
| OLM | *Olomoucký kraj* | the Olomouc Region | **CR** | ***Česká republika*** | **the Czech Republic** |
| PAR | *Pardubický kraj* | the Pardubice Region | | | |

As the stations were sorted out by types it was found out that the most numerous group in the Czech railway network are the intermediate stations (68 %), followed by connecting stations (10 %), junction stations (7 %), terminal stations (7 %) and centre stations (5 %). This classification division could be surcharged by a certain inaccuracy as many operating posts balance between more functions. As another criterion a platform layout in the

Table 5 - Platforms statistics

| Types of stations | JHC | JHM | KHK | KVK | LIB | MSK | OLM | PAR | PHA | PLZ | STC | UST | VYS | ZLK | CR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| intermediate | 81,5 | 62,8 | 61,6 | 70,0 | 79,7 | 59,5 | 66,7 | 67,3 | 57,7 | 72,0 | 67,8 | 65,6 | 65,8 | 69,4 | 68,3 |
| terminal | 5,0 | 7,0 | 8,2 | 6,7 | 6,3 | 17,9 | 11,5 | 5,5 | 3,8 | 3,7 | 5,8 | 2,4 | 2,5 | 10,2 | 6,7 |
| connecting | 4,2 | 12,8 | 12,3 | 8,3 | 6,3 | 14,3 | 14,1 | 14,5 | 0,0 | 17,1 | 11,1 | 6,4 | 11,4 | 2,0 | 10,1 |
| junction | 5,0 | 10,5 | 9,6 | 8,3 | 3,1 | 3,6 | 6,4 | 10,9 | 15,4 | 3,7 | 5,3 | 12,0 | 1,3 | 14,3 | 7,1 |
| setting back | 0,0 | 1,2 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 2,4 | 1,8 | 0,8 | 0,0 | 0,0 | 0,6 |
| crossing | 0,0 | 1,2 | 4,1 | 0,0 | 0,0 | 1,2 | 0,0 | 1,8 | 7,7 | 0,0 | 0,0 | 2,4 | 0,0 | 2,0 | 1,0 |
| center | 4,2 | 4,7 | 4,1 | 6,7 | 3,1 | 3,6 | 3,8 | 1,8 | 15,4 | 1,2 | 8,2 | 10,4 | 1,3 | 2,0 | 5,1 |
| **Platforms disposition** | **JHC** | **JHM** | **KHK** | **KVK** | **LIB** | **MSK** | **OLM** | **PAR** | **PHA** | **PLZ** | **STC** | **UST** | **VYS** | **ZLK** | **CR** |
| level platforms - low | 85,7 | 72,1 | 91,8 | 80,0 | 93,8 | 69,0 | 74,4 | 76,4 | 69,2 | 78,0 | 80,7 | 82,4 | 69,6 | 79,6 | 79,4 |
| with elevated and low level platforms | 0,8 | 16,3 | 0,0 | 0,0 | 0,0 | 3,6 | 14,1 | 10,9 | 3,8 | 1,2 | 9,9 | 4,8 | 2,5 | 14,3 | 6,0 |
| with elevated platforms | 4,2 | 9,3 | 1,4 | 13,3 | 4,7 | 25,0 | 9,0 | 9,1 | 26,9 | 19,5 | 7,6 | 12,8 | 10,1 | 4,1 | 10,4 |
| level platforms - high | 9,2 | 2,3 | 6,8 | 6,7 | 1,6 | 2,4 | 3,8 | 5,5 | 0,0 | 1,2 | 1,2 | 0,0 | 0,0 | 2,0 | 3,0 |
| **Access** | **JHC** | **JHM** | **KHK** | **KVK** | **LIB** | **MSK** | **OLM** | **PAR** | **PHA** | **PLZ** | **STC** | **UST** | **VYS** | **ZLK** | **CR** |
| crossing | 95,8 | 74,4 | 98,6 | 86,7 | 95,3 | 71,4 | 78,2 | 85,5 | 69,2 | 81,7 | 84,2 | 82,4 | 88,6 | 83,7 | 84,6 |
| underpass | 3,4 | 24,4 | 0,0 | 13,3 | 4,7 | 21,4 | 21,8 | 12,7 | 30,8 | 15,9 | 14,6 | 17,6 | 11,4 | 16,3 | 14,2 |
| footbridge | 0,8 | 1,2 | 1,4 | 0,0 | 0,0 | 7,1 | 0,0 | 1,8 | 0,0 | 2,4 | 1,2 | 0,0 | 0,0 | 0,0 | 1,2 |
| **Types of platforms** | **JHC** | **JHM** | **KHK** | **KVK** | **LIB** | **MSK** | **OLM** | **PAR** | **PHA** | **PLZ** | **STC** | **UST** | **VYS** | **ZLK** | **CR** |
| level (including low outside) | 84,2 | 68,7 | 91,3 | 71,4 | 85,5 | 57,7 | 67,0 | 72,5 | 49,6 | 73,8 | 78,3 | 81,2 | 75,1 | 81,8 | 75,2 |
| high outside | 3,6 | 3,5 | 3,4 | 4,3 | 3,0 | 4,1 | 3,0 | 4,1 | 6,2 | 8,3 | 2,3 | 2,4 | 0,0 | 0,7 | 3,3 |
| low level with two edges | 0,0 | 2,1 | 0,0 | 2,9 | 1,2 | 4,1 | 2,6 | 0,0 | 1,8 | 1,7 | 0,4 | 0,0 | 2,1 | 1,4 | 1,3 |
| high semi-island with 1 edge | 0,0 | 0,4 | 0,0 | 0,7 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,4 | 0,2 | 0,0 | 0,0 | 0,0 | 0,1 |
| high semi-island with 2 edges | 5,7 | 0,7 | 1,0 | 4,3 | 3,6 | 0,8 | 3,4 | 2,3 | 0,0 | 0,0 | 0,4 | 0,0 | 1,0 | 1,4 | 1,6 |
| low island | 2,9 | 8,5 | 0,0 | 5,7 | 3,6 | 17,9 | 5,2 | 3,5 | 12,4 | 1,7 | 8,7 | 9,0 | 18,7 | 4,2 | 7,5 |
| high island | 3,6 | 12,7 | 1,9 | 7,1 | 0,0 | 13,0 | 14,6 | 16,4 | 19,5 | 12,2 | 8,3 | 5,8 | 2,1 | 9,8 | 8,7 |
| low bay - "from surface" | 0,0 | 1,4 | 0,0 | 1,4 | 0,0 | 0,0 | 2,6 | 0,0 | 7,1 | 0,9 | 0,4 | 0,0 | 1,0 | 0,0 | 0,8 |
| high bay - "from surface" | 0,0 | 1,4 | 1,9 | 0,0 | 0,0 | 2,4 | 0,9 | 1,2 | 3,5 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,7 |
| low bay - "from platform" | 0,0 | 0,0 | 0,5 | 0,0 | 3,0 | 0,0 | 2,6 | 0,0 | 0,0 | 0,9 | 0,4 | 1,1 | 0,0 | 0,7 | 0,6 |
| high bay - "from platform" | 0,0 | 0,7 | 0,0 | 2,1 | 0,0 | 0,0 | 0,0 | 1,2 | 0,0 | 0,0 | 0,8 | 0,5 | 0,0 | 0,0 | 0,4 |
| **Access** | **JHC** | **JHM** | **KHK** | **KVK** | **LIB** | **MSK** | **OLM** | **PAR** | **PHA** | **PLZ** | **STC** | **UST** | **VYS** | **ZLK** | **CR** |
| grade separation | 10,0 | 28,2 | 7,7 | 20,7 | 9,7 | 37,4 | 28,8 | 26,3 | 48,7 | 24,0 | 20,8 | 18,8 | 21,8 | 15,4 | 22,0 |
| level | 90,0 | 71,8 | 92,3 | 79,3 | 90,3 | 62,6 | 73,0 | 74,9 | 51,3 | 76,0 | 79,2 | 81,2 | 78,2 | 84,6 | 78,2 |
| **Height** | **JHC** | **JHM** | **KHK** | **KVK** | **LIB** | **MSK** | **OLM** | **PAR** | **PHA** | **PLZ** | **STC** | **UST** | **VYS** | **ZLK** | **CR** |
| high (i.e. 550 mm above rail top) | 12,9 | 12,7 | 8,2 | 18,6 | 6,7 | 20,3 | 21,9 | 25,1 | 29,2 | 24,0 | 11,9 | 8,7 | 3,1 | 11,9 | 14,4 |
| low (i.e. under 550 mm above rail top) | 87,1 | 85,6 | 91,8 | 81,4 | 93,3 | 79,7 | 79,8 | 76,0 | 70,8 | 79,0 | 88,1 | 91,3 | 96,9 | 88,1 | 85,8 |

All values in percents in the table - share in given section and in relevant region. Region abbreviations key is in table 4.

stations was chosen. Here almost 80 % of railway stations are represented by those, which are equipped by level-access platforms. This type of platform is the least suitable, although it is the most money- and space saving alternative. It is a result of a long term disregard of the quality of the access to the trains. Although the number of vehicles with lowered door edge is increasing, regional railway transport usually does not allow the barrier-free access. Stations with a full grade separation access represent only one tenth of the total number, stations combining level and grade separation access only about 6 %. Stations with semi-island platforms (Turnov model) are represented by 3 %.

Based on the analysis we can also distinguish the types of platforms and their accesses between the regions of the Czech Republic. When comparing the access to the platform edges (level/grade separation) there are vast differences between the regions. While in Prague the ratio is almost equal, in the Liberec Region and the Hradec Králové Region the quota of grade separation access is less than 10 %. In almost all other regions the quota of grade separation access flows between 20 and 30 %. Very similar is also the ratio of high and low platforms (i.e. those with 550 mm above the rail top and the others). It is obvious that the high percentage of high platforms with grade separation access is in those regions, where the modernization of transit railway corridors and/or other railways integrated into European Rail System is being carried out (or already was).

## 4. Change Nodes Layout

Main targets when reconstructing or newly constructing a change node are reaching a high safety and comfort level for passengers, short transfer times, simple layout, easy operational technologies of all means of transport in the node, long lifetime of all construction elements and low operating costs. Level of completion of these targets is above all influenced by the node layout. Among the basic conditions that form the final image of the traffic node belong: [2]

- *Type and arrangement of the platforms* – they particularly influence the node capacity (e.g. by restricting transit traffic in the time the passengers get on and off the board). The final layout lead to different conceptual solutions: full grade separation access, grade separation access with outside and island platform, one island and one outside platform, semi-island platform or atypical constructions.
- *Length and characteristics of the transfer movement within one transfer linkage* – influences the calculation of the transfer time between different lines and it is an important factor to form a final impression of the change node. Speed of the pedestrian current is mainly influenced by: distance between standpoint of different lines (with increasing distance the speed decreases), complexity (winding) of the transfer path, surpassed height differences (emphasizing lost-height drops) and capacity of the access path.
- *Layout of the area in front of a station building (city side) and its space potentiality* – combination of the space potentiality and equipment demands in the area in front of a railway station building is a determining element for a decision, whether to set up a point of change in that particular station. Equipment demands are for example a number of parking places, park & ride car park or other similar elements. In some cases, although the location of the railway station seems to be ideal for setting up an intermodal change node, due to insufficient available space in front of the station building it is more advantageous to set up a change node in a different point of the network even if it means to allow short parallel lines.

Transfers are usually organized traditionally, i.e. a bus station is placed in front of the station building or close to it. Following designs of transfer points are very attractive for passengers and have proved good abroad [2]. Unfortunately they are still not widely used in the setting of the Czech Republic.

- *Edge-to-edge transfer* (see fig. 1 at the end of the paper) – significant for shortest distance between different means of transport without lost-height drop. One edge of the platform is designed for train halt, the opposite one is a bus stop. Limiting factor is the length of the platform, which has to correspond to the vehicle length of both means of transport. This design is suitable for railway station with lower traffic intensity, where all the trains can be furnished to one edge of the platform.
- *One way edge-to-edge transfer* (see fig. 2 at the end of the paper) – significant for shortest distance between different means of transport without lost-height drop for trains in one direction (those which are furnished to the platform by the station building). In this layout there is one platform, which allows edge-to-edge transfer (see above) and another platform in the opposite rail track group with grade separation access (island or outside platform), which serves trains in the other direction. When transferring between these platforms a passenger has to surpass the height difference twice, this means a lost-height drop. Concerning the track layout it could be useful to bring the main track in front of the station building. An advantage of train crossing on single track railway is gained with this layout.
- *Interlacing transfer point* (see fig. 3 at the end of the paper) – for this layout the stands of different types of transport are placed in different vertical levels. Moreover in horizontal view stands of one transport system must be placed between the stands of the other transport system (typically between railway tracks). This atypical layout offers the passengers comfort similar to edge-to-edge transfer.

- *Vertical transfer* (see fig. 4 at the end of the paper) – prerequisite for this layout is track crossing (preferably perpendicular) of different means of transport in different vertical levels. If this prerequisite is fulfilled it is possible to create a comfortable transfer which contains a height difference, but it is not a lost-height drop and the transfer distance is short.

## 5. Conclusion

The paper presents a brief summary of some outputs of the SGS project no. SGS10/215/OHK2/2T/16. All outputs lead to the creation of a complex attitude to solving change nodes of public mass transport, which were projected to the methodology handbook [5], which is the key output of the project. The main target is to increase the attraction of public mass transport with minimal investments and operating costs and maximal safety and reliability of the transport system.

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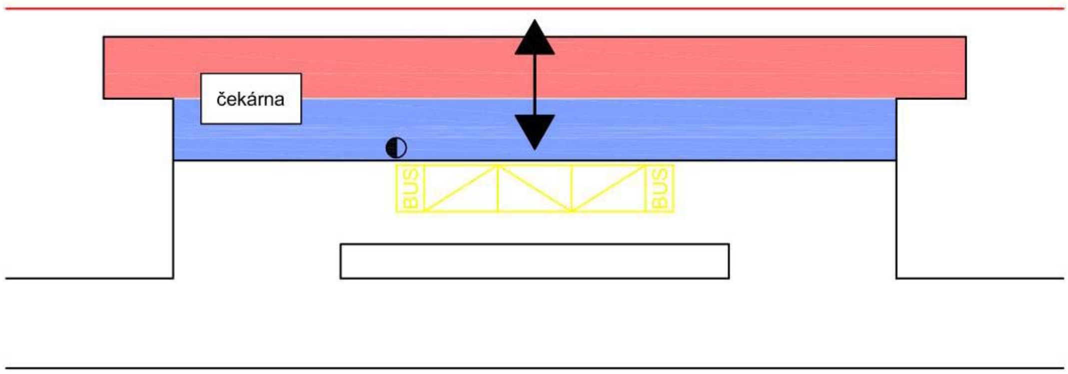



Fig. 1 – Scheme of edge-edge change

Legend: čekárna = a waiting room

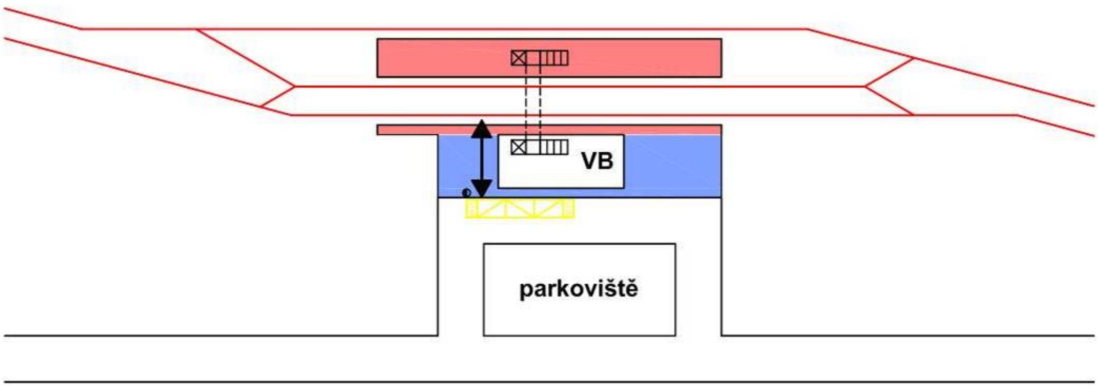



Fig. 2 – Scheme of one-way edge-edge change

Legend: parkoviště = a parking area; VB (abbreviation) = a station building

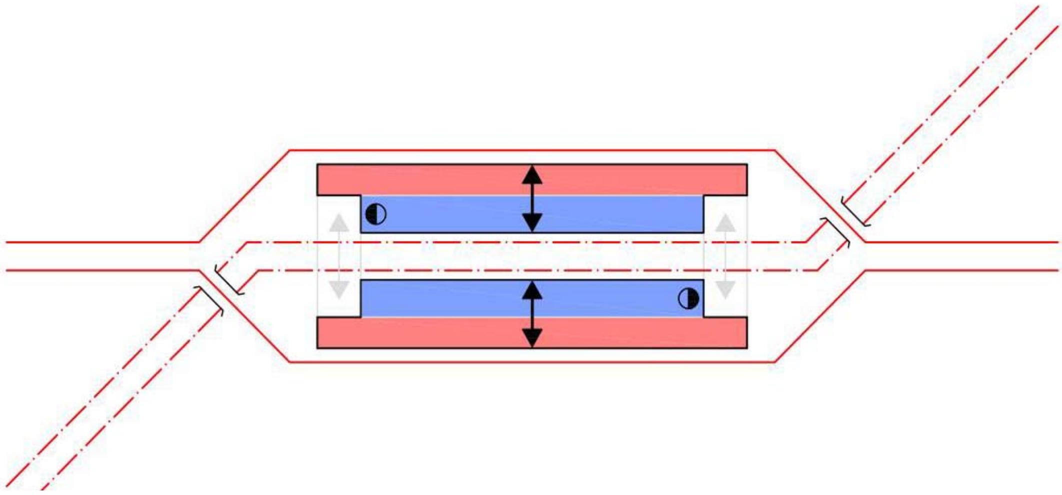
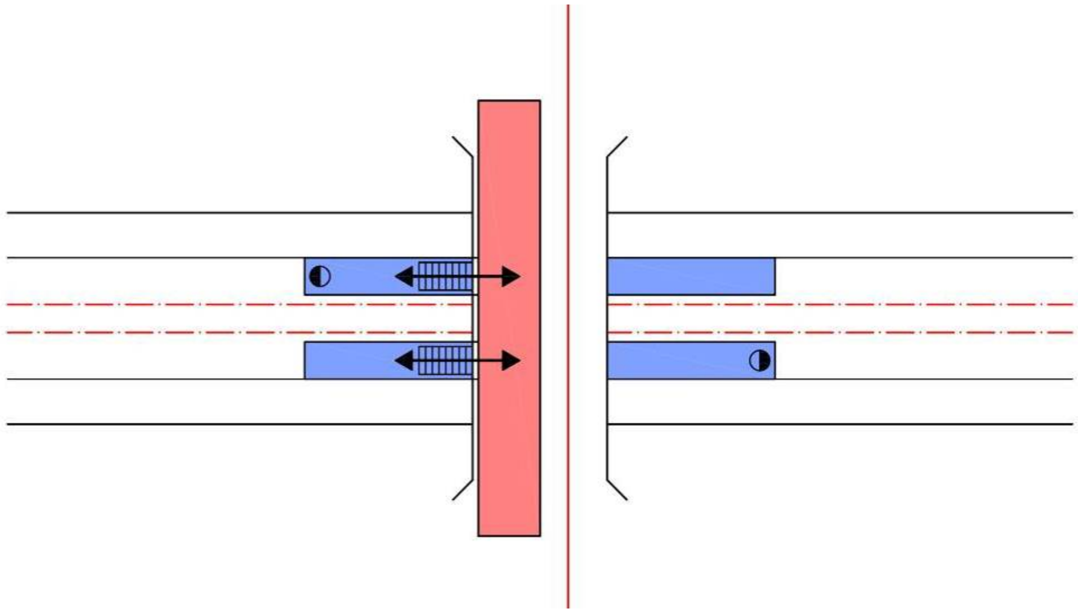


Fig. 3 – Scheme of interlacing connection

Legend: red full line – railway line; red dot-and-dash line – another transport system (tramway) a)



b)

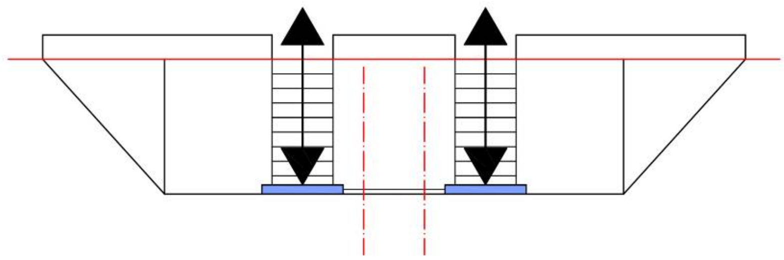


Fig. 4 – Scheme of vertical connection: (a) Dispositional scheme; (b) Cut

Legend: red full line – railway line; red dot-and-dash line – another transport system (tramway)

# Decision Support System for Distribution of Funds Allocated for Elimination of Accident Places

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**Abstract**

This paper is about the study to the dissertation thesis and method of the data collection to creating mathematical model. A study to the dissertation thesis would be intended as an introduction to road-traffic safety and financial resources of road-traffic infrastructure. This study should also describe different instruments and ways of determining accident places which should have to increase road-safety traffic, including organization occupying with activities in this area and their comparison with similar organizations in other European states should be made. The main aims and objectives of the dissertation thesis should be presented at the end paper using data available about road accidents, social and economic losses, accident places and allocated financial resources to increase road-traffic safety.

**Keywords:** funds, safety of road infrastructure, social losses, accident places

## 1. INTRODUCTION

New solutions to reduce the number of traffic accidents and economic losses are searched in Europe and over the world. Countries and organizations create strategic materials in which goals for reducing the number of traffic accidents and improving of road safety are set out. To achieve these goals there have been creating various instruments and measures to help increase the safety of road infrastructure. However, the limiting element, as in all other areas, are funds allocated for road safety. Most states pursue the objectives set out in the national transport policy or strategy of security through various organizations but not all states have a functioning system of allocation of funds for various activities (e.g. by social costs or depending on the degree of accident risk) [2].

## 2. Ensuring the safety of road infrastructure

### *2.1. Tools to improve the safety of road infrastructure*

Directive of the European Parliament and of the Council 2008/96/EC on road infrastructure safety management [3] introduced four instruments to help improve the safety of road infrastructure, while reducing the number of traffic accidents and their consequences. The instruments fulfill the objectives set out in the White Paper: European Transport Policy for 2010: Time to Decide. These are the following:

- Road safety impact assessment for infrastructure projects
- Road safety audit for infrastructure projects
- Safety ranking and management of the road network in operation
- Safety inspection

Member states are obliged to implement these tools on the roads included in the trans-European road network (in this paper hereinafter referred to “TEN-T”). TEN-T is important for fostering European integration and cohesion and should be on the necessary high level of security.

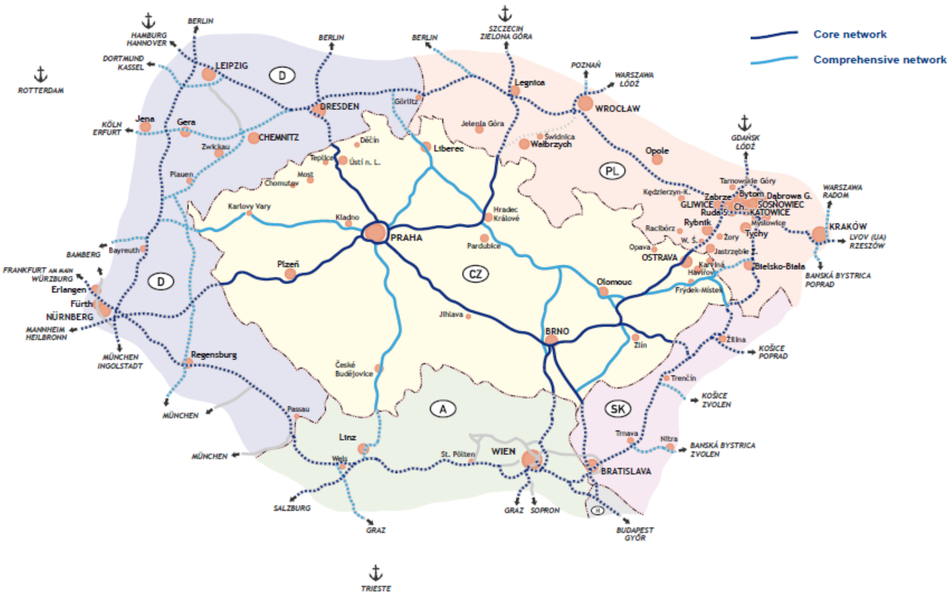

Fig. 1. Trans-European road network (TEN-T) in Czech Republic – now in force [9]

The safety level of existing roads, according to the Directive, should also be increased by channeling of funds to the road sections with the highest incidence of traffic accidents and the highest accident reduction potential. Transposition of the Directive into the Czech legal system was completed in 2011 (under Act No. 13/1997 Coll. [4], On roads and Decree No. 104/1997 Coll. [5], Implementing the law on the road) [6],[7].

*2.2. Financing of road infrastructures*

Financing of road infrastructures (State-owned) is provided by the Ministry of Transport of the Czech Republic (MoT) which is responsible body for creation and implementation of state policy goals in the field of transport. Currently, funding is secured through the following principal sources:

- funding from national sources (road tax, excise duty on mineral oils, time and charging, subsidies from the state budget)
- funding from the EU (Transport Operational Programme (OPT), Community programmes for financing of TEN-T development)
- funding from the European Investment Bank (EIB) and
- bonds

The Ministry of Transport provides following main budget priorities:

- expenditures on financing of the EU and the Czech Republic joint programmes
- compensation for the losses from the public service obligation in the field of public passenger transport
- grant for the State Fund for Transport Infrastructure (SFTI)
- expenditure on financing of asset replacement program
- accompanying social programme
- contribution to infrastructure not reimbursed from SFTI
- expenditures on security activities of the state administration

Existing financing system has many advantages including functional system for determination of responsibility and competence of the main actors in the financing system (MoT, SFTI, Road and Motorway Directorate (RMD)), a wide range of resources, involvement in OPT successive programming periods, the system of toll road infrastructure and resources of time and toll. At the same time the system has several disadvantages such as high rate fluctuation resources and expenditure on transport infrastructure, budgetary period is limited to one year only and the limited flexibility in the long-term management of financial resources, failure to use other sources of funding (such as PPP projects) high internal debt caused by long-term underinvestment expenditure on repairs and maintenance of transport infrastructure [8].

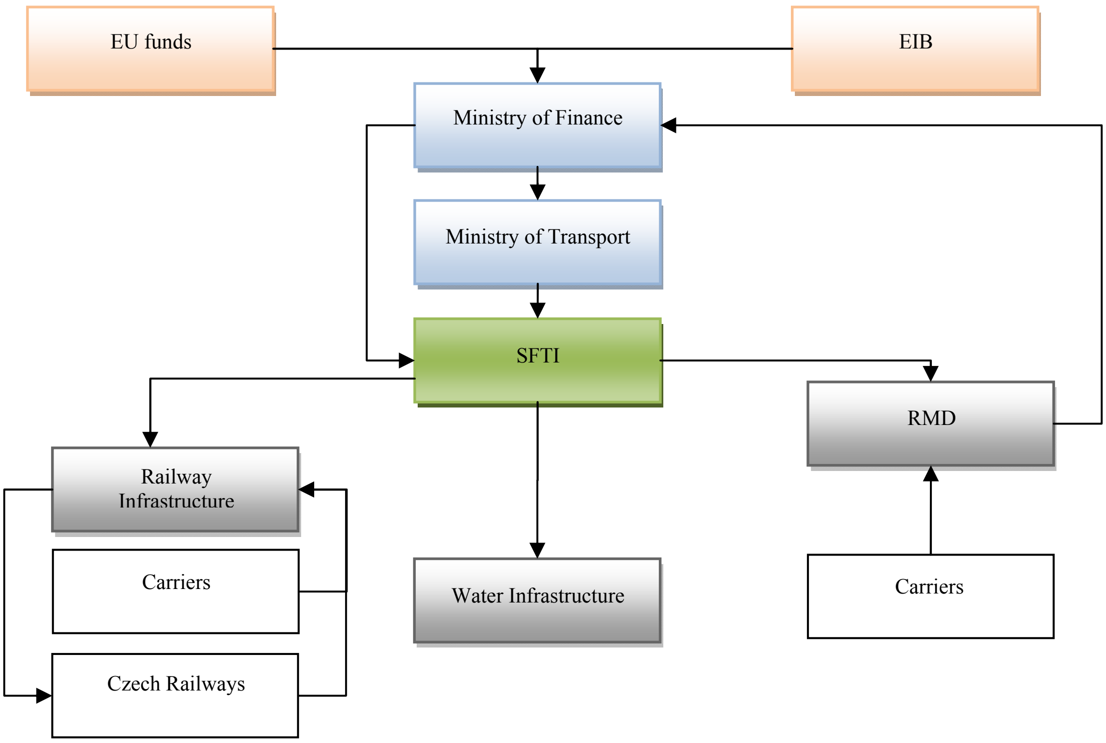


Fig. 2. Financial flows in the area of transport infrastructure [8]

One of the beneficiaries of funds deriving from the budget of the Ministry of Transport is SFTI. These resources are used for development, construction, maintenance and modernization of roads and motorways, railway lines and inland waterways. In the case of roads and motorways is funded the construction, modernization, repair and maintenance, providing benefits to transit sections, the contributions to research and design work, study and expert activities and contributions to programmes aimed at increasing traffic safety and its accessibility to persons with limited mobility. SFTI transfers funds to the purpose of the organisational units of the state, government funded organizations and government agencies (e.g. RMD) [10], [11].

Road and Motorway Directorate is a state contributory organization which was founded by the Ministry of Transport in 1997. The organization fulfils the following main tasks such as management of motorways and roads of the 1st class (major roads), provision of construction, modernization, maintenance and repairs of these communications and operation of the toll system on selected roads in the country. Annual reports contain an analysis of maintenance costs of motorways, highways and roads of the 1st class but they do not contain any item related to an extended of funds intended for road safety. These reports also state funds intended for wide-ranging repairments, on-going maintenance, construction etc. To find an activity solely undertaken for the purpose to improve safety is impossible. For the purpose of this dissertation paper as well as for determination of allocated funds input to elimination accident places should serve information about all finances for repairs and maintenance, which the expert assessment about amount of money determined for the rehabilitation of accident places is required [12].

Table 1. Sources of funds RMD during 2007 - 2011 (in thou. CZK)

| | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|
| SFTI | 44 187 818 | 48 408 940 | 54 099 412 | 49 754 147 | 39 492 514 |
| State budget | 4 190 080 | 5 363 437 | 3 383 864 | 2 313 610 | 11 465 |
| Altogether | 48 377 898 | 53 772 377 | 57 483 276* | 52 067 757** | 39 503 979 |

* The total utilization is higher due to the different accounting returns to SFTI and RMD.

** The total utilization is higher due to the different accounting returns to SFTI and RMD not shown all sources

## 3. Analysis of input data

The current legislation requires removal of such accidents sites whose proposed measures has the most favorable cost-benefit ratio. It compares money spent on construction and technical measures for the rehabilitation of accident places to economic losses resulting from traffic accidents.

The dissertation paper is based on available data on traffic accidents, the amount of allocated funds for repairs, maintenance and upgrading of roads and the financial costs of the measures proposed to design the most efficient way of allocated funds distribution according to various criteria. The basic decisive criteria and instruments determining allocation of resources are severity of traffic accidents and allocated funding.

Input data will be mainly based on traffic accidents and accident locations, social losses due to traffic accidents, allocated funds for the rehabilitation of accident places and proposed corrective actions, including their financial performance.

### *3.1. Accidents sites*

Currently, there are various applications and tools which define accident place. Principally, it is the road segments on which a given time period has a number of traffic accidents related to the transport performance. Data on traffic accidents can be obtained from police statistics; in this case, it is the absolute value which does not reflect the intensity of traffic.

Tools specifying the accident place are following:

• EuroRAP - European Road Assessment Programme (EuroRAP) which aims to reduce fatalities and serious injuries on European roads by systematic assessing and identifying risks on the roads. Statistic data about accidents and traffic intensities are created and updated regularly. There are also produced risk maps which provide a level of security compared to major European roads. Risk road sections are colour coded and determine the level of risk in which an road user becomes to be involved in a case of road accident (high risk - black, higher medium risk - red, medium risk - orange, moderately low risk – yellow and low risk - green) [13].

• Application of "Accident places" - the application contains individual traffic accident and the accident location. The system contains data and evaluation since 2008. The update is always performed after the end of the calendar year and after evaluation of various traffic accidents by Police. Accidents that were not investigated by the Police of the Czech Republic are not recorded in the system and are not evaluated. Designation of traffic accidents is using colours (accident fatality - red, with serious consequences - yellow, with light effects - blue and without consequences on health, with only material damage - green). The same colour scale is used to indicate accident locations [14].

• Allianz Road map - Road Accident map shows the most dangerous places in the Czech Republic and subsequently ranks list of 20 critical points. Updating takes place twice a year - in the spring and in the autumn. This project is based on statistic data of traffic accidents [15].

Basis for the elaboration of the dissertation paper should be a combination of these tools, especially web-based application containing absolute data on traffic accidents. At the same time, it determines accident locations based on established methodology. When using this application for the purposes of processing model, it is also necessary to use data obtained from a traffic accident statistics of the Police because such application cannot determine the number of persons killed or injured in a specific traffic accident.

### *3.2. Social losses from traffic accidents*

Economic losses have been calculated in the Czech Republic since 2001 and represent about 2 % of gross domestic product (GDP) in the European Union. The calculation of these aspects is taken into account – participant injury, mental injury, property damage and financial loss. In recent years there is seen a slight decrease of traffic accidents as a result of improvement of the level of medical care after road accidents, a higher percentage of vehicles with safety features, increased number of road safety campaigns and especially its emphasis on supporting national road safety strategy and legislative changes.

In 2010, the calculation of the losses was based on the updated method of calculating losses from traffic accidents on roads. Cost items have been adjusted in accordance with the updated methodology on prices of 2010 [16], [17].

The methodology divides the loss of traffic accidents by severity of accidents:

• with fatal injuries
• with severe injuries
• with minor injuries
• only material damage.

Table 1. The amount of total losses from traffic accidents each year (in thous. CZK)

| | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fatal injuries | 7 375 | 8 100 | 9 014 | 9 251 | 9 427 | 9 662 | 9 933 | 10 558 | 10 653 | 17 645 | 18 572 |
| Severe injuries | 2 625 | 2 797 | 2 864 | 3 106 | 3 165 | 3 244 | 3 335 | 3 545 | 3 577 | 4 863 | 4 783 |
| Minor injuries | 300 | 301 | 335 | 349 | 356 | 365 | 375 | 398 | 402 | 668 | 509 |
| Material damage | 92 | 88 | 93 | 96 | 98 | 100 | 102 | 108 | 109 | 271 | 227 |

### *3.3. Measures proposed on the selected accident place*

Law No. 13/1997 Coll., On roads, states that the Central Register of roads, among other recorded information of the sections included in the TEN-T, which would eliminate or reduce the risks of road features for participants of road led to a significant reduction in costs incurred as a result of road accidents, takes into account costs of removal and reduce these risks. This is essential for comparison of the financial costs of construction and technical measures for accident places to economic losses resulting from traffic accidents.

Proposed corrective measures which show eliminations of traffic accidents and reduction consequences should be used as baseline model. In determining the most appropriate remedy for selected accident places will be processed in accordance, but to a limited extent with regard to needs and characteristics of the model input data with Annex No. 11 "minimum range safety inspection" decree and Methodology of safety inspections of roads. Draft measures should focus primarily structural and technical modifications to roads which can be financially quantified and therefore used as one of the input values. Quantifying the financial performance of the proposed remedial measures should be based on the measurement of financial performance measures or whole buildings. Information about the amount of funds can be obtained for example from an already processed safety inspections and surveys of roads that include proposals for action, the final reports of road construction, yearbooks, annual reports or other documents provided by Road Managers [19].

## 4. Aims of the dissertation thesis

Aim of the dissertation thesis on "Decision support system for the distribution of funds allocated for the elimination of accident places" is an effort to use available information about social losses for accident places and their proposed security measures to reduce the risk of accidents and anticipated financial resources allocated for the rehabilitation of accident places. The goal is based on the input data to propose a model for distribution of funds allocated so that the highest priority for implementation of measures should show accident places with the most favorable cost-benefit ratio.

One way to set priorities remediation accident places, according to the number of traffic accidents and social losses, and incurred by resulted from them. This solution, however, reflects only one aspect that is with regard to the company and certainly the most important but it does not take into account the cost of its implementation.

Another option that is based on the current system of state administration and financing of transport infrastructures is built on ranking the most important structures within individual governments and road networks by property rights (motorways and main roads - roads, lower-class roads in respective regions). Determination of the importance of sanitation measures only within a group is unsystematic. Further the objectives of national road safety strategies and targets closer to the White Paper will be comprehensive and will only lead to different safety levels in each region. The ideal solution would be to compile a list of the most important measures and to remove the accident places not only within individual territorial units, but throughout the country. However, due to various owners of Roads (state, region, municipality), performance of individual measures and the possibility of drawing funds from various sources need to prioritize works only for a particular network (motorways, main roads, 2$^{nd}$ and

3rd Classes) which will not be limited to the region borders. When processing it should focus on the network of roads included in the TEN-T project due to better availability of information about the network and the obligation to use the tools introduced by Directive on these roads only.

One possible solution is to use measurement data about traffic accidents and subsequent cluster analysis using the estimates using Bayesian methods. Another possibility is the use of a classification model, namely a decision tree. This solution is particularly suitable for more stages decision-making processes with one decision criteria and allows to show the logical development of interconnected alternative decisions and random situations in order to determine the optimal decision-making [22], [23].

The main contribution of this dissertation thesis should be an efficient distribution of funds, which is now very limited, for elimination of accident places based on the principle of comparing costs and benefits.

## Acknowledgements

Data for the study on the dissertation thesis have been obtained from public information sources and consultation with representatives of the Ministry of Transport and Road and Motorway Directorate.

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# Global Traffic Model and Its Application for Accident Detection

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**Abstract**

Automatic Incident Detection (AID) systems serve for recognition of traffic accidents in the data from particular part of road network. The input for such systems is continuously measured traffic parameters and the output can be utilized for traffic control systems and systems informing the drivers. This paper describes AID system based on global traffic state model created from historical traffic sensors data from a particular investigated area as a whole. The very high dimension of global multidimensional traffic states is reduced using Principal Component Analysis (PCA). Finally, the clustering methods are used in order to detect the abnormal states which most probably stand for accidental traffic conditions or other unwanted non-standard situations.

**Keywords:** Automatic Incident Detection, road traffic, global traffic model, state space, Principal Component Analysis, dimension reduction

## 1. INTRODUCTION

Advanced traffic flow control, informing drivers about accidents or alternative routes suggestions contribute to increase of the overall traffic power, decrease of travel times, fuel savings and in general to higher safety and comfort on the roads. The existing traffic detectors can be effectively utilized as a data source for implemented control or telematics systems. The traffic models and their practical application can help as an intermediate element between them.

Traffic incidents (congestions and accidents) have negative impact on level of road traffic service. The Automatic Incident Detection (AID) algorithms like California algorithm, McMaster's algorithm, MEX (Tokyo Metropolitan Expressway) or ARIMA (Autoregressive Integrated Moving Average) can help to reduce their negative impact [1].

This article describes an innovative method how to create a global model of road traffic in the observed area (highway section in rural zones or a part of road network in urban zones). The conventional methods are based on evaluation of traffic parameters in a single profile of communication. The idea of the global model is a description of traffic state behavior based on historically measured elementary traffic parameters (flow rate, speed and density) at level of the whole observed area.

Traffic data are characterized as a pseudo-stochastic time series and it may also contain some unrealistic data. Therefore it is necessary to properly preprocess the sample of the testing data. It represents addition of missing samples and elimination of random component. The preprocessed traffic parameters are converted to traffic states of a state space in a discrete time intervals. However, with respect to the count of detectors and huge number of acceptable values of particular variables, the state space may have (and have) too many possible states. Therefore the proposed method considers dimension reduction using Principal Component Analysis (PCA) method. The state space having significantly reduced dimension performs better from statistical evaluation point of view, but it is also more suitable for computer processing in real time.

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## 2. INPUT DATA DESCRIPTION AND PREPROCESSING

The basic measures characterizing the traffic are flow rate, speed and density. Flow rate *q* is defined as a number of vehicles $n_t$ passing through a communication profile in time *t*. Time mean speed $u_t$ is an arithmetical average of instant speeds $u(t_i)$ of all vehicles *i* passing through the profile in time unit *t*. Density *k* stands for a number of vehicles $n_s$ observed in a unit of length *s* in one moment and as such it is defined as a section parameter, which is impossible to be measured in a particular profile [2]. Information about presence of vehicles on a communication section is represented also by time occupancy $\kappa$ of a detector (hereinafter considered instead of the density). It is a ratio of total time when the detector is occupied by vehicles and the total measurement period *t*.

The data may come from various traffic sensors like inductive loops, laser sensors or video detection. The authors used inductive loops data provided by Road and Motorway Directorate of the Czech Republic. The data came from 8 detection profiles installed on Czech D1 highway (see Fig. 1) and the data set covered almost half a year 2009. The samples represented *q*, *u* and $\kappa$ within 5 minute aggregation period.


Fig. 1. Location of the loop detectors on first 45 kilometers of D1 highway

The database of traffic characteristic has been supplemented with database of accidents registered on D1 highway by the police. Based on it, the days with an accident were excluded from the input data and not considered in the historical model but they were used for verification of the algorithm.

The traffic parameters signals have been preprocessed: missing samples have been completed and the stochastic noise component has been filtered out using Fast Fourier Transformation (FFT) into frequency domain, where the low-pass filter has been applied before inverse transformation back to the time domain.

## 3. STATE SPACE MODELLING APPROACH

State space as a representation of all possible states of a dynamic system is convenient for a traffic description. Traffic modeling and prediction has been discussed in many studies. Crucial basics and outputs illustration of the usability of its application for urban or freeway stretch data are shown in text Multivariate state space approach [3]. Authors of similar studies described formation of method of vectors based on traffic stream model data and studied chronological time series and trajectory of vectors in state space [4]. Different researches were based on implementation into STARIMA models, based on detector location and relationships between sites in city areas [5].

State space can represent a base algorithm for Kalman filter traffic state estimator [6] or it can be for adaptive freeway traffic state estimator [7] utilized. Finally, state space has been presented as part of highly sophisticated application of origin-destination estimation [8]. Authors used state-space model because of its complexity of using all necessary variables, such as historical demand parameters. Investigation of the state space problematic shows, that state space is a modern and convenient method to transform traffic data from more detectors into "state" which will represent a qualitative parameter for further traffic examination. To transform considered discrete slices into a better evaluable form, it is necessary to use convenient reduction approach.

In terms of this article, the traffic state is theoretically expressed as current traffic parameters values in the observed road network. However, in practice the data are available only at measuring points (detectors) and for a given aggregation period (e.g. 5 minutes). That means the traffic state is both space and time discrete. Formally, the traffic state is defined as a 3-tuple

$$\vec{s} = (\vec{q}_t, \vec{u}_t, \vec{k}_t), \quad (1)$$

where $\vec{q}_t$ is a vector of values of flow rate $q$ from all detectors in the area in time $t$; vectors of speed $\vec{u}_t$ and density $\vec{k}_t$ are defined by analogy. The state space (SS) is defined as a 2-tuple

$$SS = (S, \Theta), \quad (2)$$

where $S = \{s_i\}_{i=1}^{n}$ is a set of admissible states, $n$ denotes a total count of admissible states of the system; $\Theta = \{\theta\}$ is a set of transitions, while $s_q = \theta_{p,q}(s_p)$ express transition from state $s_p$ to $s_q$ [12].

Dimension of the state space follows from a number of the variables describing a single state as

$$dim(SS) = |\vec{q}| + |\vec{u}| + |\vec{k}|. \quad (3)$$

In case of one detector recording three variable $q$, $u$ and $k$, the state space dimension is $dim(SS) = 3$ (regular 3D space). For area monitored by $n$ detectors, the dimension $dim(SS) = 3n$ (so called hyperspace). For instance, 7 detectors pose a dimension of 21 with hundreds of possible values on each axis, which means unacceptable computation complexity.

The historical model is a set of measured parameters and it can be depicted graphically as traffic parameters space distribution, which is changing in time. The model thus bears information about visit rate of the states, their corresponding time of day and probability of transition into subsequent states. The Fig. 2 (a) shows five states in non-reduced state space in particular time.

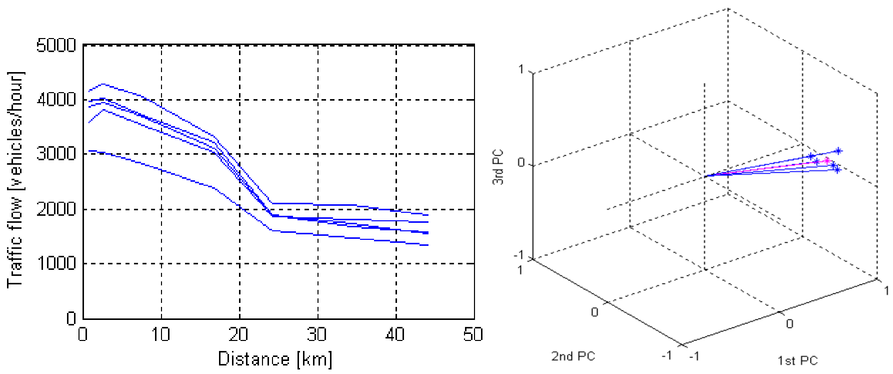


Fig. 2. (a) A spatial distribution of flow rate in time $t$ (at 9:35) measured in different days $d$ (5 successive Saturdays. The curves are linear interpolations of preprocessed traffic characteristic between detection profiles are represent the traffic states. (b) Traffic states transformed into reduced dimension state space using PCA. The three first most significant principal components correspond to the axis of the new 3D space. Coordinates of the blue points (highlighted by the vector from the origin) refer to the traffic situation (the nearby positions mean similar traffic conditions). The violet point is a so called centroid of the cluster (acting as a cluster representative).

As the traffic behavior depends on a day of the week, a different historical model has to be created for each day of week. Based on the police's accident database, the days containing an incident are excluded from the historical model in order to not affect the statistics.

## 4. PRINCIPAL COMPONENT ANALYSIS INTRODUCTION

Principal Component Analysis (PCA) was established by Pearson in 1901 and is one of the oldest methods for multiple data analysis. PCA allows transformation of entered data to a smaller spatial dimension, while preserving the original variability. It creates new vectors, so that each of the new vectors is a linear combination of the original ones. Output of this algorithm are primarily principal components, secondary outputs are component scores and variances (latent variables). The correlation values of traffic data can be plotted in a new dimension in the 2D views (main component of flow rate, occupancy or speeds of several detectors), or in 3D dimension. The following paragraph explains the PCA method analytically.

Let's assume a matrix **X** $(m \times n)$, where $m$ is a number of rows and $n$ is number of columns representing traffic data set, such as

$$\boldsymbol{X} = [x(1), x(2), \ldots, x(n)], \quad (4)$$

where $x(t) = [x_1(t),\ x_2(t), \dots, x_m(t)]^T$ and variables are correlated to each other. Because these variables are mutually correlated, another group of uncorrelated vectors exists and is given by equation

$$\boldsymbol{S} = [s(1), s(2), \dots, s(n)], \quad (5)$$

where $s(t) = [s_1(t), s_2(t), \dots s_m(t)]^T$ and $s_k(t)$ are linear combination of $x(t)$ given by

$$\boldsymbol{S} = \boldsymbol{P}.\boldsymbol{X}, \quad (6)$$

where **S** represents a new dimension generated by multiplication of **P** and **X** matrices, where **P** is projection matrix $\mathbf{P} = [p(1), p(2), \dots p(m)]$, where $p(t) = [p_1(t), p_2(t), \dots p_m(t)]^T$ and **X** represents original data matrix.

Using PCA, we obtain new dimension **S** consisting of principal components from the original data matrix **X**. First few principal components cover the largest variability part of the original data. Since there are for reconstruction typically used only first two or three principal components, information loss results in creation of error matrix [9]. There are several ways how to implement PCA and calculate principal components. Most frequently used is singular value decomposition (SVD) or conversion through covariance matrix [10]. The number of used principal components leads to standard PCA mathematical model.

When using singular value decomposition, the mean values subtraction for all columns is firstly performed. Subsequently component score and variance values are calculated from SVD equation

$$\boldsymbol{X}(m,n) = \boldsymbol{U}(m,n).\boldsymbol{S}(n,n).\boldsymbol{V}'(n,n) \quad m > n, \quad (7)$$

where **U** matrix represents eigenvectors square matrix **X.X'**, so basically it represents component score. Matrix **V** is formed by eigenvectors of **X'.X** matrix and represents variances. Both matrices are orthonormal and following equation applies

$$\boldsymbol{U}'.\boldsymbol{U} = \boldsymbol{V}'.\boldsymbol{V} = \boldsymbol{V}.\boldsymbol{V}' = \boldsymbol{I}(n,n). \quad (8)$$

**S** matrix represents a diagonal matrix with singular values, which are ordered on main diagonal according to decreasing sequence. It is true that $s_{11} > s_{22} > s_{33} > \cdots s_{nn}, m > n$. Singular values carry information about the significance of each column of matrix **U** and the corresponding matrix **V**. Principal components are calculated by multiplying of component score and variances and ordered decreasingly [11].

## 5. ACCIDENT DETECTION ALGORITHM AND RESEARCH RESULTS

The multidimensional state space historical model is converted using PCA method into 3D orthogonal state space. It allows an evaluation of the states and searching of the differences between signal of particular day and the average normal traffic behavior. The proposed approach utilizes simple clustering methods to detect sudden global traffic state deviations caused by traffic incidents.

The algorithm has two phases: at first it transforms all the historical progresses into reduced state space using PCA method as described and store the transformed historical model back into the database. Afterwards, the day which is being analyzed (data collected in real time) is processed in the same manner and it is evaluated against the historical model using clustering algorithm [13]

During the day, the traffic in the area assumes different states gradually. The algorithm processes all these states in a loop and transforms them into a new state space with reduced dimension. All the input vectors are centered by their mean value $\hat{x}$ and normalized into <-1; 1> interval (although the original values have been from $<0; x_{max}>$ interval, because centering has shifted some values to negative numbers). It is important to normalize the vectors using single joint constant $max(|x_d(t)|)$ for all detectors in order to obtain comparable results across the whole analyzed area.

The final matrix **X** entering the PCA reduction algorithm at time *t* has a form

$$\boldsymbol{X}(t) = \begin{pmatrix} q_{d_1,t} & u_{d_1,t} & k_{d_1,t} \\ \vdots & \vdots & \vdots \\ q_{d_D,t} & u_{d_D,t} & k_{d_D,t} \end{pmatrix}, \quad (9)$$

where $x_{d_i,t}$ means value of parameter *x* at detector *i* in time *t*; *D* is a total number of detectors.

The demanded outcome of the PCA transformation is a matrix containing principal components. When we select the three most significant components we obtain coordinates in the state space with reduced dimension. The five traffic states in Fig. 2 (a) (only flow rate is displayed) are transformed into 3D state space as shown in Fig 2. (b).

When processing the whole day step-by-step, the changes of traffic conditions correlates with the movement of the transformed state and the trajectory of the point characterizes daily progress of the traffic situation. If the input data contains a sudden change of traffic conditions due to an incident, it raises a rapid deviation of the transformed state. Fig. 3 (a) depicts a daily course of speed *u* at a particular detector. Fig. 3 (b) shows the daily trajectory of the transformed state, which correlates with a daily progress of the global traffic state in the observed area. The state deviation corresponding to the incident can be observed there.

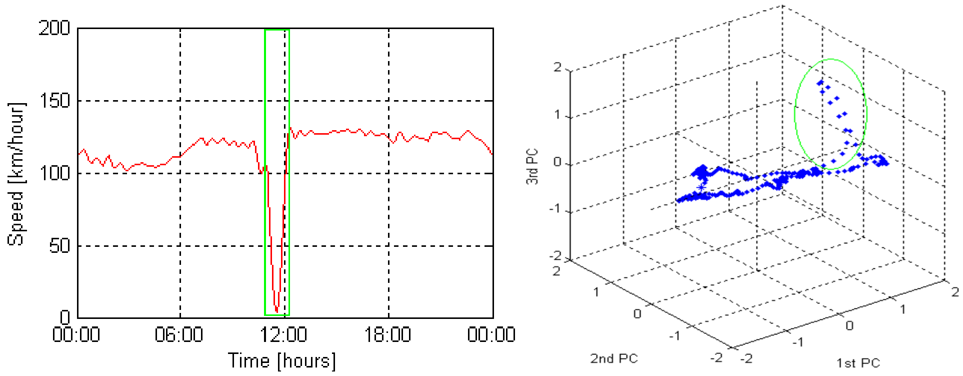


Fig. 3. (a) Time progress of mean time speed at particular detector. A rapid decrease in speed due to an incident can be observed between 11:00 and 12:15 (highlighted by the green rectangle). (b) Daily trajectory of the transformed state in the 3D state space with PCA reduced dimension. The gradual movement from left to right and back again is causally related to daily development of traffic situation in the area. The rapid deviation (highlighted by a green ellipse) is a result of changed conditions due to an traffic incident between 11:00 and 12:15.

The key idea of the automatic incident detection is based on a comparison of the transformed current state (created from the on-line collected data) and the typical daily trajectories of the historical model. As the historical model does not contain days with accidents, clustering methods [13] can be used for recognition of the distinct states representing irregular traffic conditions. Fig. 4 shows the historical model for typical non-accident Saturday (measured in 5 consecutive weeks) and a detection of the traffic accident in the processed day.

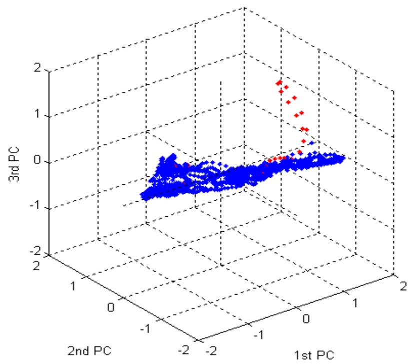


Fig. 4. The historical model consists of trajectories representing usual traffic behavior without accidents in the observed area (cloud of the blue points). The change of traffic conditions during an accident results in the rapid change of transformed traffic state (red points stand for a part of trajectory during the accident).

The further research will concentrate on application of advanced clustering methods; especially it will focus on optimization of detection rate and minimization of false alarm rate. Another considered approach is to describe the historical model using Hidden Markov Model (HMM) and utilize its statistics to evaluation of the global traffic state.

## 6. CONCLUSION

The paper describes a method for transformation of the global traffic state into new state space with reduced dimension using PCA method. It allows composing of a historical model describing the typical traffic behavior in the whole investigated area. Comparison of the on-line collected and transformed data with historical model can serve to detection of traffic congestions and accidents, using clustering methods.

The advantage of the proposed approach is its potential to be generalized from application at line highways also for urban road networks. The assumption is that the traffic in the urban area has also internal hidden relationships and the statistics implemented in historical model can take them into consideration. Such approach can be efficiently used as an input for telematics systems or systems informing the drives about accidents. The introduced system is designed in order to utilize existing traffic detectors and its implementation may help to increase safety and comfort of the drivers, with reasonable costs.

### Acknowledgements

We would like to express our thanks to Mr. Prof. Pavel Přibyl for leading our work and for his valuable remarks.

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# Railway Noise Measurements on Various Railway Superstructure Constructions

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**Abstract**

In the Czech Republic, railway noise is calculated according to the Czech national methodology during the project preparation of the modernisation and optimisation of the railway lines. This methodology, however, arose in the last century, and its use leads to significant overvaluation of the noise load in surrounding areas, in particular for upgraded and optimized railway tracks with modern construction and when using modern trains, mainly passenger traffic (disc brakes, multiple units).
The aim of the project is to determine the noise emission data, in view of the railway superstructure constructions and the rolling stock in use, alternatively to find out correction for noise reduction between the original and modernized lines, so that it was possible to define the conditions under which the noise emission values are valid. This will allow to use the Czech methodology, or foreign one, so that the results of a calculation will be as close as possible to actual conditions, which will lead to design the optimized noise reduction solutions.
The main focus of the project is therefore to determine the real noise emission values. To this end, the systematic measurement is done on the Czech railway network. Suitable sites with or without reconstruction are selected. There are realised repeated and synchronous measurements of the noise from the same train which passed through different places with various track superstructure types.
From the known parameters of a moving train, tracks and on the basis of sound pressure level values, or possibly frequency spectrum, the impact of the railway superstructure type on the railway noise will be defined.

**Keywords:** railway noise, noise measurement, sound pressure level, railway transport, superstructure construction

## 1. INTRODUCTION

The issue of transport noise is one of the current topics. Although the debate concerns mostly road traffic noise, railway transport has also been of certain interest to experts and public. When the noise monitoring based on the Directive 2002/49/ES was performed in 2007, whose purpose was to map the current level of transport related noise pollution, it was found that almost 90 million European citizens were exposed to road traffic noise exceeding 55 dB during the day. According to the WHO (World Health Organization), the noise level over 55 dB is highly disturbing and can cause various diseases. The number of citizens disturbed by railway noise is lower, the figure is approx. 10 million EU citizens exposed to the noise level exceeding 55 dB during the day, but it is not negligible percentage. Although the noise monitoring in the Czech Republic confirmed the fact that the perceived noise annoyance is from 95 % caused by road traffic, railway noise cannot be considered marginal.

The subject of this contribution is to summarize the results of noise measurements from railway transport, which had been performed in the past two years. The objective of these measurements was to gather and assess sound pressure level values depending on a railway superstructure. Within the project TAČR called “The Influence of

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Railway Infrastructure Measures on the Mitigation of Noise Generation and Transmission from Moving Trains" (2011 – 2013), noise measurements in selected areas were performed and their results are summarized in the Conclusion.

## 2. RAILWAY NOISE, ITS SOURCES AND TRANSMISSION

Sound is an integral part of human environment, by means of which a person gains an important share of information of the world around them. Sound is a progressive longitudinal mechanic vibration through elastic ambience, capable of being detected by hearing. Noise is then understood as any unwanted sound that disturbs or annoys us and has harmful impact on human health.

Noise in the environment is described in legislation by *equivalent sound pressure level* $L_{Aeq,T}$, which is always related to a specific time interval. This value is defined as stable sound pressure level, which has energy content equivalent to variable sound, and therefore presumably the same harmful effect. It is determined as average energy from the sound pressure levels A in a specific time interval, it is measured in decibels (dB) and its value is adjusted to frequency by means of a frequency weighing filter, which is used to reflect differences in human sensitivity to the noise spectrum.

Another noise descriptor, which is used mainly in places where the noise results from a series of identified noise events (discreet noise events, such as passage of individual vehicles in a specified area, overflying aircraft), is *sound exposure level* $L_{AE}$ *(SEL)*. In this case, the measured sound pressure is assessed in a randomly long time interval and related to standardized period T = 1s. This allows comparisons of individual events with each other. If we know the sound exposure level values of individual events and their frequency, we can determine the equivalent sound pressure level based on the defined relation in a specific place and in a given time interval.

There are four basic types of acoustic energy generation within railway transport, namely track noise, radio devices operation for railway staff and public information, railway station traffic, especially at formation yards with speed regulation of uncoupling with track brakes, and finally the sound signalization.
The following text is focused on the first type only, and that means on track noise. It can be generally stated that the track noise of a moving train affects the environment with a complex of noises from different sources (see Fig. 1).

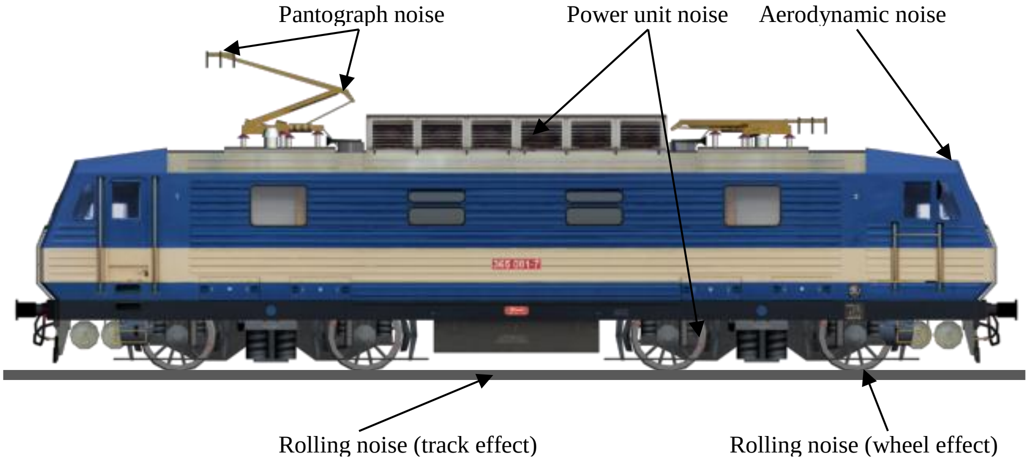


Fig. 1. Noise types [author]

The basic noise sources in railway transport are pantograph noise, aerodynamic noise, power unit noise and rolling noise. Pantograph noise in electric traction is generated in the height of approx. 5 meters. Aerodynamic noise, which increases with the train speed (for high speed trains, this noise type prevails over the others), generates from the flow of air and turbulence in the area of cars, their bogies and pantographs. This noise can be partly eliminated by using rail vehicles with better shape design. Power unit noise comes from a variety of sources including diesel and electric engines, gearings and fans. Rolling noise is caused predominantly by the wheel touchpad rolling on the rail. However, the noise is also generated in those areas of bogies, where the wheel set spinning causes friction.

The level of undesirable effects depends mainly on the routing type, traction type, construction, technical quality of superstructures and vehicles and on traffic speed and intensity. Noise transmission is dependent on climatic conditions, configurations and on the type of the surrounding ground surface.

There is some experience from abroad in terms of influence of various railway superstructure constructions on the noise [3].

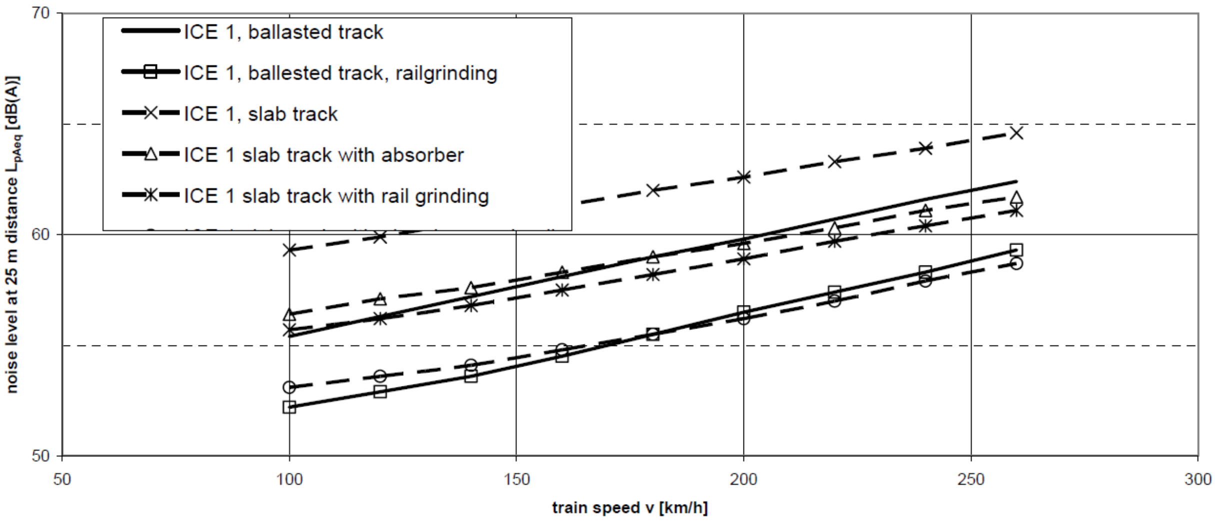


Fig. 2. Noise levels on different tracks according to “Schall03 2006” [3]

Also some noise measurements from Czech Republic presented on “Workshop 2012 of the project NOVIBRAIL” confirmed impact of different superstructure constructions – track after reconstruction reduced noise level about 2 – 4 dB and track absorbers provided additional 1 – 2 dB reduction.

## 3. RAILWAY NOISE MEASUREMENT

Before the measurement is initiated, its purpose needs to be analyzed and the objectives of the follow-up assessment need to be specified. First it is necessary to choose suitable sites and specific places for the measurement, and determine the methodology of measurements according to the legislation in force. Within the scope of the project, synchronous measurements in selected sites took place, so that the sound exposure from a single consist on different types of superstructures can be determined. Both sites after and before reconstruction have been selected.

The integral Sound Level Meters Norsonic, which were placed on every post in threes and in different heights and lengths (7.5 m away from the centre line of the track and in the heights of 1.2 m and 3.5 m above the top of the rail, and then 25 m away from the centre line and 3.5 m above the top of the rail), were used for the measurements.

As mentioned above, the measurements took place in two places of a selected track with different superstructure conditions (construction or deterioration, etc.) at the same time, so that the noise emissions from the same consists in both posts can be compared and the influence of the superstructure construction on the sound pressure level can be better determined.

For the assessment of railway noise, a method of comparing *sound exposure levels* $L_{AE}$ during an individual train passing has been chosen. This descriptor is delineated in detail in the previous chapter.

The measurements themselves were performed in measuring campaigns, which consisted of eight steps. The first step was theoretical identification of track sections, followed by practical identification including a field survey. The third step was to select specific sites in a particular section. Next in order was the measurement term planning and in the fifth step its performance, considering the weather and traffic exceptions on the monitored track sections. In the following sixth step of the campaign, data were summarized and in the seventh step prepared for the follow-up assessment. In the last, eight phase, the data were statistically processed and expertly assessed.

## 4. MEASUREMENTS RESULTS AND THEIR ASSESSMENT

The following graphs illustrate componential results for passenger trains. The dependence of *sound exposure level* in dB(A) during an individual train passing on the train *speed* and *length*, determined by the number of axles, is compared. For illustrative and clarity reasons, a product of a speed figure and a number of axles is used, in logarithmic scale. One dot in the graph symbolizes an individual train passing and there is a trend line inserted. All presented data come from sound level meters placed 7.5 m away from the centre line of the track and in the height of 1.2 m above the top of the rail.

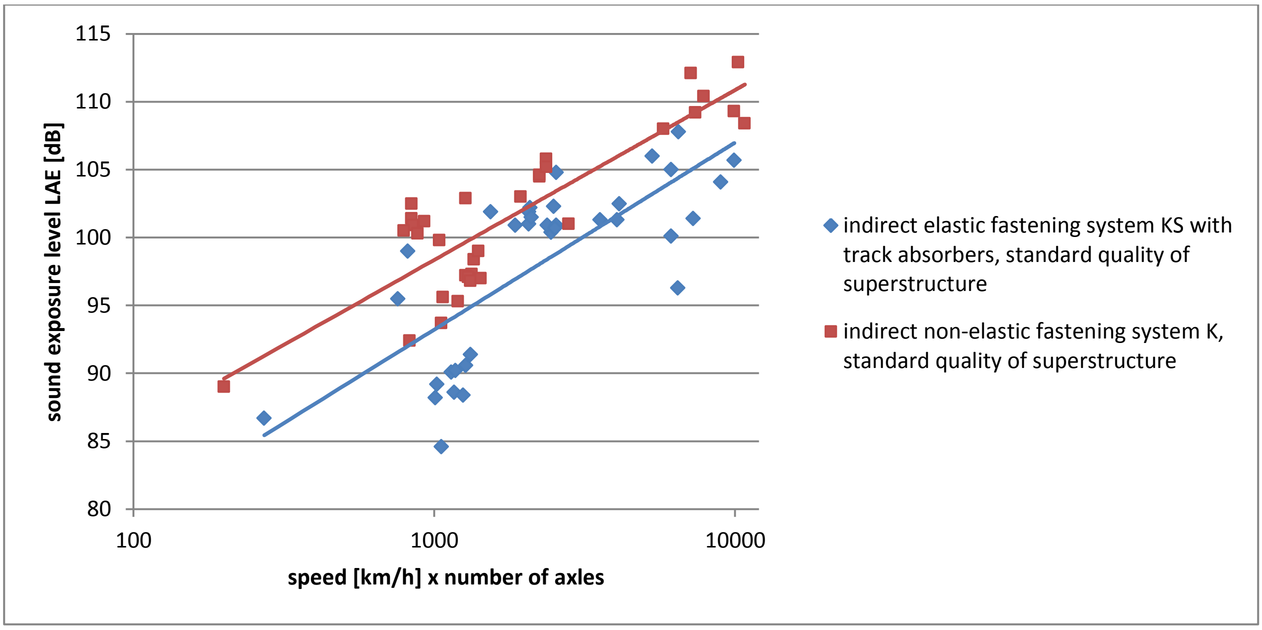


Fig. 3. Noise emissions – different fastening systems, electric traction [author]

The first graph (Fig. 3) shows the data from an electric traction, with indirect elastic rail fastening system KS with track absorbers and fastening system K. The average speed of measured trains was in both posts approximately equal, so the fastening system KS with track absorbers therefore shows lower noise level.

The following graph (Fig. 4) contains measurement data from an electric traction, too, and that with the fastening system K in standard quality and the same fastening system after reconstruction in 2009. The average train speed in the measuring post with fastening systems in standard quality was less than 10 km/h higher, no significant differences in the noise level were, however, confirmed.

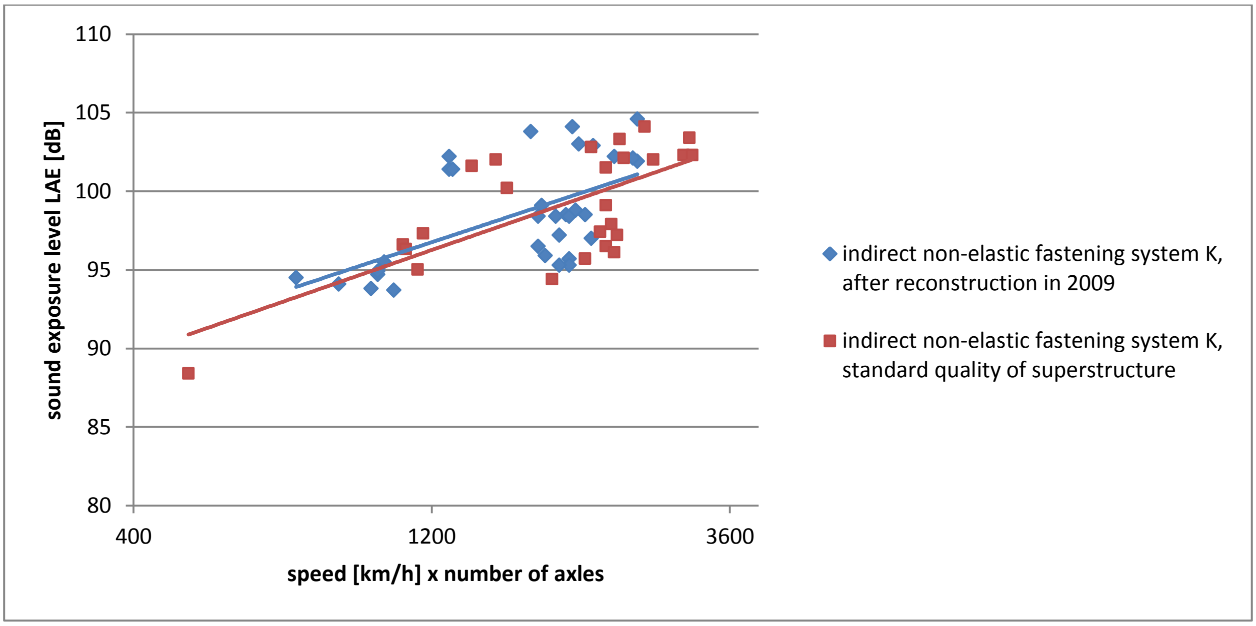


Fig. 4. Noise emissions – same fastening systems, different superstructure quality, electric traction [author]

Graph in Fig. 5 contains data from an electric traction, the indirect non-elastic fastening system with divider heel baseplate in average quality of superstructure and the direct elastic fastening system W14 with superstructure after modernization.

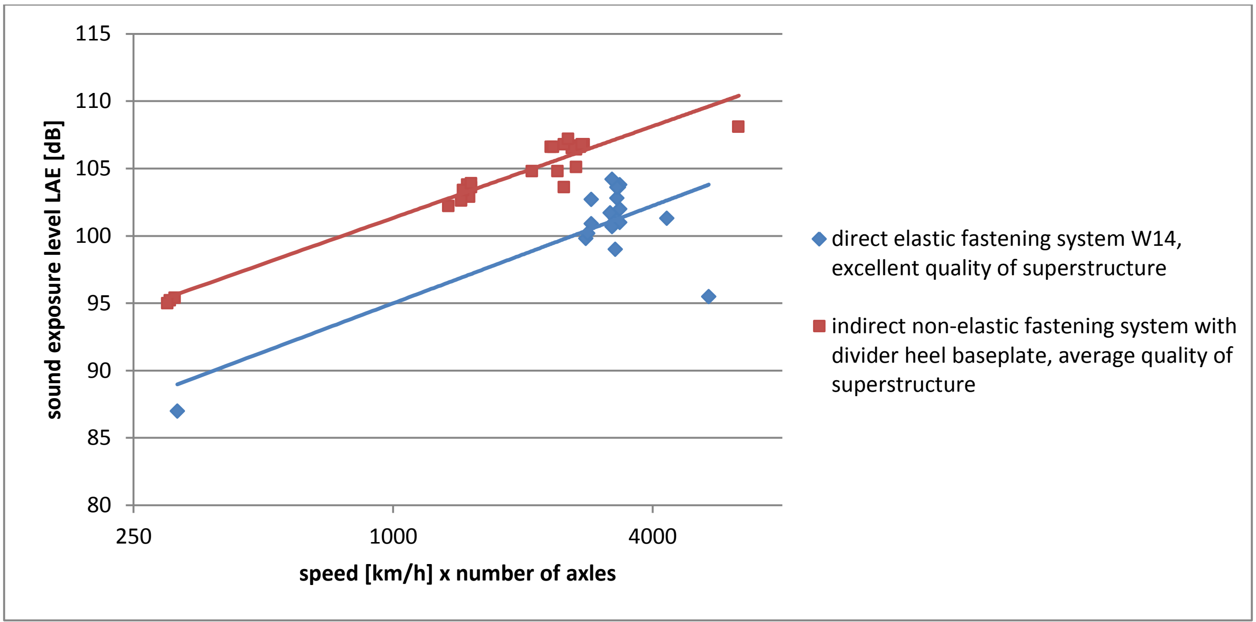


Fig. 5. Noise emissions – different fastening systems, electric traction [author]

Although the superstructure with the fastening system W14 is moved on with higher speed (more than 20 km/h higher on average), its noise emissions are significantly lower compared to indirect non-elastic fastening system.

The assessment of measurements has also proved that noise emissions level is influenced not only by technical quality of the cars in consists, but also especially by their construction. Trains consisting of modern cars with disk brakes and the EMUs (electric multiple units) of a 471-071-971 series, show lower sound exposure level in comparison to standard cars with block brakes. Graph in Fig. 6 compares data measured in posts on the same superstructure construction (indirect non-elastic fastening system K), but with different car types. Trains with disk brakes are represented by the 471-071-971 class EMU.

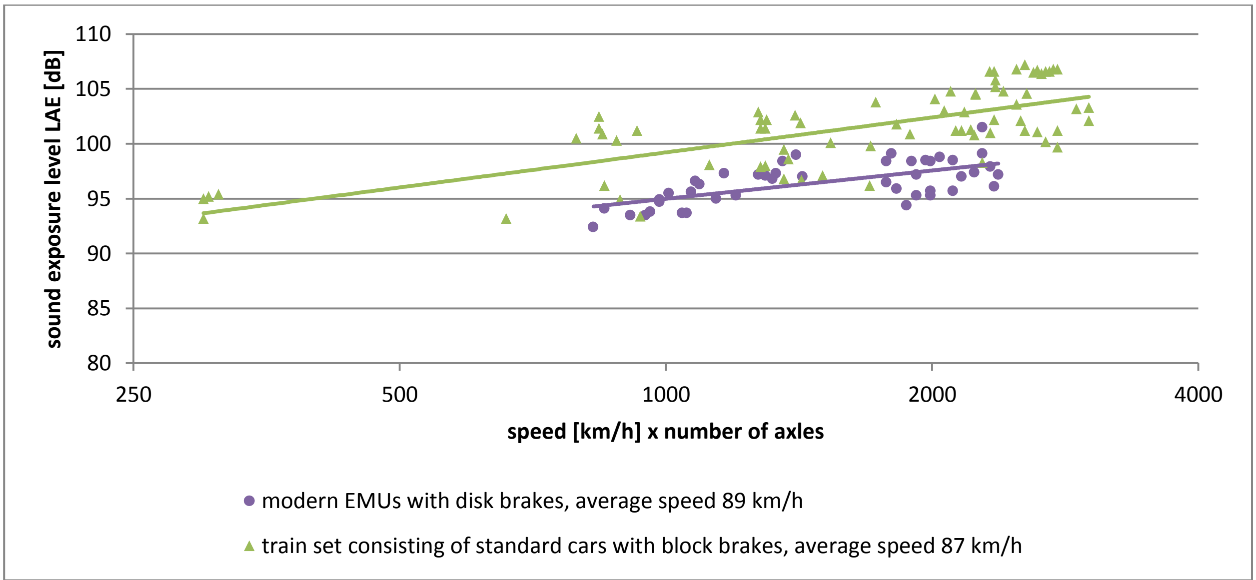


Fig. 6. Noise emissions from cars of different constructions on the superstructure with the fastening system K [author]

## 5. CONCLUSION

As it has been already mentioned in the second chapter, the basic noise sources in railway transport are traction noise (power unit noise), rolling noise (generated from the wheel rolling on the trail), and aerodynamic noise (air turbulences from a passing train). All these three main sources are associated with each other and cannot be unambiguously separated, each component is, however, dominant in a different extend of train speed. If there is a need to find dependence on different superstructure constructions, rolling noise, which dominates within the speed range of ca. 60 – 200 km/h, is essential. This fact needs to be considered when choosing measuring sites and processing the measured data. Rolling noise is further divided into wheel and track radiated noise. The above given parameters are also connected to each other and under standard operating conditions, when the measurements are performed, they cannot be separated from each other. There is a problem, though – track radiated noise is essential for finding dependence of noise emissions on different superstructure constructions; nevertheless, an element of “what moves on the track” has to be taken into account. Without the knowledge of this element, the problem of different superstructure construction cannot be solved efficiently. Measurements, which have been realized so far, confirm the given facts. It can be therefore concluded that the issue of railway noise has to be examined and solved systematically as a whole including all the influencing factors.

The aim of the project is to find out how different superstructure constructions influence noise generation and transmission from passing trains. This will result in unified methodology, which has not been present in the Czech Republic so far, and which allows definition of suitable corrections in calculation for the most commonly used methods for railway noise calculations with different track types.

In conclusion, the fight against traffic or railway noise in this case, is difficult and long-term process. Recent studies have shown that railway noise mitigation is a significant “by-product” of ongoing modernization and optimization of the railway lines in the Czech Republic.

### Acknowledgements

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# Czech Traffic Conflicts Technique

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**Abstract**

The article deals mainly with defining the way of monitoring traffic conflicts. This issue is only one part of a greater safety analysis, or risk determination process of particular location. Based on the described procedures it is possible to apply the methodology also to more complicated nodes such as level crossings, sections town residential area or rural areas.

**Keywords:** traffic conflict technique, monitoring traffic conflicts, road safety analysis

## 1. Introduction

In most studies of road safety, analysts use the information contained by accident reports to identify and understand failures of the road system and then propose appropriate corrective actions. While these analyses are essential, it is well recognized that accident data suffer from a number of shortcomings and need to be complemented by field observations in order to improve the accuracy of safety diagnoses.

Monitoring of traffic conflicts compared to traffic accidents analysis is a less used method. Conflict situations are quite similar to accident situations, but are stave off in good time, such as by changing speed or direction. The advantage of this method is that by using it can detect problems before traffic accident occurs. While monitoring and evaluation of traffic accidents can take many years, the traffic conflict analysis takes some days or at most a month. Another advantage of the method of monitoring of traffic conflicts is its complexity – from the monitored locality can be in addition obtained the traffic-engineering data. Monitoring of traffic conflicts is not only more efficient (time-efficient, money-efficient), but primarily more humane because the safety problems can be solved before any traffic accidents with material damage, injury or death occur.

A well–accepted definition of traffic conflict is: 'an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged'. (PIARC, 2003)

The project KONFLIKT (Methodology for the monitoring and evaluation of traffic conflicts in the Czech environment) has to create a practical tool for assessing and solving the road safety. The most promising approaches will be selected and these will be practically tested to verify their suitability for Czech conditions. The gained experiences will be used for creating the Czech methodology. It will be also created a special web application for training observers.

The starting point of the project is exploration of facts of previous research in the field of traffic conflicts. The main sources for the project are two American manuals 'Traffic Conflicts Techniques for Safety and Operations' – 'Engineer's Guide' (Parker & Zeeger, 1988) and 'Observers Manual' (Parker & Zeeger, 1989), the research of assoc. prof. Folprecht (Folprecht, 2000) and the Methodology for Monitoring Traffic Conflicts (Kocourek, 2010) developed on CTU by assoc. prof. Kocourek. This research builds primarily on the research of assoc. prof. Kocourek.

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**2. Methods** (PIARC, 2003 + Kocourek, 2010)

The research is focused on traffic conflicts as an alternative to accident data. Conflicts occur far more frequently in traffic and can include the whole range of incidences where the actual accident is just at one end of the scale. Techniques range from subjective to the more objective where conflicts are rated by measurements such as time to collision or post-encroachment time.

This research effort further enhances the usefulness of the traffic conflict technique as a tool to evaluate the safety of intersections. Traffic conflict technique enables to study hazards in traffic in an uncomplicated way.

For observing traffic conflict in practices is necessary to define four basic steps:

- Objective of traffic conflicts analysis;
- Conflict severity;
- Types of traffic conflicts;
- How to conduct a traffic conflict study.

*2.1. Objective of traffic conflict analysis*

A traffic conflict study can be used:

- To make progress in a safety diagnosis – Traffic conflict studies are particularly useful when accident data suffer from strong limitations (accident reports may be unavailable, the information may be insufficient or unreliable).
- To evaluate the effectiveness of a safety treatment – The main advantage of conflict studies over accident studies is that it is not necessary to wait several years before gathering sufficient data to complete the evaluation. A conflict study can be conducted soon after work has been completed and negative can be made quickly if anticipated benefits have not been achieved (or if unexpected side effects have been created).
- To compare the safety performance of different road features or traffic rules.

*2.2. Conflict severity*

For the traffic conflicts technique purposes three levels of conflicts have been defined. For the complex analysis of the studied locality even so-called level 0 and level 4 can be monitored. Thus there are five levels altogether (Fig. 1).

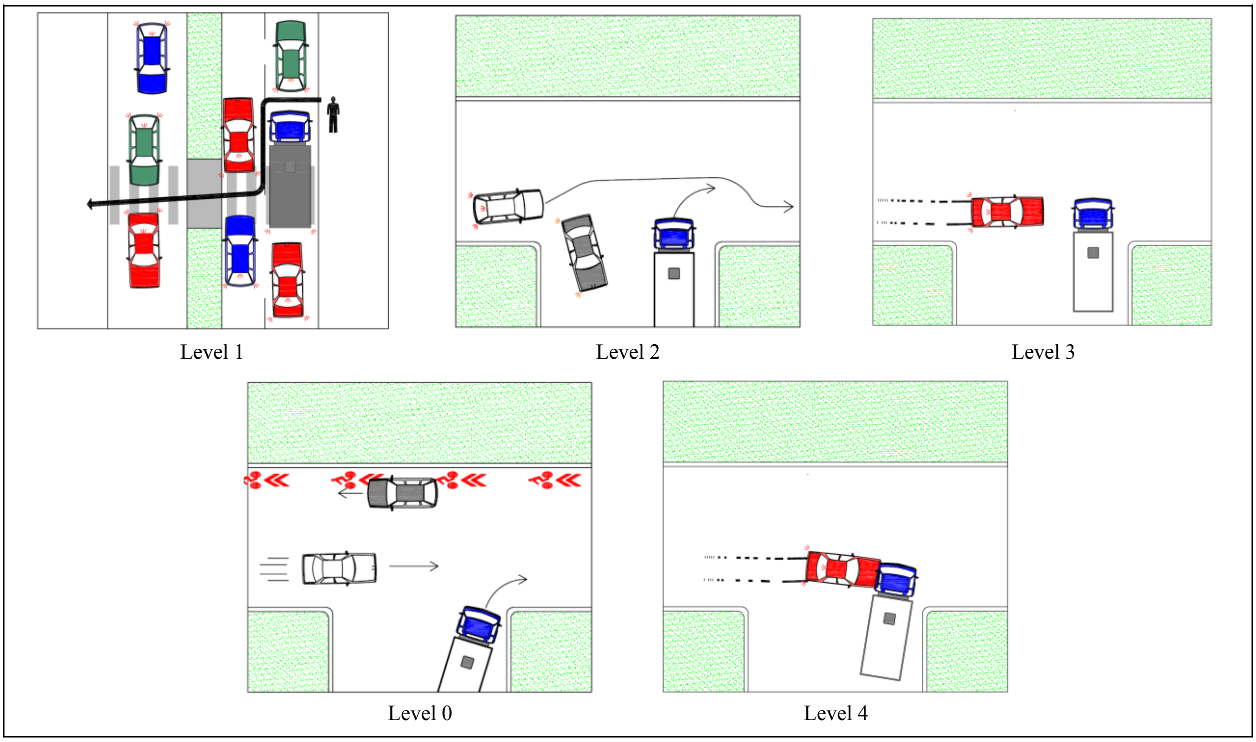



Fig. 1. Traffic conflict severity

The **level 0** is used for the record of mere breaking road traffic rules of the isolated vehicle (in the case of the roundabout this kind of maneuver was for example not to signalize stream compulsory direction change while leaving the roundabout).

The **level 1** is assigned to the controlled maneuver without any limitation or just with minor limitation. The example of this level is a conflict between a vehicle, which is standing on the pedestrian crossing, for example because of the traffic jam, and pedestrian, which would like to use this pedestrian crossing and has to go around the vehicle (see Fig. 1 – level 1). The difference between level 1 and level 2 is minor. In spite of that, it is necessary to realize that in some specific situations (the example with pedestrians) it is necessary to sort out this kind of conflict into less severe and more severe (**level 2**). According to the Czech law about traffic on the road the term 'not to be allowed to limit' is defined as the duty of the driver not to obstruct another participants of the traffic. The conflict **level 3** is assigned to such situations, when the road users are threatened and sharp maneuver (loud breaking supplemented for example with beeping) is necessary to avert traffic accident (according to the law about traffic on the road the term 'not to be allowed to endanger').

**Level 4** is used for the case when a traffic accident occurs.

Example of traffic conflict record is below (Fig. 2).

| **Traffic conflict record**<br>Problem creator / Respondent – conflict severity<br>Example: O / N – 1 | | | |
|---|---|---|---|
| O | Personal vehicle | B | Bus |
| N | Cargo vehicle | T | Tramway car |
| NT | Long cargo vehicle | Ch / C | Pedestrian / Cyclist |

Fig. 2. Traffic conflict record

### *2.3. Types of traffic conflicts*

As in the case of accident analysis, it is quite useful to subdivide traffic conflicts into different categories, based on their type. This allows the preparation of summary tables, graphs and diagrams that facilitate the interpretation of results (comparisons with localities having similar characteristics and detection of deviant types of traffic conflicts). Our research defined 14 types of conflicts between two vehicles and one type of secondary conflicts.

However, some of these conflicts have very low rates of occurrences, which reduce their usefulness. The number of conflict types rises quickly when those that may occur between motorized and non-motorized road users are added to the list (pedestrians, cyclists, others). The list of conflict types that may be observed at a locality depends upon its prevailing traffic rules and geometric characteristics; this list should be determined prior to initiating the study. It is not necessary to observe all traffic conflicts that may occur at a locality in all conflict studies. If, for example, the objective is to compare the performance of two left-turn treatments at intersections, it might very well be sufficient to collect conflicts that are related to this maneuver.

### *2.4. How to conduct a traffic conflict study*

A number of elements need to be considered in the planning of a traffic conflict study:

- Personnel training;
- Observation technique and period.

*Personnel training*

The validity and usefulness of a traffic conflict study are greatly influenced by the degree of consistency of observers. Two basic requirements must be satisfied the same observer must record conflicts consistently. Different observers must record the same conflicts consistently.

Within the project KONFLIKT is created the web application for training the observers. The program tests their perception of the severity and type of the traffic conflict. The trainees are watching several movies of traffic conflicts and they have to evaluate each watched traffic conflict. The movie cannot be stopped or replayed. The result is displayed at the end of the test.

*Observation technique and period*

The required number of observers (or the study duration when observations are made sequentially) depends on the number of conflict types to be observed, the average rate of occurrence for each conflict type, the traffic volumes, the number of intersection legs and the need for a traffic count.

The traffic conflict observation is usually conducted at daylight and in dry weather. In specific cases if traffic accidents occur at night or in wet it is recommended to conduct the observation in these conditions. The observation should not be conducted under unusual conditions such as road works, road accident etc. that disrupt a normal traffic behavior. If the road accident analysis shows the time dependence the traffic conflict observation should be planned for the time when the problems occur with the most probability.

Research is also focused on temporal variations of traffic conflicts in the traffic flow. The aim is to determine whether there are significant changes in the number and types of traffic conflicts observed in long-term monitored localities in terms of changes in annual and daily traffic variation.

## 3. Application (Kocourek, 2010)

Once observations have been completed, data must be reduced and summaries prepared. Results are presented either in summary tables or in traffic conflict diagram. Summary tables allow comparisons of conflict rates between the locality being analyzed and localities with similar characteristics, which is useful in detecting deviant patterns. The logic behind these analyses is similar to that of the accident pattern analysis. Traffic conflict diagrams are quite similar to the collision diagrams. They facilitate the identification of repetitive conflict patterns that are concentrated in some travel directions and intersection areas. For likelihood confrontation of traffic conflicts between separate junctions was chosen simple relative index of traffic conflicts $k_R$.

$$k_R = \frac{P_{ks}}{I} \cdot 100 \qquad (1)$$

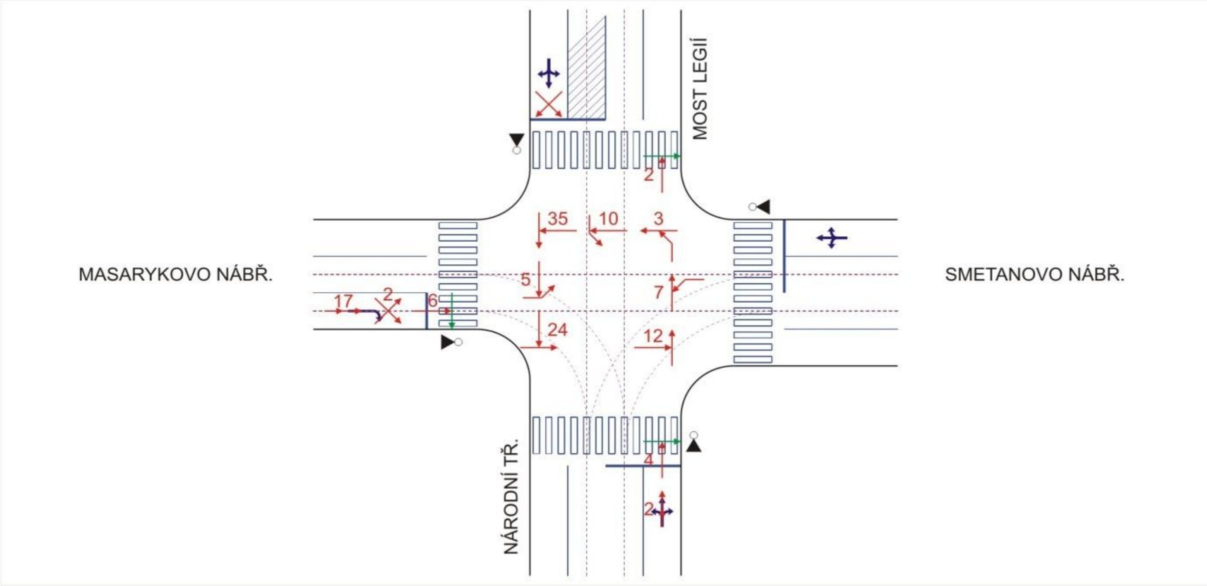
$P_{ks}$ … conflict situations per hour (traffic conflicts of levels 1 – 3 only)
I … traffic intensity cv/h (converted vehicles per hour)

### *3.1. Year-on-year traffic conflict variation* (KONFLIKT Project)

The survey was focused to detect annual changes in the stable traffic load intersection in the center of Prague at National Theatre (Národní × Smetanovo nábřeží). There was recorded year-on-year decline of traffic conflict rate, but the number and types of serious traffic conflicts remained comparable. See Figs. 3a and 3b.

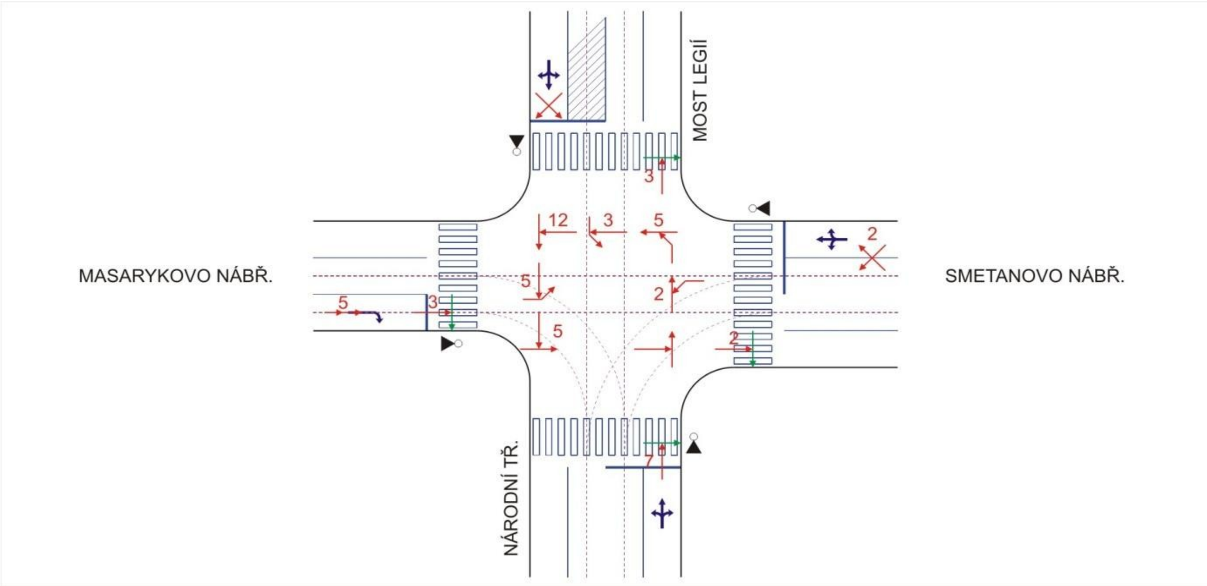
### *3.2. Daily traffic conflict variation* (KONFLIKT Project)

The survey was focused to detect daily changes in the stable traffic load intersection in the center of Prague at Jirásek Square (Resslova × Rašínovo nábřeží). In the morning rush hour there were not recorded traffic conflicts within the inner area of the intersection, which is probably due to the high traffic intensity on the whole network and also the suitable signal plan. During the day the distribution of traffic conflicts was constant. See Figs. 4a, 4b and 4c.



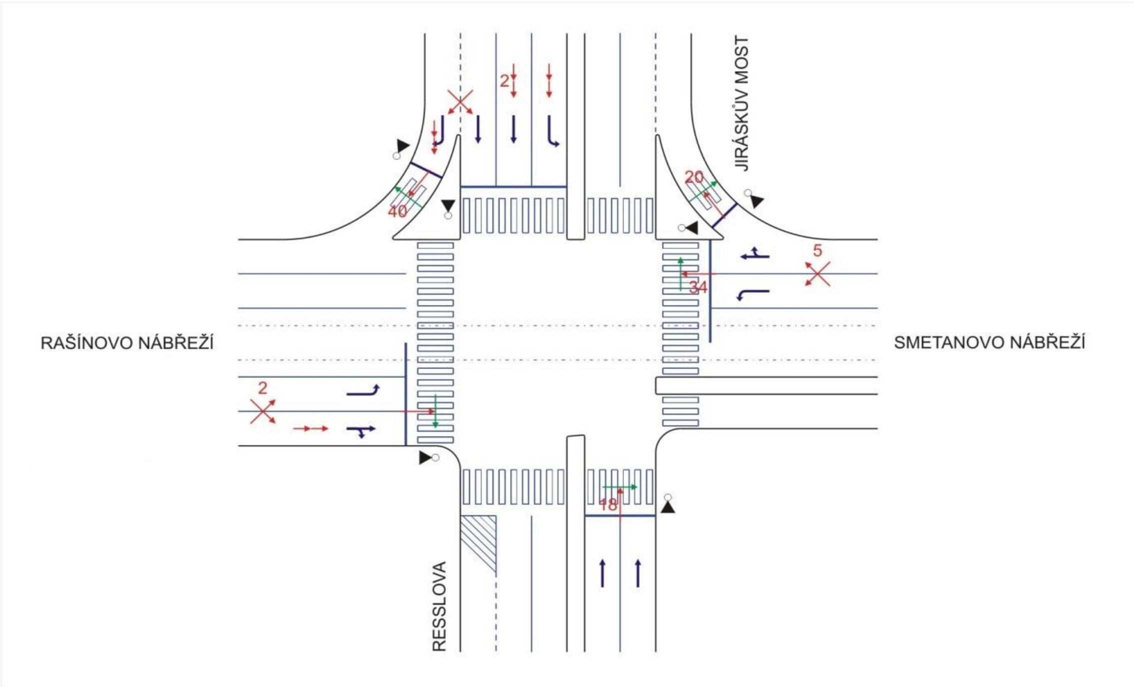

| Traffic conflict situations | | | | |
|---|---|---|---|---|
| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
| 98 | 126 | 4 | 0 | 0 |
| Relative conflict rate: $k_R = 7{,}82 = (130 \div 1663) \cdot 100$ | | | | |

Fig. 3a. Traffic conflict diagram – Prague, National Theatre, 2011



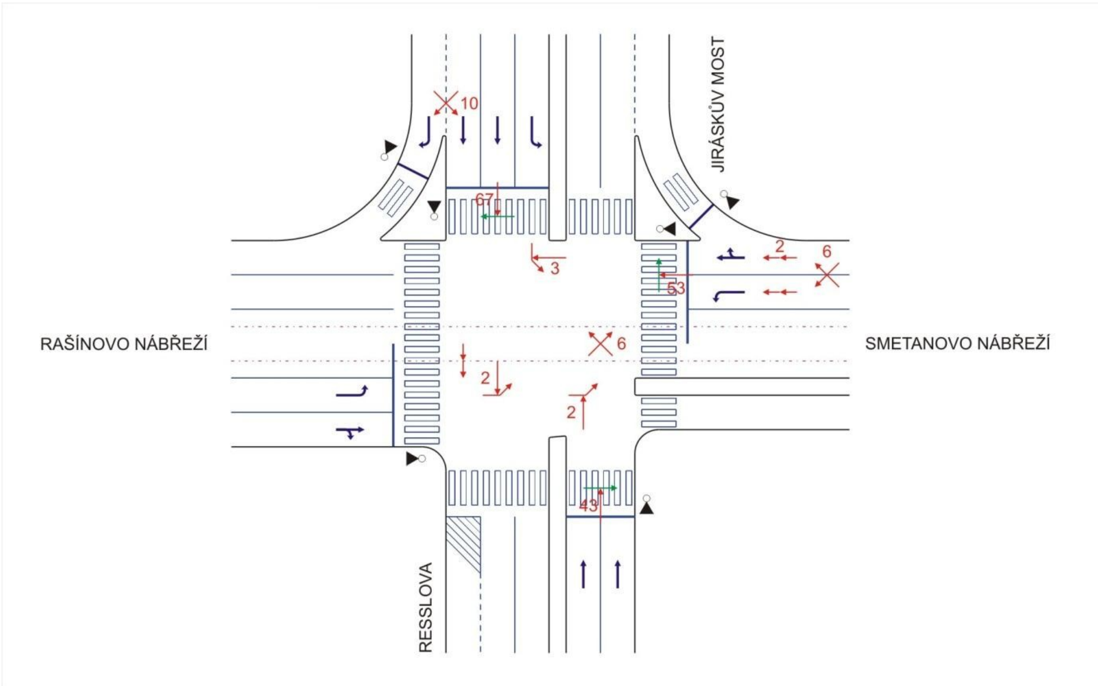

| Traffic conflict situations | | | | |
|---|---|---|---|---|
| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
| 138 | 51 | 5 | 0 | 0 |
| Relative conflict rate: $k_R = 3{,}70 = (56 \div 1513) \cdot 100$ | | | | |

Fig. 3b. Traffic conflict diagram – Prague, National Theatre, 2012



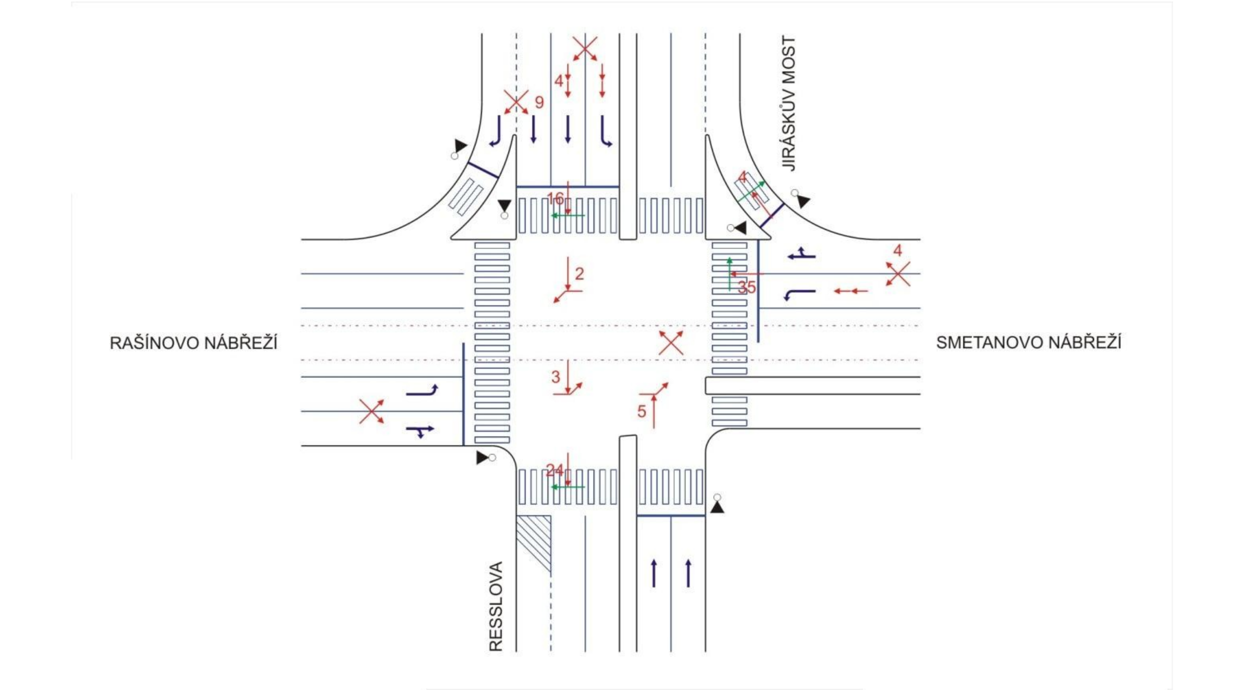

| Traffic conflict situations | | | | |
|---|---|---|---|---|
| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
| 203 | 12 | 2 | 0 | 0 |

Fig. 4a. Traffic conflict diagram – Prague, Jirásek Square, 10th May 2012, morning rush hour




| Traffic conflict situations | | | | |
|---|---|---|---|---|
| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
| 220 | 13 | 1 | 0 | 0 |

Fig. 4b. Traffic conflict diagram – Prague, Jirásek Square, 10th May 2012, midday traffic




| Traffic conflict situations | | | | |
|---|---|---|---|---|
| Level 0 | Level 1 | Level 2 | Level 3 | Level 4 |
| 275 | 11 | 3 | 0 | 0 |

Fig. 4c. Traffic conflict diagram – Prague, Jirásek Square, 10th May 2012, afternoon rush hour

## 4. Discussion and conclusion

This paper deals mainly with defining the way of monitoring traffic conflicts. This issue is only one part of a greater safety analysis, or risk determination process of particular location. Based on the described procedures it is possible to apply the methodology also to more complicated nodes such as level crossings, sections town residential area or rural areas.

Reliability of traffic conflicts records have to be ensured by thorough training of observers. Well-trained observers are actually the cornerstone for successful monitoring of traffic conflicts. Within the project KONFLIKT is developed a special web application pro observers training.

Another important part of the traffic survey is the appropriate choice of time to monitor the traffic conflicts. The partial conclusions of traffic surveys show that the number of traffic conflicts is in the long-term proportional to the traffic intensity and the types of traffic conflicts in a certain locality do not change influence of daily traffic variation.

In the next phase of project KONFLIKT will be monitored the selected problem localities with expected sufficient incidence of traffic conflicts. Selection of localities will not include only the intersections in urban areas, where the majority of traffic conflicts occur, but will take into account also pedestrian crossings, localities in rural areas and railroad crossings.

The main goal of the project is obtaining a sufficient amount of experience for developing the methodology for monitoring and evaluation of traffic conflicts that will be applicable in practice in the Czech environment.

## Acknowledgements

Many thanks to the employees and students of the CTU FTS for cooperation in the traffic conflict surveys. The contribution was supported by the project of Ministry of Education, Youth and Sports of Czech Republic No. MSM 6840770043 and by the project of Technology Agency of the Czech Republic No. TA01030096 'Methodology for the monitoring and evaluation of traffic conflicts in the Czech environment'.

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# Department of Transporting Systems Cooperation with DIPRO Company

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**Abstract**

Dopravní a inženýrské projekty, s.r.o. (DIPRO, Ltd.), one of the companies, which are involved in tram track designing in Czech Republic, was established in March 1993, so today it is 20 years old. The cooperation with Department of Transporting Systems, based on participation of some employees (designing specialists) from the company DIPRO on educational trial, started in September 2001. Contrarily, the Department of Transporting Systems provides experts, experiences and consultation services for some projects.

**Keywords:** Tram track structure, Ballastless track, Streetcar noise abatement, Tram stop

## 1. Why Special Tram Track Structures

Prague, the capital of Czech Republic, is one of the European cities with very good modal split in city transport. About 55 % non pedestrian operated transportation relationships are ensured by public transport. From this percentage is about 45 % operated by underground, 25 % by trams, 28 % by buses and 2 % by commuter trains.

Especially in the city centre is tram traffic very intensive, in the busiest section (Ječná street) is the traffic volume 120 000 pers./day – that's about 50 % of the busiest underground section! This mathematics is giving us rather real image about tram tracks load in Prague. In some directions the underground lines are absent, and, due to contemporary economic conditions, this situation can be considered to be petrified for a longer time.

This is the main reason for development of new quieter, more esthetical and more durable tram track structures. Other reasons can be a little bit paradoxical – the growth of automobile traffic after 1990 caused requirement for bigger track pavement resilience and durability, because the road capacity in greater city centre was taken for parking! Another acute reason was the massive surviving of BKV track structures (known also as "Nikex" rail) from 1990s. That very thin type of upperstructure doesn't give much of leeway for conventional ballasted track development, so it was necessary to try it without half meter of ballast bed.

## 2. Ballastless Tram Track in Prague

Concrete slab structures with concreted rail fastening were in Prague proofed already in 1960s. But this effort was not very successful, because of the superior pointing was not available in ČSSR at that time. The gaps between rail and paving were not jointed with convenient grout as well and the salt water with froze were destroying the fastening.

The main feature of the ballastless track is the ratio of initial costs and durability by friendly maintenance costs. This ratio still appears so advantageous, that in Germany, a rigid track pioneer in Europe, they coin a new slogan "Build and forget". For above mentioned advantages was in 2001 decided to test a modern slab tram track also in Prague – one of the greatest world tram networks. The tram track on concrete slab was used by repair of the track in the Na Poříčí St. between Těšnov and Havlíčkova St. in double track mileage 280 m (fig. 1). As the name in the subheading suggests, an old concrete slab, built in the early 60ties has been replaced by new base concrete layer with "pockets" in distance of 3 m in what the concrete sleepers were put and, after the definitive track geometry has been rectified, the sleepers were fixed by the concrete grout. To suppress the vibrations and

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noise of the rolling stock, a noise suppressing mate of recycled rubber placed on the subgrade, the bases of rails were coated by rubber profiles and the rail chambers were filled with recycled rubber profiles as well.


Fig. 1: The Na Poříčí Street (spring 2003)

Lately, a concrete slab (even reinforced) or asphalt bearing layer to which is lively fastened the rail was used. To easily ensure the geometric position of the track was in process of time leaved the technique in which the plug holes are drilled to the concrete slab. This in Prague already in 1960s proved technique was substituted with the idea to embed in concrete precisely line and level rectified track length (the top-down building method).

Since November 2008, after the first section of tram track, using the Vossloh W-Tram fastening and the bearing concrete slab being made after the track geometry was fully rectified, has been designed by DIPRO under the historical sight Vyšehrad, the ballastless track with the Vossloh W-Tram fastening is almost exclusively used in the Prague tram track network (fig. 2).


Fig. 2: Concreting the slab under the Vyšehrad in November 2008

### 3. Streetcar Noise Abatement

The first application of modern noise abatement materials in tram track structure was in 1994, by the reconstruction of a section of the tramway track in the Letenska St., where the track goes through a gate in a baroque house, and only 2m far of the side wall of baroque church as well. Based of relatively good results of noise suppression, this technology was designed also for reconstruction of the track-crossing by the National Theatre. The construction details have been gradually improved.

In 2001, this technology was used for the reconstruction of a tramway track in the centre of Prague in Vodičkova Street near Václavské náměstí. The strictly demand of the client, the City Public Traffic Authority, was to use the track upperstructure with a ballast bed and rails on concrete sleepers. To suppress the noise, a special cell elastomer matt placed under the ballast (on the subgrade) was proposed by the designer. The rail bases as well as the rail chambers were insulated by recycled rubber profiles. To suppress the diffusion of the noise to the sides of the track body, the special precast "L"-shape elements covered by the elastomer matt were developed and put on borders of the track body, separating it from neighbouring roadway construction.

The results of noise and vibrations checking measurement were very encouraging (noise suppression up to 5,4 dB(A) - fig. 3), so it was decided to use the noise abatement elements everywhere near housing estate.

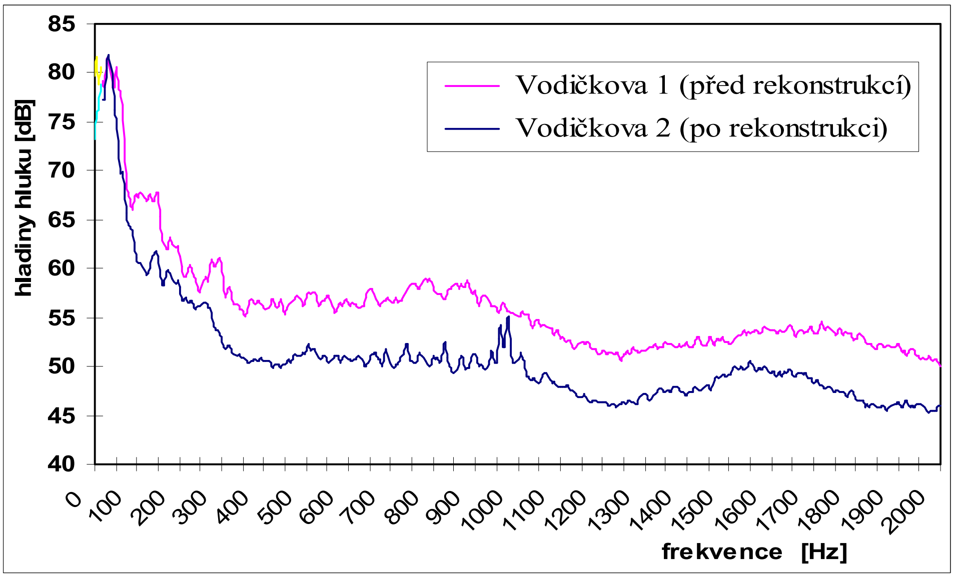


Fig.3: Noise measurement after track reconstruction in 2001 – Vodičkova Street

Today are on the subgrade usually prostrated the noise and vibration damping mattings from the recycled rubber (cast-off milled tyres) in thickness 2x11 mm. The rail bases are coated with rubber profiles, them manufacturer warrants elastic deformation. Rail webs are insulated by glued-on dampers, also from recycled rubber. Gaps between rail heads and road paving are filled with continually elastic pointing. Rail fastening is naturally elastic, almost the Vossloh W 14 system or in the track developments the ribbed baseplates with Vossloh Skl 12 or Skl 24 clips.

Combination arrangements mentioned above is able to damp down the acoustic noise approximately about 3 dB and the ground borne vibrations approximately about 8 dB. To reduce the total noisiness contributes also asphalt cover construction of the tram track with molten asphalt surface.

Noise abatement elements are providing us some "bonus" qualities, too: Attained levels of the electric resistance of the track are safety above the required.

### 4. Green Tram Track

Since 1995, the so called "green tracks" are also designed by the DIPRO company The first design of grass covered track was proposed for the reconstruction of tramway track section in the Mariánské hrady St. – Jelení St., nearby the Prague Castle (fig. 4, 5).

Fig. 4: Jeleni St., the first grass-covered track in Prague

As for at that time the client strictly demanded to use of a “standardised” upperstrusctture construction, i.e. the track of grooved rails fastened on concrete sleepers in a ballast bed as a base for the design of grass covered track, and, at the same time the client demanded a possibility of access to the fastenings (for control or eventual repair etc.) without damage of the grass cover, the designer suggested the use of special precast concrete elements, set along the rails and covering the fastening elements.


Fig. 5: Mariánské Hradby St. after reconstruction in 2005

This first section of the grass-covered track was designed without an irrigation system. It naturally brought some problems in hot summers, when the irrigation by spraying from water tank trucks must be done. Therefore, the later built up track grass-covered sections have been equipped by permanent irrigation system (so called “summer water pipeline”).

As the client´s fears of the necessity of access to the fastening elements have shown to be groundless, the bordering of rails by concrete elements was abandoned, too.

Fig. 6: Track with an artificial irrigation system – Plzeň, the Slovanská alej Street

Of course, the special tram track structure should give us some more benefits than the conventional track, but there must be a good reason for its realization. The common reasons were described in part 1) of this article. When at least one of the features mentioned in part 1) is not required, special tram track structure will not bring benefits, but rather problems, which have adverse impact on maintenance costs (fig. 7).…

Fig. 7: Not uselessly complicated, from point of view of the maintenance ideal track

## 5. Safety of Tram Stops

The combination of knowledge gained from design experience in DIPRO company and expertise of the Department of Transporting Systems, Faculty of transportation, CTU Prague is used in research of the aspects of safety on tram stops in Czech Republic. Since 2007, these issues are being looked into in the dissertation thesis of Ing. Filip Jiřík under the name „The model of layout of tram stops with consideration of safety risks“ on the Faculty of transportation, Czech Technical University in Prague, expected to be finalized in 2014.

A tram stop is defined as a place on the tramway track with prescribed layout used by passengers for getting on and off the train. Several regulations are used for placement and layout of tram stops. The fundamental document is Czech Technical Standard ČSN 736425-1 „Bus, trolleybus and tramway lines halts, transfer hubs and posts – Part 1: Design of halts“. Other relevant documents are mainly technical standards and regulations dealing with the layout of tramway tracks, urban roads and areas used by pedestrians, including requirements on barrierless usage.

If a new tram stop meeting all the requirements of technical standards is designed, the evaluation of its safety may be reduced to evaluating individual design features according to relevant regulations. However, in practice, there are often situations where an atypical solution that does not meet all the standardized requirements is needed. These situations occur especially when reconstructing an existing stop, where a need to comply local conditions in limited space is required. In these situations, there is currently no procedure in Czech legislation that would determine the order of importance of relevant technical standards.

So in practice, there are often different solutions used in quite similar situations, which makes the orientation in traffic harder (fig. 8). These different solutions of tram stop layouts are an example of situation, which may be subjectively considered as dangerous. The concept of tram stop safety is, however, subjective and is not precisely defined. It may be not only an implementation of measures for precaution of accidents, meeting the requirements of standards for persons with reduced mobility or ensuring the psychological feeling of safety among the passengers.

In the research part, the emerging dissertation thesis will contain a set of selected safety risks resulting from different layout solutions of tram stops. From this complex set of input data, a variable describing the rate of dangerousness will be gained. This will enable an unbiased comparison of particular design features and organizational solutions. To achieve an objective comparison, an analysis based on expertise and knowledge will be made, which will enable a description and evaluation of particular risk elements on a relative numerical scale.

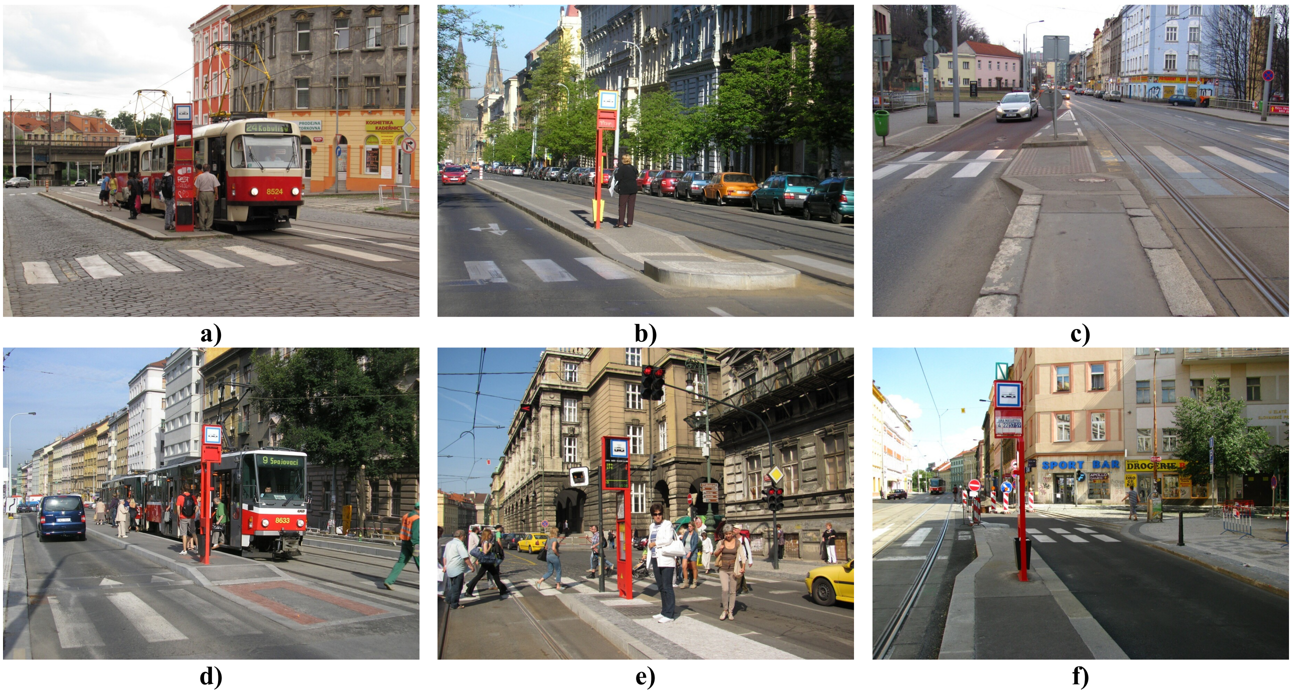

Fig. 8: Examples of diversity of tram stops of similar parameters - a) condition before reconstruction; b-f) condition after reconstruction

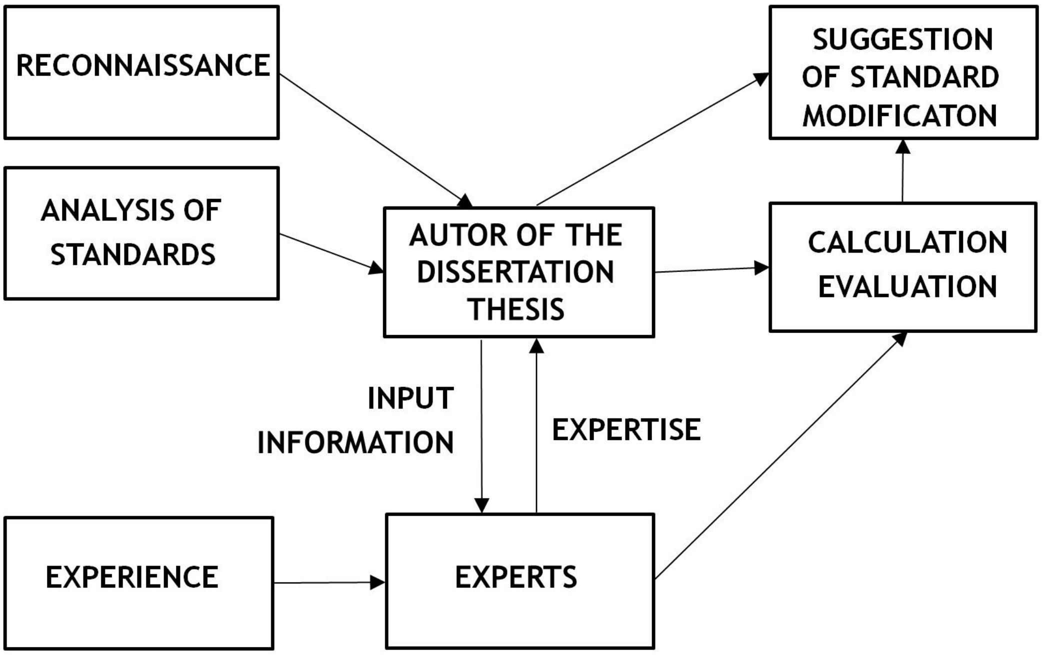


Fig. 9: Scheme of expected progress

The SAFMEA (Statistically Adjusted Failure Modes and Effects Analysis) method is suitable for these needs. A group of experts from different relevant fields and professions will be assembled for the needs of this method. This group of experts will, in the first phase, determine safety risks of elements used in tram stop design. In the second phase, the rate of dangerousness will be defined on a relative scale. Gained data will be statistically evaluated afterwards. A scheme of expected progress in the ongoing work is depicted on fig. 9.

On the basis of the analysis, risks that are acceptable, conditionally acceptable and non-acceptable will be determined. From gained data, conditions for practical use will be set, mainly to eliminate design features that generate non-acceptable safety risks. Gained knowledge will then be used for general technical design, mainly:

- Suggestion of standards for placement and parameters of tram stops according to extended set of input values;
- Methodology of designing tram stops in limited space;
- Involvement of gained knowledge into technical standards, e.g. by a revision of ČSN 736425-1;
- Methods for determination of the rate of dangerousness of an existing tram stop.

# Decision support system of ITS standards deployment

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**Abstract**

Successful implementation of ITS standards in praxis can be the engine for economic development. The biggest obstacle for deployment of ITS standards in praxis is their volume and high specialization. The project STANDARD shows that there it is possible to reduce a number of pages of standards without significant loss of content. Standards are transformed into extracts according strictly methodology. This idea is viable and brings significant effect in the form of a decision support system for a wide spectrum of users.

**Keywords:** ITS standards, CEN, ISO, ontology, decision support system, Aristotle square

## 1. INTRODUCTION

As the actual development of the Road Transport and Traffic Telematics (RTTT) focuses on the mass implementation of intelligent transportation systems (ITS) also in European environment, it is necessary to create a common platform based on the ITS architecture and to ensure functional integration of single subsystems and their interoperability across Europe. Practically, the only way for integration telematics systems represents standardization. In the field of traffic telematics there are standards worked out by European technical commission CEN/TC 278 “Road Transport and Traffic Telematics” or international technical commission ISO/TC204 “Intelligent Transport Systems”.

The scope of activities of both committees is often similar and they develop some of working items in parallel manner according to Vienna agreement between CEN and ISO. Technical committees are divided into working groups (WG) processing numerous standardizations activities related to relevant ITS themes. During the existence of the committees some WG have been suspended or merged together. This means that the whole process is very dynamic along the dynamic development of ITS. The last meeting of TC 204 was held in Prague in April and the last meeting of TC 278 was held in Vienna in March this year. The present status of active workings groups is depicted in Table 1.

| ISO WG | Name | CEN WG | Name |
|---|---|---|---|
| WG1 | ITS Architecture | WG1 | EFC/ETC |
| | | WG2 | Freight, Logistics and commercial vehicle operations |
| WG3 | ITS database technologies | WG3 | Public Transport |

| | | | |
|---|---|---|---|
| WG4 | | WG4 | Traffic and Traveler Information |
| WG5 | | WG5 | Traffic control |
| WG7 | Fleet management/Com Freight | WG7 | Geographic data files |
| WG8 | Public transport | WG8 | Road database |
| WG9 | Integrated Transport Information | WG9 | DSRC |
| WG10 | Traveller Information | WG10 | HMI |
| WG11 | Navigation | | |
| | | WG12 | AVI/ERI |
| | | WG13 | ITS Architecture |
| WG14 | In-vehicle systems | WG14 | After theft recovery systems |
| WG15 | DSRC | WG15 | eSafety |
| WG16 | CALM | WG16 | Cooperative Systems |
| WG17 | Nomadic devices | | |
| WG18 | Cooperative Systems | | |

Table 1. Actual status of working groups in CEN and ISO technical committees

It is quite a long way from the approval of a new work item to a completed standard for publication. It usually takes two or three years and the standard passes through several stages – preparatory stage, committee stage, enquiry stage, formal vote stage and the process is finalized by approval stage.

While some ITS application can be provided without standards generally accepted inside the European or world market, this is not the case for the majority of ITS services. As example of a relatively insular type of standards some automobile standards can be mentioned. A curve speed warning system or a lane keeping assistance system need to have sensors inside a vehicle, but they do not have to communicate with other vehicles or with infrastructure. Many ITS services can only be defined in collaboration. It is possible to mention electronic tolling, co-operative systems etc.

## 2. ITS technology standards development process

The editorial of Computer Standards&Interfaces, ref. [[1]], raises the question if the crisis of IT technologies is being caused also by non-sufficient support of appropriate standards. The relation between suitable standards and the necessity of coordinated development of technologies is still very important.

The Congress of the United States has published a report “Global Standards: Building block for the future” which addresses standards broadly but it spends considerable space on particular needs of IT standardization.

Being aware of the importance of coordinated efforts in the standardization of ITS across Europe, the European Commission has published essential document “ICT Standardization work programme 2010-2013”, ref. [[2]]. The scope of standardization work programme is spited into 14 priority domains of which the domain 3 “Intelligent transport” is interesting in terms of this paper. Concrete actions are required in specific ITS domains starting from EFC, via digital mapping, co-operative systems to electric vehicles. The response of standardization committee TC 278 refers, on 44 pages, the scopes of standardization items, the work plan and milestones of the fundamental areas of interest, ref. [[3]].

This impulse has resulted in a great progress in new standards development. As an example of the necessary support to produce relevant ITS standards for the future market regulation is EU support to develop certification and testing conditions for EFC. For illustration of the volume of standards, in 2007 there were about 7 standards in the EFC domain created by WG1. The report of the convenor of CEN/TC278/WG1 to the ISO meeting in Prague describes more or less 45 items which are finished or under elaboration, ref. [[4]]. Nevertheless publication of standards guarantees neither their successful deployment nor the practical implementations.

## 2 ITS technology standards deployment crisis?

As follows from the short analysis in the previous chapter the elaboration of the standards supported by common European policy is relatively successful. It is possible to identify about 180 ITS standards at present (together with ISO, it is more than 310), some of them are being elaborated, some are under revision and a significant part of standards has been finished. They are focused on the different market applications, starting from CEN/TC278/WG1 “Electronic Fee Collection” (EFC) up to the ISO/TC204/WG16 “Wide Area Communications/Protocols and Interfaces” (CALM) communication standards as examples.

There are two basic problems limiting their successful utilization in real praxis. ITS standards are very complex (in general a standard often has almost 100 pages). There are more or less 17 000 pages of ITS standards, which is a huge quantity for comprehensive reading. The standards are frequently written in the Universal Markup Language (UML) or eXtensible Markup Language (XML) conventions and they need an advanced reader. Even for experts in ITS standardization it is often difficult to follow such a complex set of standards. Generally said, standards are not readable at all, it is a problem especially for investors and decision makers. Also for people who plan to propose a new public tender based on existing standards it is very hard to find relevant ITS standards at once.

The deployment of standards must not be the brake of a successful ITS implementation. This is the reason that "deployment" is very frequent word in ITS standardization process.

To facilitate this problem, Mr. R. Williams has published the book "Intelligent transport systems standards", ref. [7]. This book has two primary objectives: "to list, summarize, and categorize ITS standards that currently exist, or were under development at the time of the writing, and to provide direction and guidance about where to look in the future to find relevant standards for ITS systems". The book creates relations among different standards and provides short abstract of each of them in a verbal form.

The ministry of transport of the Czech Republic supported two research projects aiming at simplification of information search in sets of ITS standards. The first project ZNALSYS has introduced a new approach to deploy fundamental pieces of information included in standards as application oriented knowledge units. The basic difference to the known full-text programs is that this system works as a knowledge engine mining requested knowledge by the contents and formal semantics being pre-processed in the standards. It also uses different form of logical functions to be able to answer complex questions raised by end users.

The second tool for ITS standards deployment in the praxis, which is end user oriented, has been developed in the project STANDARD. The idea is simple and therefore effective – to enhance reading by reduction of a volume of each standard to a reasonable level of several pages of a concise text within a single document. A new form of document is called Extract. In addition, the project is developed as a web application enabling on-line looking for relevant standards and obtaining specific extracts.

Extracts are created syntactically by semantically oriented analysis of standards. It means that standards are transformed into the same formal structure containing semantic entities disclosing the reader the most important content of the standard. Semantic entities are to chain according to the particular expert elaborating an extract.

The reduction of pages of original standard into an extract was limited to 5 pages with focus to reveal fundamental information of original standard and its possible applications. 175 extracts have been elaborated in the frame of STANDARD project during three years. The web site allows general public or a specialist to find relevant extracts to concrete ITS application in a few minutes at present.

The mechanism of STANDARD project is described in the following part of this paper.

## 3. Size reduction of standards

The basic idea of standards volume reduction is mentioned in the previous chapter. To achieve the same level of results by elaboration of a number of standards by a few experts required to prepare and discuss the methodology. The methodology describes the complete process, starting by standards analysis and ending with description of procedures how to elaborate an extract. The experts are the members of Czech national standardization mirror committee to CEN/TC 278 and ISO/TC 204 and they have at least four-year experience in a standardization process. The completed methodology and the first few extracts elaboration were discussed at several meetings.

The process of volume reduction of ITS standards is possible to formulate with the equation

$$S(P_n, \Psi) \xrightarrow{\otimes} E(P_{\max 5}, \lambda\Psi) \tag{1}$$

The original standard $S$ contains $n$ pages $P$ and information content is depicted as $\Psi$. The transformation $S$ into extract $E$ could have *max 5* pages. It is a strict regulation. The second important point determines that information content giving information concerning the scope of a standard should be reduced very carefully, in minimum. The parameter $\lambda$ shall stream to 1, but in reality could be around 0.8. This number was repeatedly achieved by comparative tests of original standards and equivalent extracts provided by independent persons.

The task of reduction of pages without the loss of majority of information content is not valid generally, but standards are very proper for this process, because of strictly defined formal context structure which usually simplifies the extracts elaboration. An experienced expert needs only few hours (average 3-5 hours) to elaborate an extract of appropriate quality.

ISO DIS 12855 „Road transport and traffic telematics - Electronic fee collection - Information exchange between Service provision and Toll charging“ could be an example an extract elaboration to reach significant reduction of pages volume. The original draft of international standard has 107 pages and its extract has 5 pages only. Regardless the reduction to only 5,35 % of original draft pages the extracted information could give to an ordinary person or a specialist sufficient information what the standard says and for what purpose it should be used.

Another standard ISO TR 17452 „Intelligent transport systems - Using UML for defining and documenting ITS/TICS interfaces“ has in original version 27 pages which are transformed into 4 pages. In this case the reduction of the text is 7 times into 15%.

The project has been based on the requirement of the Ministry to bring knowledge found in the standards to decision-makers and so to initiate using ITS standards in praxis in the Czech Republic. That is why the extracts have been made in Czech language only. Nevertheless, the complete English version of the searching tool is available on the web site http://www.silmos.cz/standard/en/ and could provide reader with crucial information concerning the outputs of the project.

To conclude this chapter it is possible to summarize basic features of transformation of standards into extracts:

- Extract is a document created by reduction of a standard to approximately 5 pages, prepared according to the methodology with respect to formal and content elements of the standard in such a way that it provides the experts with adequate information about the scope of the standard.
- Extract has become a new type of document exclusively created for raising awareness of existing ITS standards. To assure the consistency and unification of the form, context and content of the extracts a specific methodology for its creation shall be used. Extracts processors must be informed in detail about the whole procedure.
- Extract is a simplified text about a technical standard providing its reader of detailed information about the content of the standard. The aim of the extract is to deliver information about the intended use and application of the standard. The extract does not describe the full scope of the standard, nor replaces the standard itself, its purpose is to provide the specialist the possibility to make a good choice among the standards for his/her intention and guide him/her to buy and use the standard
- Non experts, as investors or decision makers, could use extracts to define conditions of tenders by specifying relevant standards or raise higher level discussion with suppliers or communicate ITS also at political level.

## 4. ITS extracts searching engine

The purpose of the project STANDARD is to provide a user with an on-line overview of ITS extracts that are properly classified and make them be found by several searching methods according to his/her needs. The goal of the search is to find relevant extracts or sets of extracts.

The results of the extracts search provide at first the number and the list of extracts being found; then the user chooses a particular standard to get more information, provided by their extracts. All the extracts contain basic information (the number, type of normative document, title, type of implementation to the Czech standardization framework, the classification number within the system etc.). The extracts are also provided with the possibility to get in touch with the author (Question to the author). There is also another tool which is under testing. Twenty standards, the “most important of that time”, are provided with e-learning that is done by a particular web application.

This extensive database of extracts includes hundreds or even thousands of heterogeneous information in a form of knowledge entities. This heterogeneity of knowledge is done by wide spectrum of ITS standardization activities, see Table 1. It is not easy to discover information latently hidden in an extract.

### *4.1. Basic searching tools*

There are several searching methods to discover semantic entities. The simplest is the fulltext search, which provides the search for a certain standard (group of standards/extracts) by identification of the standard (its number), part of its title or part of its extract´s text or key words. This simple tool is very well known and it will be not discussed more, because it is not able to provide targeted search. The full text search does not bring consistent results for a user who looks for a particular set of standards for a particular purpose in ITS (e.g. an ITS service, an ITS application etc.).

The other possibilities for users' search are: search by user categories, search according to the originator (WG) and search by domain oriented ontology. The first two choices are familiar to all involved in ITS standardization and they are a basic tool in the project. The ontology or similar tool use has been provided in the frame of the research part of STANDARD project and it is described as a particular matter in the next chapter.

Searching by user categories results from the following considerations: USERS are divided according to their particular interest in general or detailed information into four types:

1. Non specialist (general public),
2. Expert category: manufacturer, test laboratory,
3. Expert category: contractor/supplier,
4. Investor/owner.

For the type 1 non-specialist and for the type 4 investor/owner the search is done through simple questions, coming from the fact that these users have only very general information concerning searching information. As a surplus for investor/ITS system owner some variants of thematic classification are available. More advanced searching is available for the type 2 and 3 expert because the pre-defined semantic model is applied. The "Expert" category represents a user who is already familiar with the technical content of the ITS world and market profit of data model that leads him towards the relevant extracts immediately.

### *4.2. Object oriented searching tools*

The ability to search and fuse information from heterogeneous standards or extracts can significantly contribute to the discovery of added value knowledge that is unreachable using classical searching methods. In order to provide an efficient information mining from extracts a knowledge-based model is an optimal solution. Using an ontology approach, a coherent, consistent and non-redundant knowledge model could be designed.

In information science, ontology is defined as a formal representation of knowledge as a set of individuals (instances, terms), classes (concepts), attributes, and relations between those concepts. Instance depicts the basic object and it is indivisible. In the sense of the paper an instance unit of text in an extract could be represented as a semantically uniform term. It is also possible to speak about hierarchical categorization which describes the same model as the ontology is.

In theory, an ontology is a "formal, explicit specification of a shared conceptualization", ref. [5], expressed as a shared vocabulary, which can be used to model a certain area. There are universal ontologies, as for example SUMO (Suggested Upper Merged Ontology). SUMO ontology creates high-level ontologies for different domains – finance, computers, geography, transport etc. and it is too generic to help us mining appropriate information from standards. A domain-specific ontology models describing given area of interests in more detail are used more widely.

Creating ontology is not a trivial problem generally and it is especially complicated in the field of ITS. This is the reason that ITS ontology is not being processed until now. The technique of elaboration of ITS ontology is described in ref. [6], but the praxis has shown huge complexity of this process and a simpler tool has been used in the frame of STANDARD project. The discussion with Korean delegation during ISO meeting in Prague highlighted necessity to start with it. The first step should be domain oriented ontology of cooperative systems. This supports a non-conflicting development of standards in this area, because CEN and ETSI are supposed to work out about 40 relevant standards.

The effort to categorize and to describe the people activities on similar and well formalized style has appeared through many centuries. In history a few philosophers tried to create a set of "universal knowledge about the world". From the present point of view they wanted to prepare a model of knowledge system. The first idea came from Plato and this idea was being developed by his scholar Aristotle (348 – 322 B.C) who published two books - Metaphysics and Categories. He tried to recognize basic features and segmented all activities into ten basic categories.

In the writing "Ars Magna" Ramon Llull (1232-1316) described logically combinative graphical system independent on language, culture and religion. It was made absolutely in the feature oriented system predetermining nowadays object oriented modeling. The effort to create universal description language was a part of the work of philosopher and mathematician Gottfried Wilhelm Leibnic (1646-1716). At the beginning of $17^{th}$ century German mathematicians started to use the term “ontology”, practically in the same meaning as we are using it now.

*4.3. Categorization based on Aristotle square*

The discussion within working team of STANDARD project has led to the solution that is possible to implement relatively quickly. This tool of categorization of arbitrary fact is so called Aristotle square of opposition, more generally Aristotelian logic. It is a simple diagram representing relations between four propositions which are logically opposed one another. The scheme of Aristotle square is in Fig. 1, ref. [9].

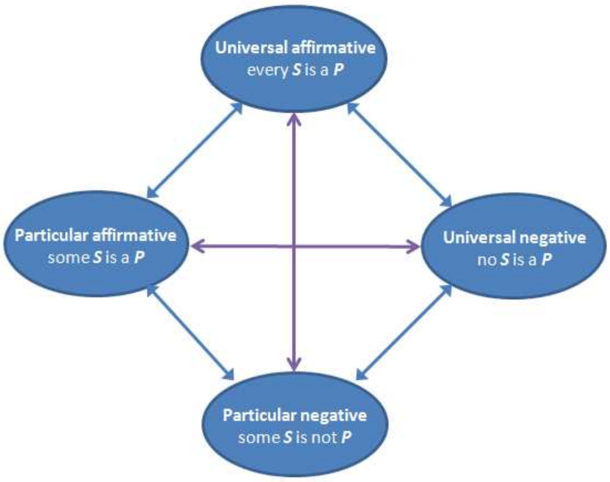


Fig. 1. Aristotle square of opposition

The description of categorical proposition, which contains two terms in general, subject and predicate, could be reduced to one of four logical forms:

1. “A” proposition is valid, if “every S is a P”, name: universal affirmative;
2. “E” proposition is valid if “no S are P”, name: universal negative;
3. “I” proposition is valid if “some S are P”, name: particular affirmative;
4. “O” proposition is valid if “some S are not P”, name: particular negative

According to this scheme the Square of opposition delimits several propositions by their logical relationship (polarity). The use of the tool prevents creators from possible repetitions or overlaying of the categories. The use of the tool has brought 48 different categories classified within three groups of 16 categories. Each of the group is described by “**higher bipolarity**” and each of their elements, “**basic bipolarities**”, is subdivided into four elements, (4 x 4 = 16). The three identified groups (higher dipolarities) are User and standard (formal categories), Transport and data (general categories) and Interface and communication (specific categories). For illustration the following table might help to fully understand.

The square of opposition elements are defined by quality (positive or negative proposition) and quantity (particular or universal proposition). The table below shows example of the matrix of the system of categories.

| Higher bipolarities | Basic bipolarities | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| **1.User and standard** | 1.1. User of a standard | non specialist | manufacturer, test laboratory | service (system) provider | investor/ ITS system owner |
| | 1.2 Implementation of a standard to ČSN | not implemented | implemented by endorsement | implemented by English original | implemented by translation |
| | 1.3 Type of a standard | standards for standards (“metastandards”) | test standards | product standards | system specification standards |
| | 1.4 Use of a standard in ITS | system design | software | hardware | system operation |

**Table 2.** Example of the matrix of categories

To evaluate the applicability of elaborated data model is an interesting activity concerning frequency of use of terms/categories in a set of standards. More than 180 standards have been checked. Table 3 illustrates the resulting facts and underlines the need of a user to be more specific when looking for an extract. A user should combine more categories to get effective number of results.

| Category | Nr. of standards | Category | Nr. of standards |
|---|---|---|---|
| service (system) provider | 140 | DSRC | 54 |
| Data element | 106 | Hardware | 42 |
| investor/ ITS system owner | 96 | EFC | 31 |
| Communication | 88 | GNSS | 22 |
| Software | 76 | Data-structured language | 14 |
| In-vehicle assistant system | 61 | Driver | 14 |

**Table 3.** Illustration of numbers of matched results for specific categories of search

The web application enables ITS extracts search by combining the categories/terms. This way of search significantly reduces the number of extracts found and leads user to the target very quickly. Another category can be added at any time during the search to make the resulting output more specific. As example – the category “Urban area” raises 68 extracts, in combination with the category “DSRC” we get 24 extracts. To plug together “Urban area”+”DSRC”+”EFC” reveals 10 extracts (EN 12253, EN 12795, …, ISO TS 25110).

Each extract also identifies the way of the standard implementation; whether the relevant standard is implemented by translation, or in English with Czech comments or it is not implemented at all. The membership of the Czech Republic in CEN brings the obligation to implement all European standards (EN); ISO standards are implemented selectively. The implemented standards can be bought via national standardization organization (UNMZ).

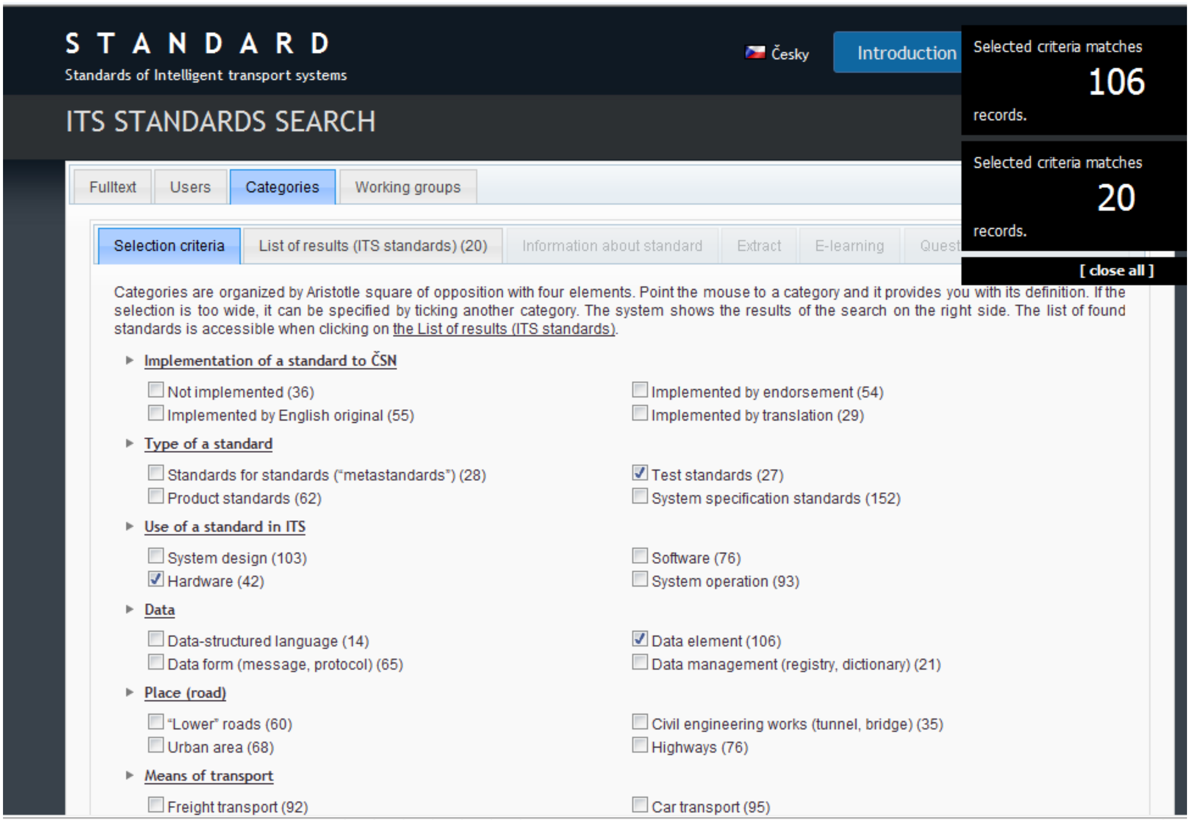


Fig. 4. Search by combining categories

## 5. CONCLUSIONS

Successful implementation of ITS standards in praxis can be the engine for economic development. There is not only a group of ITS standards but the technology of traffic, information and communication systems is covered by many more standards and so providing reference to other groups of standards is essential.

The biggest obstacle for wide use of ITS standards in praxis is their volume (about 20.000 pages) and high specialization (UML, XML, ASN.1…). Nevertheless there are other possibilities how to bring subject of standards to users and support their decisions.

The first one is the title and abstract of a standard as provided by the relevant normalization organizations (as CEN, ISO) on their Web sites. To get the precise content of a standard, and its subject, it is necessary to obtain the full Standard, although there is not enough information to decide, if this concrete standard could be beneficial.

The second one represents a very good possibility how to gain some deeper knowledge of standards, the book of Mr. Williams, ref. [7]. It provides a short annotation of each standard; standards are clustered into groups according to ITS services and the book also contains generic information about ITS.

The third possibility goes more in detail because it transfers a standard to its extract according to the defined procedure. The crucial thing is to reduce a number of pages without significant loss of content. The project STANDARD shows that this idea is viable and brings significant effect in the form of a decision support system for a wide spectrum of users.

The last and more advanced possibility is to develop a real knowledge system. This work is just being developed in the frame of ZNALSYS project, ref. [8]. The aim is to find out knowledge units automatically and linked them through metadata to a qualitatively-new knowledge, which is not explicitly done by single units.

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# Knowledge mining of ITS standards

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**Abstract**

The project STANDARD has created theory using knowledge based system for mining hidden information in hundreds of standards covering the field of Intelligent Transportation Systems. Unlike conventional web search engines, each knowledge unit is completed by semantic information and information about the context in the document. Searching mechanism produces new knowledge as a chain of information. Thereby is a process accompanied by the possibility of linking knowledge, or the formation of knowledge with the help of mathematical logic. The whole procedure, including the proposed system architecture is described in the paper.

**Keywords:** ITS, Standards, knowledge system, architecture, web searching

## 1. INTRODUCTION

As the actual development of the Road Transport and Traffic Telematics (RTTT) focuses on the mass implementation of intelligent transportation systems (ITS) also in European environment, it is necessary to create a unanimous platform based on the ITS architecture and to ensure functional integration of single subsystems and their interoperability. A way for integration telematics systems creates standardization. In the field of traffic telematics there are standards worked out by European technical commission CEN/TC278 or worldwide ranging commission ISO/TC204.

The elaboration of the standards is supported by many countries and it is relatively successful. We could identify about 200 standards at present. They are focused on the different applications, starting from WG1 "Electronic Fee Collection" (EFC) up to the WG16 "Wide Area Communications/Protocols and Interfaces" (CALM) communication standards as examples. There are two basic problems limiting successful utilization in a real praxis: the standards are very complex (in general often have hundreds of pages) and frequently written in the Universal Markup Language (UML) or eXtensible Markup Languege (XML) conventions. Even for the involved experts is it difficult to keep overview in the complex set of standards.

This is the reason why successful deployment is rather complicated. For people who are new to this area and plan to propose a new tender based on existing standards is selection of the suitable once fast impossible.

In this paper we introduce a new approach to deploy the basic information included in standards as application oriented knowledge units. The basic difference to the known full-text programs is that this system works as knowledge engine mining requested knowledge by theirs contents and formal semantic pre-processed in the standards. It also uses different form of logical function to be able to answer complex question raised by end user.

A new system for deployment ITS standards to the praxis which is end user oriented has been developed in the frame of STANDARD project. It provides more than just a known search engines. This approach is based on so-called semantic web which basically adds meaning to data, so that it can be processed by human as well as machine agents. This mechanism is described in the following part of this paper. The second part is dedicated to a real application to standards and describes practical directions how to start with implementation of the proposed method.

## 2. SEMANTIC SEARCHING ENGINE FOR ITS STANDARDS

The ordinary web (also called 2nd generation web) is often described just like a heap of websites. The amount of these websites is growing and it is more and more difficult find the relevant information. These thoughts were at the beginning of the idea of semantic web.
The web of new generation (semantic web) is a technology, which can be used by human as well as machine agents. According to ref. **Chyba! Nenalezen zdroj odkazů.**, it provides just-in-time, on-demand, and customer specific data by expressing meaning of the data.
The main improvement is in the way in which information content of a web is dealt with. Basically the information content:

- can be processed by a machine, and
- is associated with meaning.

Semantic web is enriching of the common web. The information is organized in layers, so as depicted in Fig. 1.

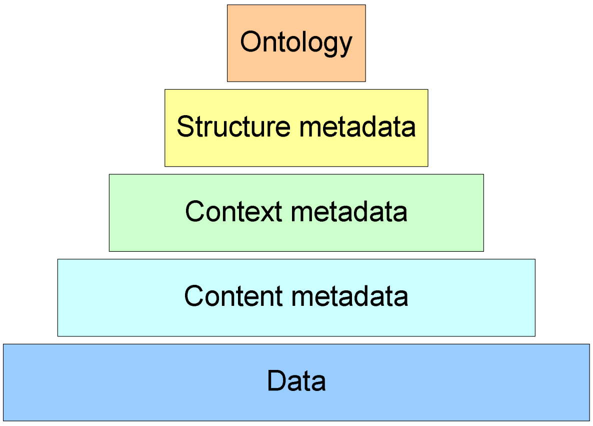


Fig. 1: Architecture of a semantic web, ref. **Chyba! Nenalezen zdroj odkazů.**

The particular layers are described in the following paragraphs: The **data layer** is the only layer presented also in the 2nd generation web. The data are in semantic web usually represented in a structured form, divided into pages or sections. Nowadays, the XML is used as a standard tool to keep the structure of documents. It means that everyone can create their own tags or sections of text on the page.

To each data unit (section, chapter, entire standard …) so called **metadata** is added. Metadata is oft described also as "data about data", and the main purpose of this step is adding semantics to a document which could be machine understable. At the basic level, metadata provides a common set of tags that can be applied to any resource. A process in which semantic information is added to the web documents is called semantic annotation, ref. **Chyba! Nenalezen zdroj odkazů.**. The standard tool for adding semantic to the document is the Resource Description Framework (RDF).

Even by adding metadata to data, there is always the danger, that two authors express the same topic in different ways (*module*, *component*, *unit*, *part*, *element*, and others). For this reason is it necessary to introduce so called **domain specific ontology**. The ontology describes formal conceptualization and corresponding dictionary for given field, rules in which the knowledge and meaning is stored etc. For example, it can say that all the mentioned terms from previous example are mapped to the term "*component*" in the standardization domain. Similarly, it unifies abbreviations (*ITS* and *Intelligent Transportation Systems*), or for example syntactic differences (*eLearning*, *e-Learning*). This part is also referred to as **content metadata**.

In order to specify the purpose and scope of the given document, so called **context metadata** are added. For example in the area of standards they can cover terms such as: *preliminary standard*, *extract*, *ISO standard*, *example*, *introduction*, *tutorial*, and others. This enables really aimed search from the point of view of the user of such system.

The content of each web site (also standard) can be split into small homogenous bits of information. Basically each study area is split into standards, each standard into chapters etc. User can select only those parts which are really relevant for given problem.

In order to keep the overview about the structure of the original material, the small pieces are equipped with **structure metadata**, for example *prev*, *next*, *isPartOf*, *hasPart*, *requires*, and others. There are rules also among these relations, such as *prev* is opposite to *next*.

To summarize, this layer adds the rules needed for reasoning with the metadata in order to enable processing by human as well as machine agents.

The metadata only is not sufficient for the needs of a semantic web. Several standards have been developed for the technologies representing the metadata, for example XML, RDF, DAML+OIL, OWL, ref. **Chyba! Nenalezen zdroj odkazů.**.

## 3. KNOWLEDGE SYSTEM FOR ITS STANDARDS

The following section will describe the proposed system for storage and search in standards, as described in introduction to this paper. Basically there are two major parts of the system. First, the knowledge has to be added to the data according given ontology of concrete domain of ITS and specific rules for managing of knowledge units could be added. This is the phase of providing the knowledge by experts. The second process is the searching in the data and knowledge by the user. It is important to mentioned that here we are providing searching engine based on the content and context meaning of the data.

The process of **providing the data and knowledge** is depicted in the Fig.2 and described in the following paragraphs.

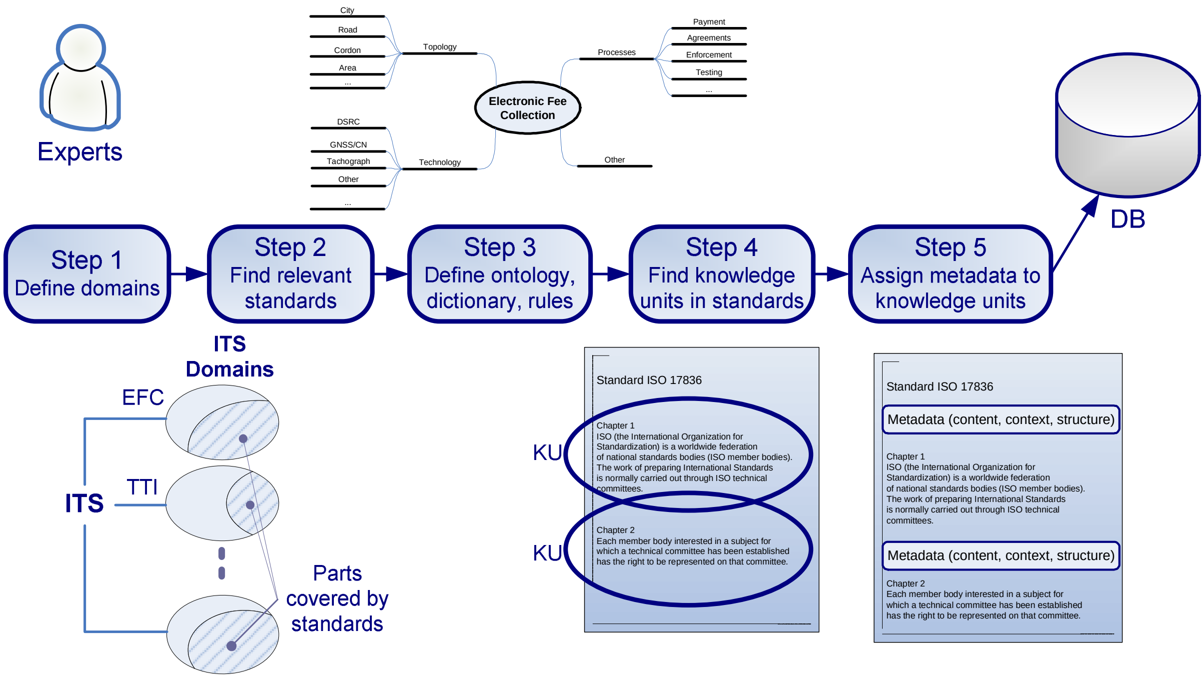


Fig. 2: Data and knowledge providing

First step is to split the area of ITS systems (or more general the area of interest) into homogenous areas. ITS systems are formally divided into a set of sub-systems or domains according to ITS European architecture titled KAREN, ref. **Chyba! Nenalezen zdroj odkazů.** or national ITS architecture of the Czech Republic, ref. **Chyba! Nenalezen zdroj odkazů.**. Coexistent, there are standards related to EFC, traffic and travel information (TTI) and others domains of ITS (Step 2). There are standards that cover the whole, but most likely just a certain, part of each domain. The task of the expert is to find the relevant standards and eventually other relevant information.

In the Step 3 is created a domain specific ontology. Basically, the complete terminology including synonyms, antonyms and other relation and rules among the terms must be defined. In order to make the ontology consistent, complete and easy to understand is to use a form of a simple mind map (knowledge map) where main branches represent knowledge segments which are terminated by knowledge units.

It means that metadata is defined by the expert and will be different for a different domains of ITS. For example, part of a knowledge map for the EFC is shown in Fig. 3. To elaborate this map is a very specific task for the expert who must have complex knowledge concerning the domain. At the same time, he must be very well informed about all relevant standards covering this domain.

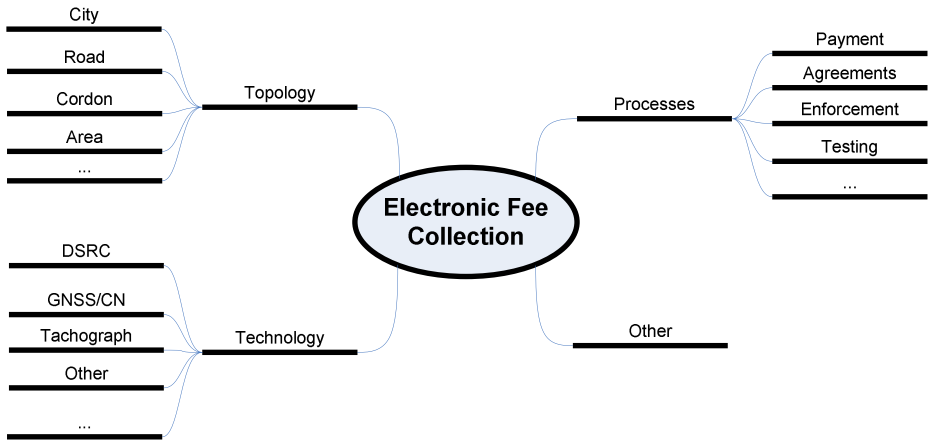


Fig. 3: Knowledge map of the EFC domain (example)

Each standard is decomposed from the point of view of its knowledge units according a basic scheme of domain presented by knowledge map. It is a step to the concretization of presentation of information of the analyzed standard. It means that generic model given by mind map determines by explicit ontology how is concrete standard analyzed. In philosophy, ontology is theory about the nature of existence, but in our meaning ontology describes a formal, shared conceptualization of a particular domain of ITS systems. Ontology's are well-suited for describing heterogeneous and distributed information which can be found in ITS standards.

The next task (Step 4) of the expert is to find small homogenous bits of information - knowledge units - in the present standards or other data and assign them the metadata (content, context and structure) according to given ontology (mind map). A knowledge unit has to have its own tags that annotate sections of text. There are two important technologies which is possible to use: eXtensible markup Language (XML) or its extension, the Resource Description Framework (RDF).

Generally, the $P^{th}$ standard is characterized by $n$ knowledge units $KU$ and $R^{th}$ standard is characterized by $m$ knowledge units

$$
\begin{aligned}
S^P &\cup \left\{ KU(j,k,l)_n^P \right\} \\
S^R &\cup \left\{ KU(j,k,l)_m^R \right\}
\end{aligned}
\qquad (1)
$$

where $j$ …content units
$k$… context units
$l$ …structure units

## 4. ARCHITECTURE OF THE KNOWLEDGE SYSTEM

The architecture of the proposed system is presented in Fig. 4. There are depicted both major processes discussed above. First is the providing and storage of the data. The expert familiar with the domain collects all relevant standards and other sources of information, creates the domain specific ontology and adds the metadata to the data, exactly as discussed above.

Here we focus on the second process, **searching in the data**. It is expected that there are users with different level of understanding of the problem, eventually even using different terminology. To improve the search results, the user is presented with the mind map so that the terminology he is using is mapped better to the ontology. Also the user can add and store personalized information, for example the present level of knowledge of given problematic, need for technical details, recently searched topics and others. The inference engine processes these requests, according to the stored rules searches the stored metadata and for the passing presents the resulting data.

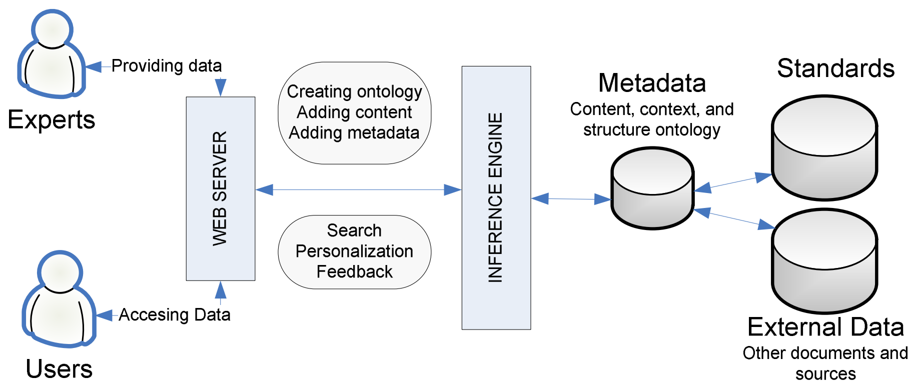


Fig. 4: Proposed architecture of a proposed knowledge engine

In principle, it is possible to form specific requests by end user and inference engine is able to chain data into new knowledge, *nKN,* using different logical functions (AND, OR …) above basic knowledge units. For example, next equation combines new knowledge, n*KN*, using AND functions. It uses two units (n; n+1) from the $P^{th}$ standard and one unit, *m*, from $R^{th}$ standard

$$nKN = KU_n^P \vee KU_{n+1}^P \vee KU_m^R \qquad (2)$$

It is a knowledge system, which based on a request and meaning of each standards provides all relevant knowledge.

## 5. CONCLUSIONS

In this paper, an innovative methodology for storing information in the complex field of standards is presented. It enables all different users with different level of knowledge and different objectives to find relevant knowledge which is latently included in dozens of ITS standards. Important is that this search is intelligent, based on the content and context meaning of the data, not just a simple word search.

The pilot application of the presented methodology is being prepared in the frame of STANDARD project for selected domain of ITS.

The application field is enormous. Nowadays, it is very complicated if not impossible to find needed information in a set of standards.  It is true especially for an occasional user, who could be for example a decision maker preparing tender for EFC.

Another advantage of the presented methodology is, that it can be further extended for example for designing of an e-Learning tool for standard. This is going to be the next step in the project.

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# Section Speed Control as Effective Tool to Improve Road Safety

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**Abstract**

The article presents results of measurement of the speed in the road tunnels which could be applied on the same way for open roads too. The Section Speed Control (SSC) method is used. This method is much more effective than point measurement which is still broadly used. The results show that the average speed decreases for 23 km.h$^{-1}$ in the Strahov tunnel in Prague after SSC had been installed. The standard deviation was also small and it means that a traffic flow is well harmonized. It decreases a volume of risk potential and enables to equip tunnel on optimal way from safety point of view.

**Keywords:** traffic parameters, speed control, traffic flow, road tunnels

## 1. INTRODUCTION

The police statistic in the Czech Republic (CR) shows that about 38% of people killed on the CR roads are due to high speed. Nevertheless, a speed is very danger especially in a road tunnel, because a number of accidents in a tunnel have fatal consequences. This was the reason that speed management strategies have been tested and fixed in the Czech standards elaborated for road tunnels. The basic ideas are presented in the national standard for design of tunnels, ref. [1] und more technical orientated description contains technical standard TP98, ref. [2]. The technical and organizational means lies from physical traffic calming measures through variable warning signs to enforcement connecting to progressive penalty system. There is a lot of research that discussed speed reductions at danger places and as a result accidents and death are reduced. Best praxis is possible to see, for example in France where installations of a few hundreds of speed radars a few years ago have decreased number of fatalities at about fifty percent.

This article describes research and field tests of speed enforcement system worked up in the frame of research project SAFETUN (SAFe TUNnels). Three years project was supported by Ministry of Transport and project team created five organizations led by ELTODO EG.

The speed control and its improvement to the reduction of accident and death in the road tunnels was one of the topics elaborated by this project. More recently tests showed quite clearly that it is impossible to measure point speed in the tunnels. The effect of this measurement on number of accidents is even negative. Some drivers, slamming on their brakes when they recognize radar of a fixed measurement point because they driving quickly through a tunnel. This maneuver is potentially very dangerous for all drivers.

## 2. SECTION SPEED CONTROL

With negative results of point measurement in mind, a very effective method known as point to point speed measurement was tested for a few years and now is mandatory applied in all tunnels in the Czech Republic with heavy traffic, see Ref. [2]. Point-to-point measurement or time-over-distance measurement is more frequently named as Section Speed Control. SSC is also used on highways especially at the positions where traffic fatalities occur very often.

There is one principal psychological advantage – whilst a radar measurement is provided in secrecy and police and radar are usually hided, the SSC plays with a driver absolutely fair-play. The section where SSC is installed is usually signed by special signs which warn that speed will be measured for example through the section of 3 kilometers. The driver getting from A to B without breaking the law will have not any problems.

The concrete principal scheme of the Section Speed Control measurement is depicted in Fig. 1. The section of a speed measurement is marked by two white lines which determine exact length of the section. An image of the vehicle entering the monitored zone is captured and the same picture is then captured at the exit point. Because the length of measured section $l_{A,B}$ is known and the time difference Δt between enter and exit of the section is recorded, the section speed is simply calculated by the formula

$$v_{av} = \frac{l_{A,B}}{\Delta t} \quad (1)$$

Specific infrared camera positioned above a traffic lane pictured a front of a car and send it to a central unit. Central unit elaborates pictures from all connected cameras. Special software (LPR – License Plate Recognition software) is able to recognize a car number. Software mainly uses special procedures to recognize contour of a letter or a number and subsequently a procedure of pattern recognition is applied. The software is often based on a principle of artificial intelligence, as neural networks or fuzzy rules are.

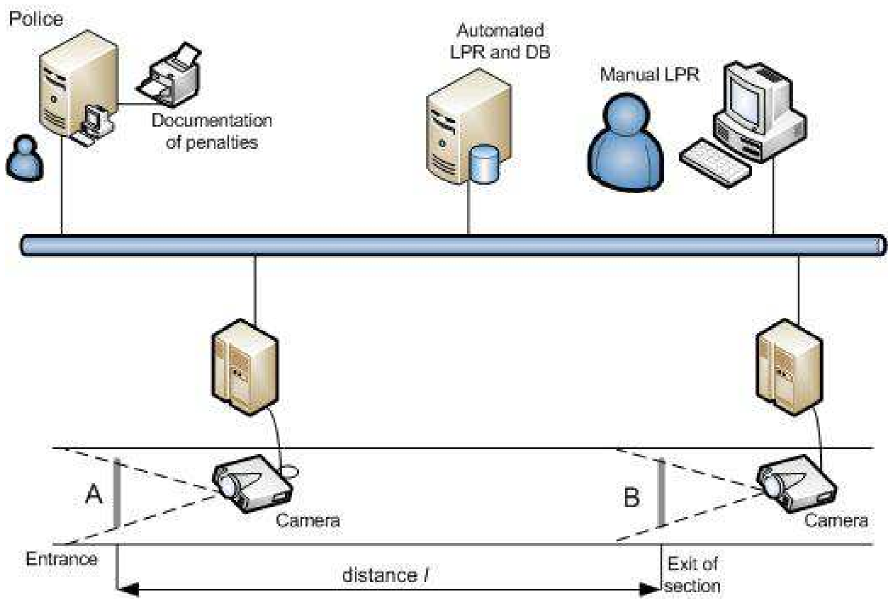


Fig. 1: Principal scheme of Section Speed Control

Fig. 2 shows practical output elaborated by software which is used also in the Czech tunnels. Couple of license plates together with time stamps determines time Δt.


Fig. 2: Photo at entry of measured section (left) and the same car at exit (right). The recognized license plate is on left hand site

## 3. REASONS WHY CONTROL SPEED IN ROAD TUNNELS

The European commission DG TREN published realistic prediction of traffic growth between year 2005 and 2020. It is forecasted that number of personal cars will be about 25-35% higher than in the year 2005. It is also known that 2% of GDP of the whole EU is vanished due to congestion at present. There are different possibilities how to help solve tremendous traffic problem. Very rapid and progressive solution is application of Intelligent Transport Systems (ITS) which could improve mobility and safety on principle about tens of percent.

Fundamental solution how to improve mobility and safety is to build new road infrastructure, as a matter of course with new tunnels. Underground traffic is sometimes known as “fourth dimension of traffic”. Building of a tunnel is quite expensive and it is necessary to optimize investments and operational costs. The separate part of a total cost is a cost of traffic, technological and safety systems. The amount of these subsystems is usually between 10 and 15% of a complete price of a whole tunnel buiding. There are mandatory subsystems as ventilation and lighting in a tunnel. These subsystems are designed by standard procedures and it is very complicated to minimize a cost of them. The final price of tunnel equipment is essentially influenced by complex safety system. The safety system has to be evaluated by a risk analysis which determines quantitative or qualitative parameters of a risk and social acceptable risk.

It is very well known that speed and number of accidents are connected very close. The trial on the M1 motorway in Great Britain showed causality crashes reduced by 36% during the year when speed enforcement system and connecting penalty system were in operation, ref. [3]. Long term research in Germany showed very similar results. The highway traffic on the A3 has been controlled by a set of variable message signs influencing a speed of cars. The number of fatalities decreased about 35% during the time when the system for speed control was in operation, ref. **Chyba! Nenalezen zdroj odkazů.**.

It is possible to conclude that risk and to him equivalent and necessary technical equipments of a tunnel are directly and close connected to an operational speed in a tunnel. By the higher speed is necessary to apply also more and more expensive safety equipments and safety systems. Lower speed improves driver behavior and his reaction to an extraordinary situation and this fact reduced significantly number of accidents in a tunnel. Speed harmonization means that the drivers accepted allowed speed, so the speed difference between the quickest and the slowest vehicle is getting lower and also standard deviation of the speed is low. This process significantly influences a safety.

Very important is also influence of harmonized traffic flow to a ventilation system. A more consistent and harmonic traffic flow will reduce car pollutions which decreases operational cost of ventilation.

## 4. PRACTICAL MEASUREMENT IN STRAHOV TUNNEL

Strahov tunnel is very important for the traffic management in the whole Prague. A closing only one line, for example due to accident influences negatively traffic in large traffic areas in a few minutes. Tunnel is 2200 m long and it connects north and south part of inner traffic circle. The two tubes with two traffic lines each, transfer about 30-40 000 cars per day. The slope of the tunnel is 3,6%. According Czech standards the tunnel belongs to the highest safety category A, which means that it is equipped by a newest technology inclusive videodetection system. It checked the whole profile of the tunnel and it is able to recognize an accident or a stopping car in a few second.

All traffic accidents in the Czech tunnels are monitored on a systematic way beginning at the year 2002. The duty to monitor and evaluate all extraordinary events (accidents, fatalities, fires) follows from the European Directive 54/2004/ES, ref. [5]. It stated that each member state has to evaluate regularly all events occurring on trans-European road network and to bring solutions how to restrict similar events in a feature to ensure higher level of safety for tunnels users.  The generic idea of this Directive is to bring the same level of safety in an arbitrary tunnel around the Europe.

From point of view of the number of accidents in the Strahov tunnel the safety situation was not too much good and it was higher than it was expected. Preliminary consideration supposed that an unsuitable speed could be reason. The following measurement made in the tunnel in the frame of SAFETUN project disclosed that about 14% of the cars have average speed in the tunnel higher at least about 20 km. The columns of histogram in the Fig. 3 show the number of cars in a one traffic line during October (17.10-30.10) and the numerical value in the same column shows the number of drivers who exceeded permitted speed at least for 20 km per hour. These driver are potential danger for another drivers because the tunnel and its traffic design are not designed for theirs speed.

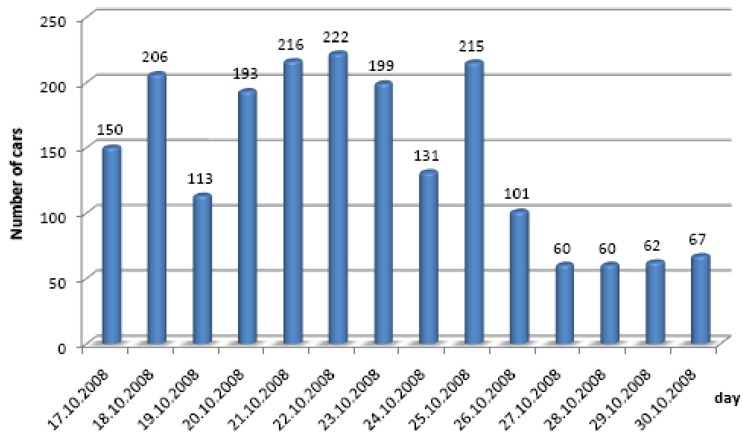


Fig. 3: The whole number of cars and number of cars exceeded speed more than for 20 km within 14 days

Even more potentially danger situation shows next Fig. 4. It is typical example of speed measurement of one line between 6 and 12 hours. Figure depicts how many cars exceed the correct speed. The total number of cars respecting speed regulation was 3200 (100%), but 900 drivers run over 20-29 km faster. More than 50 drivers drove for about 50 km faster and there were even drivers exceeded the speed about 70 kilometers. This situation is absolutely alarming from safety point of view.

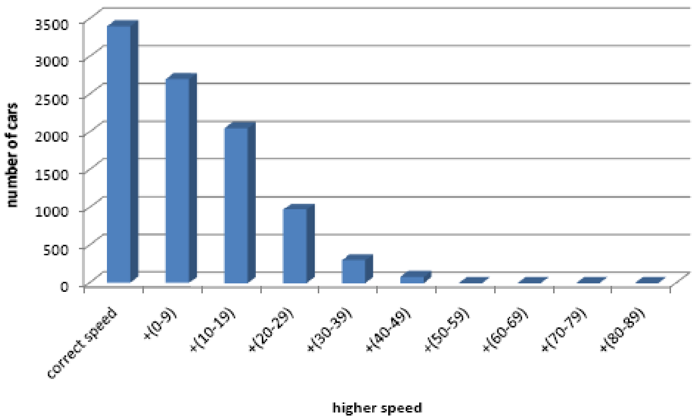


Fig. 4: Absolutely exceeding of the permitted speed

## 5. PROVISION HOW TO IMPROVE BEHAVIOR OF DRIVERS

The complex measurements and evaluation provided for Strahov tunnel showed that it is necessary to reduce a real speed in the tunnel by restrictions connected with penalties for drivers. The reason is simply. Tunnel is equipped on very progressive way. There are active LED speed limitation traffic signs around the whole profile of tunnel. The warning displays are placed on different points in the tunnel, the special warning is also before the tunnel, nevertheless only a lot of drivers do not respect it.

There are two basic possibilities how to measure speed. Very traditional method is point measurement mostly provided by different type of radars. The experiment to install and to measure in the tunnel, respectively 50 m beyond portal, was absolutely failed. The drivers knowing the position of radar braked very rapidly before entering its position and this spot was very dangerous from safety point of view. This was the reason that section speed control has been applied in the frame of OPTUN project.

The field test has been distributed through thee years to get a lot of statistical numbers and to be sure that SSC could really influence a driver behavior. The measurement of speed in the tunnel is provided by microwave sensors mounted under roof of the tunnel. There was not any speed measurement during the year one of pilot test. The example of evaluated data is in the Tab.1. The average speed is 76,6 km.h$^{-1}$ but potentially very dangerous is a high number of standard deviation. For example at October 2$^{nd}$ is *s=17,31* km.h$^{-1}$ and it means that some drivers drove quite slowly and others drove very fast. It is very dangerous and probability of accident is quite high.

| **datum** | 29.9 | 30.9 | 1.10 | 2.10 | 3.10 | 4.10 | 5.10 |
|---|---|---|---|---|---|---|---|
| $\bar{v}$ [km .h$^{-1}$] | 81,84 | 81,91 | 77,81 | 79,00 | 79,13 | 78,08 | 77,72 |
| **s** [km .h$^{-1}$] | 8,34 | 13,52 | 13,10 | 17,31 | 11,16 | 5,89 | 7,94 |

Tab. 1: Average speed and its standard deviation-without speed measurement, without SSC control: reference year

The second phase of experiment supposed to install Section speed control without any warning to drivers. SSC was really installed in August and evaluation of the first results was surprising for all. The speed was at once lower for about 23 km.h$^{-1}$. The reason could be only one. The drivers saw something extraordinary in the tunnel –new cameras and the lines on the road and they deduced that it should be something as a speed control. It should be that different papers describing foreign experiences were published in the same time and the drivers drove often in western countries of Europe where these systems were in operation. But it was really surprising because the average speed was newly about 53,5 km.h$^{-1}$ and standard deviation significantly decreases too.

| **datum** | 27.9 | 28.9 | 29.9 | 30.9 | 1.10 | 2.10 | 3.10 |
|---|---|---|---|---|---|---|---|
| $\bar{v}$ [km .h$^{-1}$] | 53,15 | 53,22 | 52,39 | 52,78 | 53,74 | 54,43 | 53,23 |
| **s** [km .h$^{-1}$] | 5,15 | 5,58 | 5,60 | 5,35 | 4,50 | 2,78 | 4,86 |

Tab. 2: Average speed and its standard deviation- speed measurement installation but out of operation, without warning signs

Installation of warning signs informing drivers that a speed is measured had started third phase of field tests. These signs are very important. They informed driver in advance that the speed will be measured. It is important also from psychological point of view because it forms fair play relation to the drivers and they usually respect it.


Fig. 5: The warning sign “Measurement of the speed” before the portal of Strahov tunnel

The table 3 presents the results after installation of traffic warning signs which were placed in the sufficient distance before the SSC. It is possible see that there is not significant influence coming from installation of warning signs. The average speed is slightly above allowed speed which is in the city 50 km.h$^{-1}$ and standard deviation is also very low. It shows that a traffic flow is quite well harmonized as is very important from safety reasons.

| **datum** | 25.10 | 26.10 | 27.10 | 28.10 | 29.10 | 30.10 | 31.10 |
|---|---|---|---|---|---|---|---|
| $\bar{v}$ [km .h$^{-1}$] | 53,38 | 53,72 | 53,21 | 53,58 | 53,79 | 54,24 | 53,90 |
| **s** [km .h$^{-1}$] | 5,17 | 4,91 | 5,71 | 5,20 | 3,85 | 2,35 | 3,29 |

Tab. 3: Average speed and its standard deviation- speed measurement in operation and warning signs are installed

The summary and graphical presentation is pictured in the next fiure:

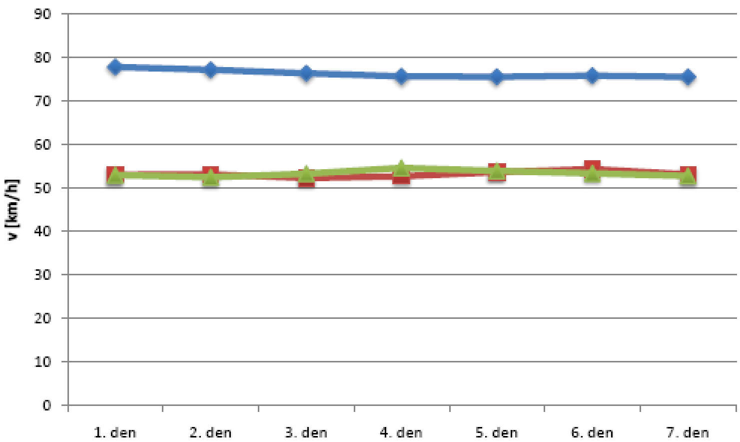


Fig. 6: Three phases of field tests of SSC in the Strahov tunnel (without SSC – blue curve above; SSC in operation with/without warning signs – red/green curve); measured for seven days (1.day … 7. day)

## 6. CONCLUSIONS AND NEXT WORK

Optimization of tunnels equipments is crucial question for safety of users from one side and for cost of investment and operation for a state or a municipality from the other side. It is very dangerous for drivers if is tunnel designed not sufficiently. There is very expensive operation and service when a tunnel is over-equiped. To find a proper balance helps using of risk analysis. The original method based on probabilistic trees and expert system CAPITA had been developed in the frame of OPTUN project. All analysis showed the huge importance of speed of cars in a tunnel to a resulting risk. The concrete measurement in the longest tunnel in Prague confirmed preliminary consideration that drivers do not respect prescribed speed which is in the city 50 $km.h^{-1}$ although there is a set of traffic signs.

The research project OPTUN had demonstrated that installation of Section speed control is extremely efficient and it influences behavior of drivers on very significant way. Decreasing of speed and mainly harmonization of traffic flow through tunnel improve results of risk analysis and tunnel could be designed on optimal way.

The positive results of this long term experiments have been worked up into new version of the Czech standard TP98 "Tunnel equipments and systems" on the following way. All tunnels corresponding to the highest safety category* (it is category A) shall be equipped by SSC.

New research project supported by Ministry of transport SAFETUN continues in a developing of the risk analysis method CAPITA. The accent is on a deploying of the method into broad praxis and to optimize the equipment of tunnels.

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* The safety categories A, B, C, C-H, D and D-H are defined in the standard TP98

# The Influence of Interval Length and Operation Punctuality on the Vehicles Occupancy

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**Abstract**

The content of this document is a partial result of author's research conducted in the PhD thesis[1]. In the text are described the relationships among the particular transport parameters and their impact on the effectiveness of line management of public transport.

**Keywords:** public transport, line management, interval length, operation punctuality, vehicles occupancy

## 1. INTRODUCTION

The interval length together with the operation punctuality and capacity of vehicle are involved in the total transport capacity of the line. It is not only the product of the values for the number of connections per hour and the capacity of vehicles. Operation punctuality plays an important role too. When designing the line management and setting the line transport parameters it is necessary to consider transport punctuality which is possible to be operated by the carrier. The shorter the interval is the more punctual the operation has to be.

## 2. THE INFLUENCE OF PARTICULAR PARAMETERS

### *2.1. General explanation*

The interval length has the influence on the reduction and induction of transport demand. The shorter the interval the higher the level of transport demand potential. The interval length influences the total transport time from start to the destination. The shorter is the interval the shorter is the total transport time. On the basis of these facts there can be deduced that the shorter intervals will be on the particular lines, the better. But this deduction has the limitation in the value of the minimum effective interval. The minimum effective interval is the shortest possible value which still does not reduce the real line transport capacity. After reaching the minimum effective interval each further shorter interval value reduces the real line capacity and the so called interval paradox arises. This phenomenon relates to the particular line connections transport punctuality and to the fact that during the short intervals in a matter of minute period is the number of passengers coming to the stops relatively steady. Steady demand distribution requires the regular intervals among the particular connections. The shorter the line interval is the more is the transport punctuality influenced. The less operation regularity the line will show the greater variance of demand for particular connections along the route will be. Assuming uniform distribution of demand and regular interval in the range of transport period, the uniform occupation of vehicles on the line influences the ratio between interval length and transport punctuality. For example when planning the line interval for 10 minutes then the real interval among the particular line connections will be in the range of 7 – 13 minutes thanks to the variance of operation punctuality (in the case of 3 minutes variance of operation punctuality). In the case of a thirteen-minute interval there will be 30 % more passengers waiting at the stops. In the case of half interval that is 5 minutes, the real interval will be in the range of 2 – 8 minutes. In the case of eight-minute interval on stops there will be already 60 % more passengers waiting! These demand variances have to be absorbed by capacity reserve of vehicles, so that maximum effective transport capacity would not be overcome. Therefore can be assumed that the constant operation punctuality together with interval shortening reduces the usable average vehicles occupancy. The size of necessary vehicles capacity reserve (NVC) is possible to explain as the ratio between the value of operation punctuality (OP) and the line interval (LI).

$$NVC = \frac{OP}{LI} \tag{1}$$

Interval paradox will occur when the shortening of interval causes such an increase of the required capacity reserve of vehicle that even increasing the number of connections will reduce the real line capacity. This implies that the minimum required transport capacity offer ($CO_{mr}$) is the product of transport demand (TD) and necessary vehicle capacity reserve (NVC) for the case of demand variation due to variance of operation punctuality.

$$CO_{mr} = TD \times NVC \tag{2}$$

From these facts the overall conclusion can be deduced which is that the introduction of very short intervals for particular lines does not always have to be effective because it does not necessarily contribute to their capacity.

*2.2. An example of specific values*

The following part describes an example of decreasing the possibility of vehicle capacity use for the most widely used vehicle in Prague's public transport, the twelve-meter bus with the capacity of 60 passengers assuming punctuality of operation in the range of 3 minutes, which is the Prague's standard[2]. The calculation of transportation line capacity is based on these partial relations:

$$VRI = LIT \pm OP \tag{3}$$

VRI is the variance of real interval values in traffic which is influenced by the operation punctuality, LIT is the regular line interval planned by timetable and OP is the value of operation punctuality. The result of this equation can be the minimum or the maximum real interval value.

$$P_{MRI} = \frac{C_{veh} \times MRI}{LIT} \tag{4}$$

$P_{MRI}$ is the number of passengers in the case of minimum real interval value, $C_{veh}$ is the capacity of vehicle, MRI is the minimum real interval value and LIT is the regular line interval planned by timetable. Of course the number of passengers in the case of maximum real interval value must not be higher than the capacity of the vehicle, which is 60 passengers in our example bus.

$$NVC = C_{veh} - P_{MRI} \tag{5}$$

The necessary capacity reserve (NVC) for the phenomenon of transport demand variance has a big influence on the total line capacity. The total line capacity (TLC) is a product of the values of number of connections per hour ($NC_h$) and number of passengers on the vehicle in the case of minimum real interval value ($P_{MRI}$).

$$TLC = NC_h \times P_{MRI} \tag{6}$$

In the following table 1 there are shown the particular values of the necessary capacity reserve and their influence on the total line capacity.

Table 1. The particular values of the necessary capacity reserve and their influence for the total line capacity

| LIT [min.] | VRI [min.] | $P_{MRI}$ [pass.] | $C_{veh}$ [pass.] | NVC [pass.] | $NC_h$ | TLC [pass./hour] | Total number of places [places/hour] |
|---|---|---|---|---|---|---|---|
| 60 | 57 – 63 | 57 | 60 | 3 | 1 | 57 | 60 |
| 30 | 27 – 33 | 54 | 60 | 6 | 2 | 108 | 120 |
| 20 | 17 – 23 | 51 | 60 | 9 | 3 | 153 | 180 |
| 15 | 12 – 18 | 48 | 60 | 12 | 4 | 192 | 240 |
| 12 | 9 – 15 | 45 | 60 | 15 | 5 | 225 | 300 |
| 10 | 7 – 13 | 42 | 60 | 18 | 6 | 252 | 360 |
| 6 | 3 – 9 | 30 | 60 | 30 | 10 | 300 | 600 |
| 5 | 2 – 8 | 24 | 60 | 36 | 12 | 288 | 720 |
| 4 | 1 – 7 | 15 | 60 | 45 | 15 | 225 | 900 |
| 3 | 0 – 6 | 0 | 60 | 60 | 20 | 0 | 1200 |
| 2 | 0 – 6 | 0 | 60 | $>C_{veh}$ | 30 | 0 | 1800 |
| 1 | 0 - 6 | 0 | 60 | $>C_{veh}$ | 60 | 0 | 3600 |

The table implies that in the case of five-minute and four-minute interval the total line capacity already decreases. If the interval is the same or shorter than the operation punctuality value, it is not possible to keep a sufficient capacity reserve on the vehicle and so the required transport service.

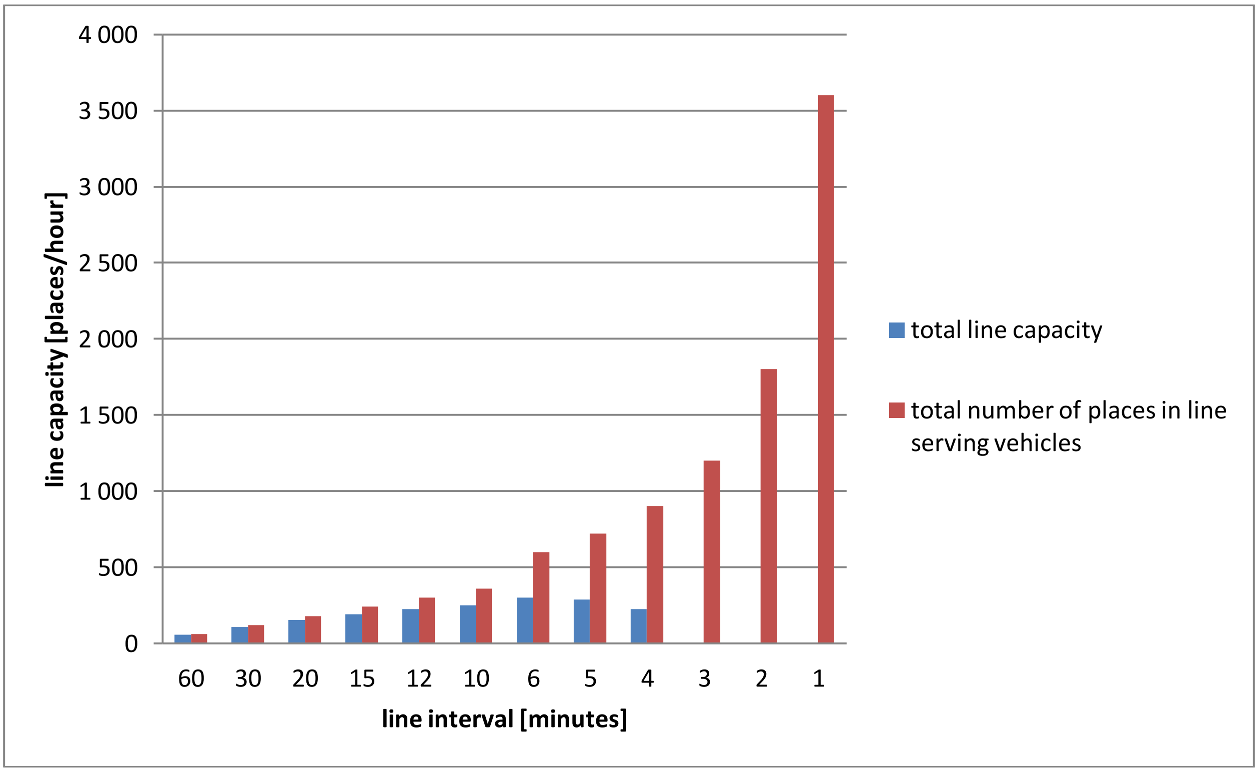


Fig. 1. The dependence of the line capacity on the line interval for twelve-meter bus and three-minute dispersion of operation punctuality

### *2.3. The practical example from Prague – the tramline No. 22*

The tramline No. 22 is one of the most important lines in Prague. In rush hours it is operated at four-minute frequency[3]. According to the timetable in a selected stop particular connections should depart in minutes of 00, 04, 08, 12, 16, 20 etc. Due to the three-minute operation punctuality under standard conditions[2] can particular connections really depart for example in minutes of 00, 04, 10, 12, 19, 20, etc. Intervals may therefore be in the range of 1 – 7 minutes. In the case of a two-minute delay, that is half of the interval (the example of connections in minutes 04 and 10) 50 % more passengers are waiting at particular stops. In the case of a three-minute delay (the example of connections in minutes 12 and 19), even 75 % more passengers are waiting. This fact must either be compensated by high capacity reserve in vehicles which means significantly uneconomical operation, or exceeding the vehicle capacity occurs. Exceeding the vehicle capacity leads not only to decreasing of passengers comfort. Due to this phenomenon there also occurs further delay reaching the trams in convoy and unsteady usage of vehicles capacity arises. The total use of overall transport capacity of the line No. 22 can therefore be lower than the total use of the overall transport capacity of the other lines with longer standard eight-minute frequency and the same transport punctuality because of not so great transport demand variation.


Fig. 2. Prague's tramline No. 22 is operated in peak hours in four-minute interval but the operation punctuality is in the three-minute range which is the value of three quarters of interval. Due to this fact the variance of demand for particular connections is very high and their occupancy is very uneven.

In Prague this effect could have been already observed for example in the years 2002 – 2003 on tramlines XA and XB, operated in four-minute interval which were the substitute lines instead of flooded underground. It was the time of maximum public transport priority. The tram convoy could not be only the result of congestions in the city and not even the product of delay. In contemporary situation in Prague the convoy can be the planned state.

It shows the necessity of analyzing the phenomena that existed in traffic in the past and using mathematical relations when designing the public transport lines and determining their operation parameters. The solution for the contemporary situation on the tramline No. 22 is either the reorganization of the line routes and decreasing the frequency of the line No. 22 or managing such measures which lead to the increase of operation punctuality and thus decreasing the transport demand variation. In the case of reorganization of line management it is appropriate to use the method of transport demand control[4]. By this method it is possible to partially regulate the demand distribution in the particular sections of the network and thus create conditions for the appropriate frequency distribution of particular lines.

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# Qualitative analysis of accidents on the railways in the Czech Republic in the years 2006 - 2012

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**Abstract**

This paper presents qualitative analysis of accidents on the railways in the Czech Republic in the years 2006 – 2012 and provides overviews of the most serious accidents according to the number of fatalities and injuries and the material damage. The causes of accidents are classified into various subsystems of railway system and they are analyzed.

**Keywords:** railway, accident, fatality, injury, material damage

## 1. Introduction

This qualitative analysis of accidents on the railways in the years 2006 – 2012 was created as a basis for dissertation on improving the safety of railway system, especially railway infrastructure. The aim of the analysis was to determine the most common causes of accidents, to compare their consequences and partly to show the possible precautions to reduce accidents.

## 2. Data sources

Information about accidents on the railways can be gained from various sources – media, monographs, or investigation reports. Media provides information in real time, but for the purpose of qualitative analysis this information is too brief. Newspaper article is usually limited to description of events and their consequences, without any mentioning of the cause of the event or more details. Contrary to the media the monographs provide a more comprehensive view on the accident, but currently there is no summarizing monograph about accident rate in the Czech Republic.

For qualitative analysis, it is the best source to use the accident and incident investigation reports published by the Rail Safety Inspection. The main reason is the complexity of the report, which describes occurrence, its background, external circumstances, event chain, analysis and conclusions. The Rail Safety Inspection investigates only serious accidents and accidents or incidents which, under slightly different conditions, might have led to serious accident or are relevant to the completed system.

## 3. Database of accidents in railway transport

The database of accidents for the years 2006 – 2012 was formed on the basis of investigation reports published by the Rail Safety Inspection on its website.[1] The database was created using MS Excel and every accident was described by the following information: date, time, location, grade of accident, type of railway, fatalities, injuries, material damage, traction unit, signalling and command system, causes and their subsystem and notes.

The grade of accident is defined by legal standards of European Union. There are three grades: serious accident, accident and incident. Serious accident means any train collision or derailment of trains, resulting in the death of at least one person or serious injuries to five or more persons or extensive damage to rolling stock, the infrastructure or the environment. Accident means an unwanted or unintended sudden event or a specific chain of such events which have harmful consequences; accidents are divided into following categories: collisions, derailments, level-crossing accidents, accidents to persons caused by rolling stock in motion, fires and others. Incident means any occurrence, other than accident or serious accident, associated with the operation of trains and affecting the safety of operation. [2]

Type of railway is divided into three ones – nation-wide railway, regional railway and sidings. Nation-wide rail system serves international and national public rail transport and is marked as such. Regional rail system has regional or local significance and serves public rail transport. Sidings serve needs of its own operators or other businesses.

The number of aggrieved means fatalities and injuries together. Person who died as a result of injury in thirty days after the accident is covered to the number of fatalities.

The causes of the accident stem either from the railway system or from its environment. For the purpose of subsequent risk analysis (not covered in this paper), the railway system is divided into several subsystems, which generate similar errors leading to accidents – railway infrastructure, rolling stock, control-command and signalling, human factor, standards and rules.

## 4. Analysis of data from the database of accidents

There were analyzed 114 accidents in the years 2006 – 2012, on the basis of investigation reports – 34 serious accidents, 72 accidents and 8 incidents. The most common cause of serious accidents was human factor error (58%), followed by infrastructure failures (18%) and rolling stock faults (15%). Causes from other subsystems occurred in negligible quantity.

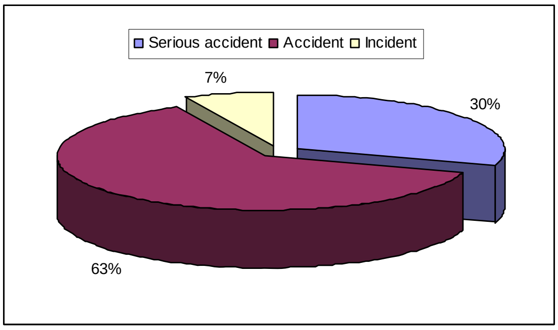


Fig. 1. Grades of accidents

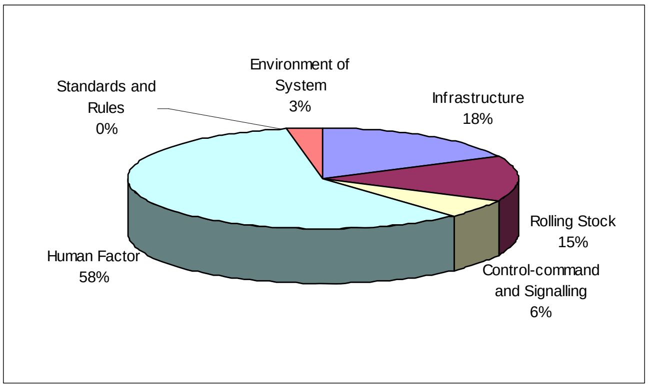


Fig. 2. Causes of serious accidents

Inclusion of accidents into grade such as serious accident, accident or incident does not reflect the seriousness of consequences. For instance, into the grade of serious accident, there can be included only accident types train collision or derailment of trains. Any level-crossing accident with much more serious consequences is automatically included into the grade - accident. Therefore, twenty accidents with the most severe consequences were selected for the following analysis. The first table presents twenty accidents with the highest number of fatalities and injuries and the second one twenty accidents with the highest material damage.

Table 1. Twenty accidents with the highest number of fatalities and injuries

| **Date** | **Location** | **Grade** | **Occurence type** | **Consequences** | **Subsystem of cause** |
|---|---|---|---|---|---|
| 8th August 2008 | Studénka | serious accident | train collision with an obstacle | 7 fatalities, 88 injuries | infrastructure |
| 16th February 2009 | TS [1] Vratimov-Paskov | serious accident | trains collision | no fatality 57 injuries | human factor |
| 20th June 2007 | Černý Kříž | serious accident | trains collision | no fatality 24 injuries | human factor |
| 25th May 2012 | Třešť | accident | level crossing accident | 1 fatality 19 injuries | human factor |
| 2nd February 2011 | TS Číčenice-Vodňany | serious accident | trains collision | 1 fatality 15 injuries | human factor |
| 20th December 2010 | Kamenné Žehrovice | serious accident | trains collision | no fatality 14 injuries | human factor |
| 1st September 2007 | TS Bavorov-Vodňany | serious accident | trains collision | no fatality 13 injuries | human factor |
| 17th December 2008 | TS Branka u Opavy-Moravice | accident | level crossing accident | no fatality 13 injuries | infrastructure |
| 10th November 2008 | TS Hlinsko v Čechách-Ždírec nad Dobravou | serious accident | trains collision | no fatality 11 injuries | human factor |
| 1st September 2009 | TS Horní Lipová-Ostružná | serious accident | trains collision | no fatality 11 injuries | human factor |
| 28th June 2010 | Ústí nad Labem hl.n. | serious accident | train derailment | 1 fatality 9 injuries | human factor |
| 29th January 2012 | Kaštice | accident | level crossing accident | no fatality 10 injuries | environment of system |
| 20th February 2006 | Kropáčova Vrutice | serious accident | trains collision | no fatality 9 injuries | human factor |
| 11th August 2006 | TS Šlapanice-Blažovice | accident | level crossing accident | 1 fatality 8 injuries | environment of system |
| 20th January 2012 | Březnice | accident | level crossing accident | 1 fatality 7 injuries | environment of system |
| 14th July 2007 | Čerčany | serious accident | trains collision | 1 fatality 6 injuries | human factor |
| 22nd October 2011 | Odra | serious accident | train derailment | no fatality 7 injuries | human factor |
| 5th March 2012 | TS Kobylí na Moravě-Velké Pavlovice | accident | level crossing accident | no fatality 6 injuries | environment of system |
| 21st July 2011 | TS Hodkovice nad Mohelkou-Rychnov u Jablonce nad Nisou | serious accident | train collision with an obstacle | no fatality 6 injuries | infrastructure |
| 19th May 2008 | Moravany | serious accident | trains collision | 1 fatality 4 injuries | Control-command and signalling |

[1] TS = train section

Table 2. Twenty accidents with the highest material damage

| Date | Location | Grade | Occurence type | Material damage (CZK) | Subsystem of cause |
|---|---|---|---|---|---|
| 28th June 2010 | Ústí nad Labem hl.n. | serious accident | train derailment | 70 914 339 | human factor |
| 8th August 2008 | Studénka | serious accident | train collision with an obstacle | 62 458 840 | infrastructure |
| 3rd January 2006 | Brodek u Přerova | serious accident | train derailment | 33 688 904 | rolling stock |
| 9th March 2010 | TS Prackovice nad Labem-Lovosice | serious accident | train derailment | 32 060 418 | rolling stock |
| 19th March 2007 | TS Vraňany-Dolní Beřkovice | accident | level crossing accident | 27 598 393 | environment of system |
| 23rd August 2011 | Praha-Libeň | serious accident | trains collision | 27 405 556 | human factor |
| 1st December 2007 | TS Kyje-Praha-Běchovice | serious accident | train derailment | 25 330 271 | infrastructure |
| 8th December 2010 | TS Přerov-Prosenice | serious accident | train derailment | 20 150 000 | rolling stock |
| 15th September 2009 | Omlenice | accident | level crossing accident | 16 159 394 | environment of system |
| 14th May 2008 | TS Neratovice-Úžice | accident | level crossing accident | 14 115 844 | environment of system |
| 16th February 2009 | TS Vratimov-Paskov | serious accident | trains collision | 14 073 507 | human factor |
| 17th October 2006 | Děčín východ | serious accident | train derailment | 13 376 617 | infrastructure |
| 19th May 2008 | Moravany | serious accident | trains collision | 12 643 092 | control-command and signalling |
| 29th January 2012 | Kaštice | accident | level crossing accident | 12 615 533 | environment of system |
| 13th September 2008 | TS Moravičany-Mohelnice | serious accident | trains collision | 11 643 496 | human factor |
| 17th October 2011 | TS Ostrava-Třebovice-Děhylov | accident | train collision with an obstacle | 11 607 808 | rolling stock |
| 22nd October 2011 | Odra | serious accident | train derailment | 10 649 688 | human factor |
| 8th June 2011 | TS Napajedla-Huštěnovice | accident | level crossing accident | 9 755 000 | environment of system |
| 22nd June 2008 | TS Zábřeh na Moravě-Lukavice na Moravě | serious accident | train derailment | 9 449 727 | infrastructure |
| 28th November 2011 | Kolín | serious accident | train derailment | 8 950 000 | control-command and signalling |

The cause of accidents with large number of fatalities and injuries is usually human error. There was found in the analysis of the accidents that the human factor mistook especially in non-standard situations. The engine drivers were influenced by time pressure caused by delays, bad organization of track possessions or they did unusual activities such as shunting operations. Serious accidents happened in operating posts D3. In these stations there is no dispatcher here, so the whole track (with all stations) is remotely controlled by one dispatcher from other place. Because of this, majority of responsibility for organizing rail traffic was transferred to the engine drivers. Any exception in the standard mode, such as special permission for departure from station only on certain days of the week or on certain trains, can be fatal. The two mentioned exceptions were the cause of the accidents on the track Číčenice-Volary. Engine drivers´ and dispatchers´ actual health and mental condition also influenced the accidents caused by human factor. For example the derailment of a passenger train in Ústí nad Labem was the result of sudden health indisposition of engine driver. Also in the accident, where was allowed arrival of train to occupied track in station Čerčany, the dispatcher's mental condition was not suitable for the service.

The human errors (especially caused by engine drivers and workers organizing rail traffic) can be reduced by elimination of exceptions from the established rules and by the special training of non-standard situations, so that solution to this situation became easier for workers. Another option could be to install safety equipment on rolling stock, where it can stop the moving of a train if the engine driver didn't respect the signal.

The point of view from infrastructure, the most common causes of accidents with large material damage are rail brake, switch tongue break, buckling of the track, respectively damage of subgrade or of track structure. These defects can often not be diagnosed by conventional methods such as visual inspection of the track condition and a fault can hardly be avoided. On the contrary, many defects are resulted from the lack of maintenance or systematic neglect of tracks, either because of lack of funding or incompetence of workers.

Another big problem is grown vegetation along the track and especially trees, which fall on the track, may cause serious accidents for the light construction vehicles, which are frequently used on regional lines. The level-crossings are dangerous for road users because of insufficient field of view or bad design, such as location of the level-crossing nearby to the road crossing. There are possibilities for reducing of the number of accidents related to infrastructure by improving track maintenance, increasing communication among infrastructure managers and railway undertakings and removal of hazardous elements of the rail subsystem.

The accidents caused by defects of the rolling stock are usually caused by bad maintenance of vehicles and the effort of the management of railway undertakings to reduce costs of preventive maintenance and repair, which leads to a decline in rail safety.

Control-command and signalling subsystem has become a cause of accidents mentioned in the database only twice. In the first case the system error of the device caused the train collision in Moravany and in the second case the accident was caused by bad connection of the new system in Kolin station. Subsystem control-command and signalling caused the accident rarely, but with large consequences.

The level-crossing accidents and accidents that occurred during the track repairs are caused by elements of the system environment. The level-crossing accidents can be prevented primarily by education among road users and reconstructions of level-crossings. Accidents, associated with the repair and construction of the track, were created by miscommunication between construction companies and infrastructure managers or there were not established specific traffic conditions during construction activities.

## 5. Conclusions

The accidents with a large number of fatalities and injuries are caused by human factor (workers of infrastructure managers and railway undertakings) and also by human error from the environment of railway system (road users). This amount is up to 80% of all causes of accidents. On the contrary, causes of accidents with large material damage are almost equally stratified among various railway subsystems and railway environment, expect subsystem standards and rules. The purpose of the paper was to analyze the main reasons of serious accidents and shown the basic possibilities of improvement. The detailed measures to increase safety are subject of further work.

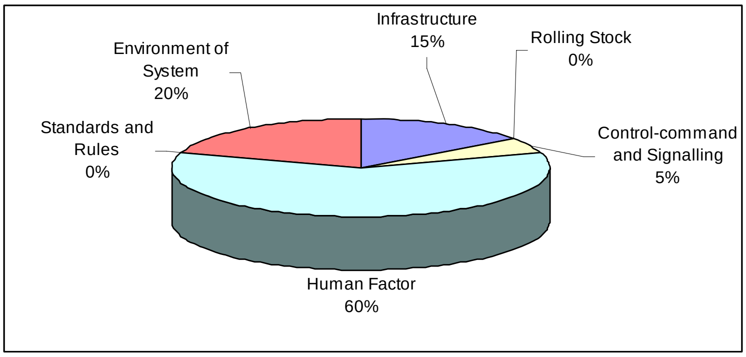


Fig. 3. Causes of accident with highest number of fatalities and injuries

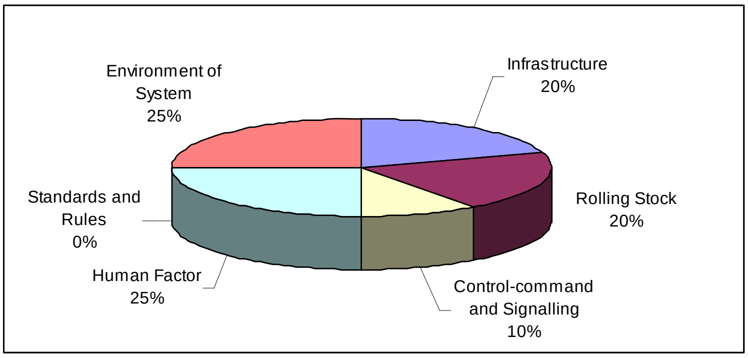


Fig. 4. Causes of accident with highest material damage

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[2] DIRECTIVE 2004/49/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 29 April 2004 on safety on the Community's railways and amending Council Directive 95/18/EC on the licensing of railway undertakings and Directive 2001/14/EC on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification

# Tool for Analysis of Extraordinary States in Complex Traffic Networks

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**Abstract**

Urban areas are equipped with hundreds of traffic sensors. The basic problem is to transform the tremendous time series of measured traffic parameters to the simple parameter which estimates the quality of services over this network. This happens mostly based on the judgement of dispatchers sitting in control centers. The paper presents a method for evaluating comprehensive transport network based on the methods of artificial intelligence. The collected data are transformed into 3D state space where real-time traffic data analysis is being running instead to provide analysis of time series over a set of measured detectors. State space transform is provided by Principal Component Analysis application. It enables significant data reduction and their representation in new dimension. New data are represented by principal (main) components. These outputs usually have lower volume of data and reduced dimensionality, in comparison with the original input data. In further research step is to be introduced some classification method for recognition of extraordinary traffic situation.

**Keywords:** traffic, quality, reduction, state, space

## 1. INTRODUCTION

An intelligent traffic system holds a significant role in field of traffic. The quality of traffic management significantly affects our everyday lives. Many densely populated areas are equipped with sufficient amount of strategic and intersections traffic detectors. The system manages traffic streams by traffic lights, variable message signs and by other devices. An absenting part inside of the current telematic systems is inadequate system for evaluation of collected traffic data for global traffic model covering the managed network. Operators in traffic surveillance centers are evaluating situation based on visual survey by CCTV or using simple mechanism for searching locations with too low speed. This paper describes a mathematically supported algorithm of traffic quality estimation, based on combination of two methods:

- Current state of traffic situation based on detectors outputs in discrete time slices is conceived as point in a State Space (SS) which shall represent quality of traffic, known as Level of Service (LOS);
- Transformation of each data set in the discrete time into 3D space is carried by Principal Component Analysis (PCA)

Output of the above described system composed of PCA and SS approaches is a state vector in new dimension. Quality of traffic can be classified into categories according to position of this vector by couple of methods. One of them uses artificial intelligence methods based on searching relationship and similarities between on-line collected data and historical models of traffic data. A plenty of foreign literature confirms, that by closer evaluation of

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historical data samples in state space we can better understand characteristics of present traffic states. On this base it is possible to provide more effective traffic management system and supply existing system by effective incident detection identification system, queue prediction, etc. Trajectory of LOS viewed in a state space gives also very good visual overview about development of quality of traffic. The extraordinary event is recognizable directly, feature development of LOS is also possible to see in a simple way. State space is generally considered as a new modern approach and it is not used more widely for traffic analysis.

## 2. Traffic data collection

First of all, for considered traffic quality estimation method it is necessary to specify data source. Traffic situation can be examined by many approaches from traditional traffic data, floating car data, videodetection or other surveillance method. In our research we work with traditional traffic data collected by traffic detectors. Traffic detectors are determined for traffic data collection, in technical terminology (Přibyl, 2005) called strategic detectors and typically provide standard traffic data such as vehicle volume (vehicle count per 3 min), average or unit speed (km/h) and detector loop occupancy (percentage unit) in defined aggregation interval, e.g. each 3 or 5 minutes. For relevant traffic state description it is crucial to use more than one traffic data type. Detectors should be placed on "strategically interesting positions", which means on measuring sites with stable conditions.

In our research we use real data from seven measuring profiles based on induction loop detectors installed under concrete surface traffic deck regularly placed in a consecutive cascade on a 10 km highway section near Prague. Traffic detectors cover all traffic lanes on monitored section located each 0.5 to 1 km. Detector profiles location is shown in Fig. 3.

Traffic data consisting of vehicle volume, detector occupancy and average speed from each detector profile are aggregated into 3 minutes intervals are transferred to highway surveillance center to be saved into the database on real-time basis. For the analysis purposes, data were exported from database and split up into three independent groups, namely volumes, detector occupancies and average speed. During further analysis performed in MATLAB® environment data were sorted according to date and additionally filtered using basic linear regression algorithm. We obtained reference flows, which were used for classification algorithm training. We chose several flows representing non-standard situations, such as queues or restrictions caused by accidents.

## 3. Literature and research review

State Space analysis seems to be a convenient method suitable for traffic states description. According to articles focused on traffic data evaluation, state space offers several advantages, mainly:

1. Ability to easily handle multiple inputs and outputs systems;
2. System modelling includes both internal state variables as well as output variable;
3. It directly provides a time-domain solution;
4. Matrix input into vector on the output modelling is highly efficient from computational standpoint.

State space as the representation of all possible states of the dynamic system is convenient for a traffic states description. Studies discussing traffic data modelling and prediction show an application of state space for urban or freeway stretch data (Stathopoulos & Karlaftis, 2002). Authors of other texts described creation of vectors based on traffic stream model data and studied chronology of time series and trajectories of vectors in state space (Lan et al. 2007). Different researches were based on implementation into STARIMA models, based on detector location and relationships between sites (Kamarianakis & Prastacos, 2002).

In other literature was state space method used can be a base algorithm for Kalman filter traffic state estimator (Wang & Papageorgiou, 2004) or adaptive freeway traffic state estimator (Wang & Papageorgiou, 2008) utilized. Finally, state space has been presented as a part of highly sophisticated ITS application of origin-destination estimation (Zhou & Mahmassani, 2007). Authors used a state-space model because of its complexity of using all necessary variables, such as historical demand parameters. Investigation of the state space problematic shows, that state space is a modern and convenient method to transform traffic data from more detectors into "state" which will represent a qualitative parameter for further traffic examination. To transform considered discrete slices into a better evaluable form is necessary to use convenient reduction approach.

Principal Component Analysis (PCA), considered as a convenient reduction method, has been discussed in a number of articles. In all papers, main benefits such as formation of new orthogonal dimension, where original data are reduced, non-correlated resulting variables and larger variability of original values covered by the first of principal components of PCA were highlighted. Series of studies were carried out in the last years to find a method for detection of non-standard states from traffic data and its classification (Jin et al. 2008; Foester, 2008). For example in real-time adaptive on-line traffic incident detection article (Xu et al. 1998) there were real-time adaptive procedures for obtaining principal components from traffic data, namely speeds and flow densities described. Adaptive means that PCA was formed into neural network structure to create traffic states from the dynamic model. Traffic states were finally evaluated by intelligent classificator. Other texts from the same authors were for huge amount of traffic data compression or missing data supplementing approaches focused (Qu et al. 2007). Some researchers studied day flows reduction into principal components and its behaviour related to cluster analysis. All studies used real historical traffic data and showed high flexibility of proposed method. Negative features like unsuitability for time series analysis because of its variability caused by component score relations were also mentioned. Investigation showed that different data matrices consisting of very similar data series can have different dimension in space, which excludes independent conversion. This brings us to conclusion that we need another method to pre-process data before PCA analysis.

## 4. Mathematical background

In this section we shortly describe mathematical operation necessary for applying studied method on real traffic data. We start from idea, that traffic state in any city area or freeway stretch can be represented by predefined and ultimate number of states (normal state, slightly crowding traffic, queues, etc.). This description is very close to almost known and often used Level of Service (LoS) categorization, famous from dynamic web maps, variable message signs or radio reports. Main goal is to use the state space for description of traffic situation by states similar to LoS, which will offer more complex macro view on monitored area than typically used LoS approaches offer (Pribyl, 2005) for traffic state estimation. Typical traffic states, which cover all typical traffic situations (normal, medium or dense traffic, congestions), we obtain from historical data. Based on historical data we classify real-time data into clusters, where each cluster represents trained traffic state. Due to the effort to use more than one traffic parameter for traffic quality estimation we assume to use multiple traffic inputs of volumes $\mathrm{q}$, speed $\mathrm{r}$, and occupancy $\varkappa$ from a certain number of detectors, we execute traffic data analysis in multiple spaces. To reduce a big amount of data, we use PCA, while preserving its variability, clearing out correlations and creating new orthogonal dimension for better evaluation. After applying PCA reduction on system state, we get a single vector, which belongs to the defined state and represents traffic quality state.

### *4.1. State space description*

System state description appears from physics. States are based on vectors, which contain all the information about the system. State vector is linearly independent set of variables. State space is a set of all possible states of the dynamic system, where each system state corresponds to a unique point in the state space [19], defined generally by two equations. The first equation called state equation

$$\frac{\mathrm{d}\boldsymbol{u}}{\mathrm{d}t} = \mathrm{A}.\boldsymbol{u}(\mathrm{t}) + \mathrm{B}.x(t), \text{ where } x(t) = \begin{vmatrix} \mathrm{q}_t^1 & \varkappa_\mathrm{t}^1 & \mathrm{r}_t^1 \\ \mathrm{q}_t^2 & \varkappa_t^2 & \mathrm{r}_t^2 \\ \mathrm{q}_t^\mathrm{n} & \varkappa_t^\mathrm{n} & \mathrm{r}_t^\mathrm{n} \end{vmatrix}, \tag{1}$$

where $\boldsymbol{u}$ is a vector representing the internal state and $x$ is set of new traffic input parameters. The second equation called output equation has the form

$$y(t) = \mathrm{C}.\boldsymbol{u}(t) + D.x(t), \tag{2}$$

where parameter $y$ should be scalar representing output, for example states similar to LoS. The matrixes A, B, C and D determine the relations between an internal state and input and output variables. The output scalar represents searched traffic quality parameter, which can be presented in many grades, depending on a suitable classification method, for example:

$$y(t) = \begin{cases} \text{normal state/incident}\{0,1\} \\ \text{historical model q}, \varkappa, \text{r} \left\{\text{např. q}_{[5-10]}, \varkappa_{[10-14]}\right\} \\ \text{level of service } \text{y}\{\text{A} - \text{F}\}, \text{y}\{1 - 5\} \end{cases} \tag{3}$$

To determine scalar output directly from eq. (1) and (2) is a problem in the case of traffic system. The traffic systems are non-linear systems and they are described by differential equations of higher order. These systems have common multiple inputs in case of a city road network and only one output is searched. In the case of a highway, it could be presumed that only single input will be used. To find the matrixes, which are moreover nonstationary, is very complex problem and it was not successfully solved for general traffic system until now. The proposed solution transfers multi-dimensional state variables into 2D or 3D space where it is possible to estimate appropriate traffic status by position of a vector Φ.

Generally, each set of values, represented by discrete slice shown in the Fig. 1, represents the state space of a dynamic system. In case of traffic data, these values are represented by real traffic flow parameters. Traffic state can be derived from several parameters simultaneously, as shown in Fig. 1. Future states can be obtained via step-predictor or other prediction methods (Kalman filter, etc.). The number of dynamic system freedom degrees represents the dimension of phase space. In fact, only a certain number of variables is needed to fully describe the system (Terman & Izhikevich, 2010). Dynamic system development corresponds to the trajectory of vectors motion in this space. In state space we observe traffic data at intervals of aggregation as slices, as it is shown in Fig. 2 right. Aggregation slices, visualized as connection between flows, represent system state, which is reduced and examined in next steps for traffic quality monitoring. Reduction method, considered as a transformation method, should eliminate less significant and correlated variables and transform a large amount of input variables generated by traffic detectors into a few parameters to create vector for further examination of states a should represent a quality of traffic, known as Level of Service (LOS).

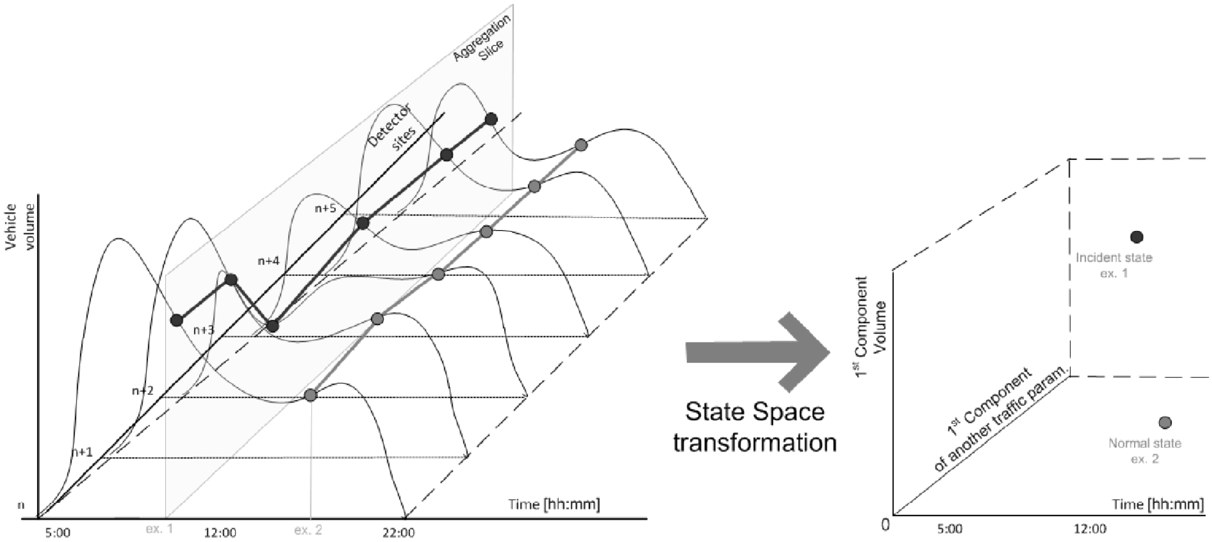


Fig. 1: State Space transformation example. We assume that in each aggregation interval traffic data are produced on each traffic detector. In state space, we analyze all data types (volumes, speeds) from all considered detectors all at once. Data in each aggregation interval (rectangle area) create a discrete time slice, representing the system state. Our goal is to transform these data using convenient reduction method to get a single vector. One single vector in a new dimension allows us to classify global traffic state of observed city area or line stretch.

### *4.2. PCA reduction*

Principal Component Analysis was established by Pearson in 1901 and is one of the oldest methods for multiple data analysis. PCA allows transformation of entered data to a smaller spatial dimension, while preserving the original variability. PCA creates new vectors, so that each of the new vectors is a linear combination of the original vectors. Output of this algorithm are primary principal components, secondary outputs are component scores and variances (latent variables). The correlation values of traffic data can be plotted in a new dimension in the 2-D views (main component of intensities, occupancy, or speeds of several detectors), or 3D dimension. The following text explains the PCA analytically. We have a matrix D (m × n), where m is a number of rows and n of columns, representing traffic data set

$$\mathrm{X} = [\mathrm{x}(1), \mathrm{x}(2), \ldots \mathrm{x}(\mathrm{n})], \qquad (4)$$

where $\mathrm{x}(t) = [\mathrm{x}_1(t), \mathrm{x}_2(t), \ldots \mathrm{x}_\mathrm{n}(t)]^\mathrm{T}$ and variables are correlated to each other. Variables $\mathrm{x}_1, \mathrm{x}_2$, etc. represent various data traffic data types. Variable T represents a period of monitored flow and t is aggregation time. Because these variables are correlated to each other, another group of uncorrelated vectors exists and is given by equation

$$\mathrm{Y} = [\mathrm{y}(1), \mathrm{y}(2), \ldots \mathrm{y}(\mathrm{n})], \qquad (5)$$

where $\mathrm{y}(t) = [\mathrm{y}_1(t), \mathrm{ys}_2(t), \ldots \mathrm{y}_\mathrm{m}(t)]^\mathrm{T}$ and $\mathrm{y}_\mathrm{k}(t)$ are linear combination of x($t$) given by

$$\mathrm{Y} = \mathrm{P}\,.\,\mathrm{X} \qquad (6)$$

where Y represents a new dimension generated by multiplication of P and X matrices, where P is projection matrix $\mathrm{P} = [\mathrm{p}(1), \mathrm{p}(2), \ldots \mathrm{p}(\mathrm{m})]$, where $\mathrm{p}(t) = [\mathrm{p}_1(t), \mathrm{p}_2(t), \ldots \mathrm{p}_\mathrm{m}(t)]^\mathrm{T}$ and X represents original data matrix. Using PCA, we obtain a new dimension Y consisting of principal components (PC) from original data matrix X. The First few principal components cover the largest variability part of original data. Since there are for reconstruction typically used only the first 2-3 principal components, information loss results in creation of error matrix (Meloun & Militký, 2006). There are several ways how to implement PCA and calculate principal components, most frequently used singular value decomposition (SVD) or conversion through covariance matrix (Shlens, 2009). The number of used principal components leads to a standard PCA mathematical model.

### *4.3. QoT Mathematical model*

Based on knowledge of state space transformation and PCA reduction we designed a mathematical model for traffic quality (QoT) estimation, based on combination of these methods. As an input we use traffic data collected by traffic detectors located in a monitored area namely vehicle volume $q$, detector occupancy $\varkappa$ and average speed $r$. For each discrete time slice we transform these data into a matrix structure

$$x(t) = \begin{pmatrix} q_t^1 & \varkappa_t^1 & r_t^1 \\ q_t^2 & \varkappa_t^2 & r_t^2 \\ q_t^n & \varkappa_t^n & r_t^n \end{pmatrix}, \qquad (7)$$

where $t$ represents timestamp. Each of these n-dimensional matrices representing traffic state $S^n$ in selected discrete time is consequently reduced by PCA to a simple $j$-dimensional vector $\Phi$ consisted of several PCs with minimum information loss. However, correlations among measuring profiles are effectively removed.

$$S^n[x(t)] \xrightarrow{PCA} \Phi^j(t)\,, \text{where } \Phi^j(t) = \{pc_q(t), pc_\varkappa(t), pc_r(t)\} \qquad (8)$$

The reduced states represented by the first principal components PC of each reduced data type $q, \varkappa$ or $r$ are stored in a database. For the currently analysed data, the database is named $RS$, where all reduced discrete time slices $\Phi^j$ are stored. Historical database containing PC data collected for a long period is named $\Theta$. Finally, traffic quality level similar to LoS is determined by comparing currently analysed reduced states against model states, using the following formula

$$QoT_{Level}(t) \in \{RS(t), \Theta(t)\}. \qquad (9)$$

The output quality of traffic levels can be defined either heuristically or based on long term experience.

## 5. Data examination and traffic quality estimation

Research oriented to estimation of quality of traffic above a set of detectors described in this paper is based on working with real data collected on D1 highway near Prague, as was noted in chapter 2 – Traffic data collection. From both sources, model and incidental, a two hour flows around incident detection time were cut out. Thus for further analysis we used six data matrices. All matrices were rotated by ninety degrees, to get discrete slices. In next step we linked model and incident matrices into one matrix for each data type separately, which represents dimension unification necessary for next step. Finally we transformed discrete slices using PCA method into a new dimension. Each time aggregation formed by discrete slice is in new PCA dimension represented by simple value called state vector instead of array given by amount of traffic detectors. This state vector is the primary output of algorithm described above and represents traffic quality parameter. Output state vector is three dimensional and could be formed by: the first three main components of chosen traffic data type (Fig. 4), the first component of volume, speed and occupancy data (Fig. 5) or by two traffic flow parameters (e. g. volume and speed) and time, when traffic data were recorded. This quality of traffic output vector is ready to be classified into predefined states based on knowledge of all states from historical data of trained model using methods of artificial intelligence and training recognition structures. Recognition algorithms can be based on using carefully created historical models. The goal is to recognize position of the real-time state vector in a new 2-D or 3-D space according to model vector from historical database indicated in the same day time using classification algorithms similar to Euclidean distance measurement or highly professional methods like classification three, neural networks, pattern recognition or any other artificial intelligence method.

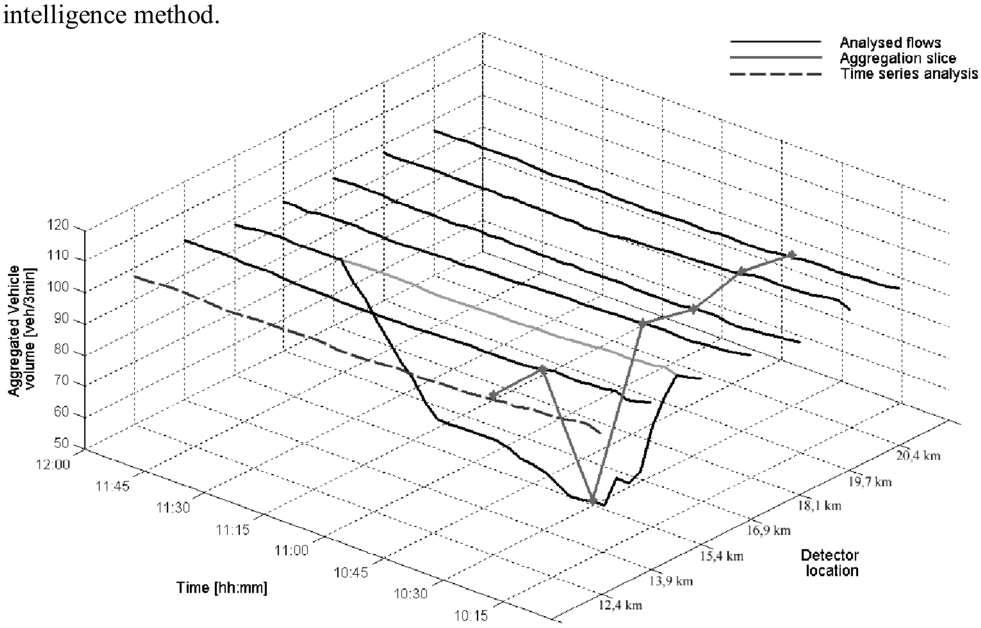


Fig. 2: Time-space vs. State-space analysis. Figure shows traffic volume flows measured on seven detectors. Time series analysis means that each detector is analyzed separately (dashed flow means one detector). State space analysis means that all detectors are analyzed together, where data sliced in aggregation interval (grey slice connecting all detectors) are transformed by particular method into a new space. Decrease of traffic volume on one of detector means that incident occurs. Average (historically typical) flow is showed by light grey. Analogical situations are valid both for occupancies and average speed flows (not shown in this paper).

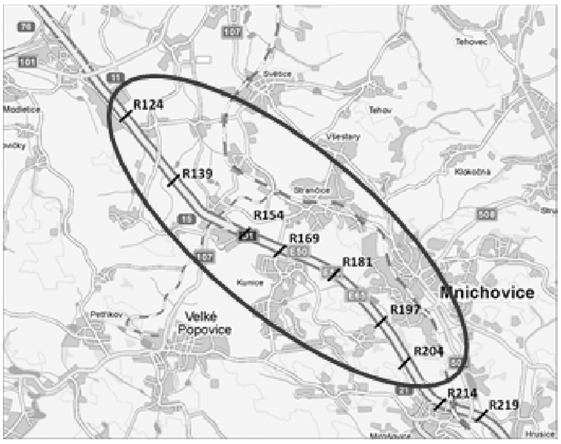


Fig. 3: Detector location on D1 highway near Prague.

Analysis output examples for non-incident and incident traffic situation are shown in the following Fig. 4. We see two clusters, which represent typical states given by trained model and incident data. Vectors matching incidental situation are situated out of model vectors cluster. Few outliers between two clusters represent transition states when traffic situation in incident flow was changing from normal to incident state and back.

Vector distribution of model and currently analysed data is necessary to be equal. If the PCA transformation was performed for the model and for incident data separately with different input matrix structure, dimensions would not be identical. New orthogonal dimension of two matrices with identical structure allows us to compare currently analysed and reduce data in identical space created by component scores.

Recognition of traffic state or both traffic quality parameter using only one traffic parameter, as it is shown in Fig. 4, does not lead to reliable results as it is referred in text (Přibyl et al. 2003). Using only one data type in the original or reduced dimension leads to miss important events, which may not occur in the selected parameter later or due to the monitored area structure may not occur at all (Přibyl & Mach, 2003). Using the first component of volume and occupancy, volume and speed, occupancy and speed or all three parameters together will lead to more accurate traffic quality estimation outputs than using only one traffic parameter.

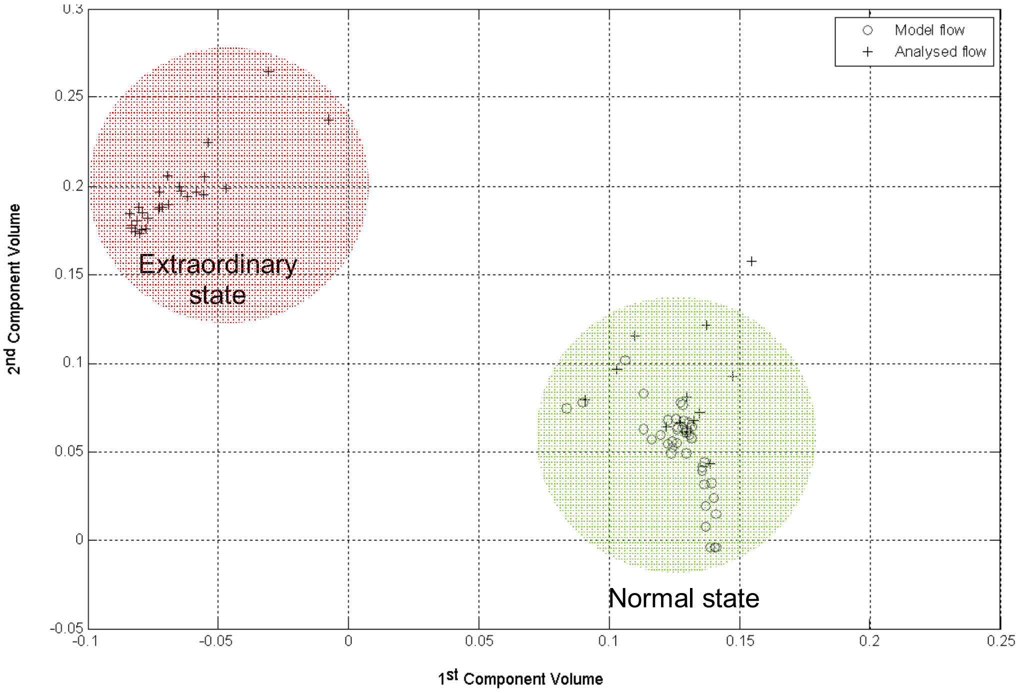


Fig. 4: The first and second PC coordinates of normal vs. extraordinary traffic situation based only on volume data projected into a new dimension.

In the reduced dimension, the first principal component covers the biggest part of variables from the original dimension. In case of vehicle volume data analysed in example show in Fig. 2, further research focused on each principal component showed, that the first three components covered overall 95% variability of input values. The first PC of volume data corresponds to approx. 80%, of original vehicle volume variance, the second PC after all correlation with the first PC corresponds to approx. 10% and third PC to 5% of original volume variance. The first principal components represent for each discrete time slice one reduced state of traffic quality and as well as one record in above mentioned $RS$ or $\Theta$ databases.

Considering the knowledge discussed in the paragraph above, for relevant traffic quality estimation it will be more convenient to use the first principal component of two or three traffic flow data types, such as volume, speed and occupancy. It is both possible to combine two traffic flow data types with time axe for well-arranged visualization. The final quality of traffic state estimation is based on evaluation of the first components of model and extraordinary states consisting of reduced original traffic data, as it is shown in Fig. 5. In figure it is also noticeable benefit of variables reduction. Two hours flow of seven detector features from 280x3 records, when three data types (vehicle volume, speed, occupancy) are collected. In a new space these data are reduced to just 40 records, which represents a vector composed of three various first components.

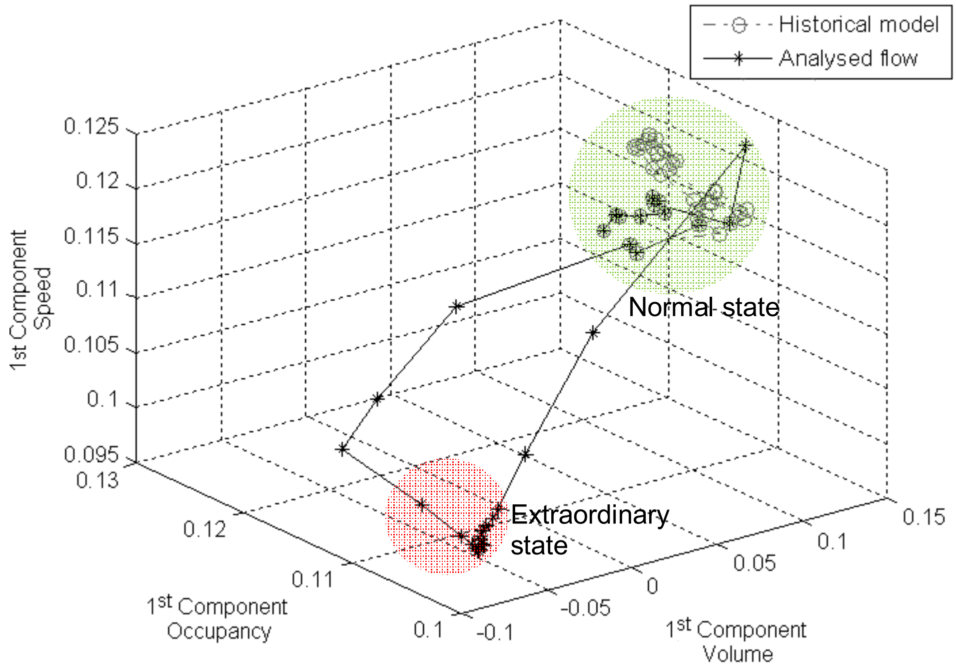


Fig. 5: Traffic state vectors in the new reduced dimension. The figure compares two-hour flows from the example shown above. Grey dashed plots represent historical model from equivalent day and time period. Black plots represent flow with detected incident. We see that incident values lies out of the model cluster and can be identified based on distance from the model state in discrete time.

## 6. Conclusion and further research

Traffic data analysis for the purpose of designing ITS system for traffic quality estimation brings undisputed advantages, such as quick incident and queue detection, and creates the head stone for reliable traffic management system. We know from experience, those operators from the number of surveillance video displays on the video wall are not able to recognize bad traffic situation immediately and respond appropriately. When this process is automated, effectivity of data evaluation increases and operators will only verify and confirm traffic states and take correct action to minimize all external and unwanted influences. That is the reason for historical traffic data investigation, and searching for new approaches to its evaluation and archivation. State space using principal component analysis for transformation, supplemented by appropriate classification algorithm provides optimal basement for this research.

The importance of this research lies in three main facts. First, good traffic quality evaluation system will help with integration with variable message signs, mobile navigation devices, RDS-TMC or Internet to drivers to select an optimum route. Secondly, the above mentioned on-line system could provide an accurate knowledge of existing traffic conditions in order to guide traffic control more effectively. Lastly, efficient dispatching of emergency services is enhanced.

The mathematical model described in this study may represent the core of such an intelligent traffic system. Modern mathematical approaches lead to use of artificial intelligence elements, where the system is trained of all possible states from historical data. Based on the memorized states it is able to evaluate the level of quality of traffic on roads and inform drivers about conditions. This concept represents an alternative to a simple roads expanding.

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# Use of Stacker Crane Based Technology for Automated Parking Solution

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**Abstract**

This document provides an overall view of the author's bachelor, diploma and doctoral thesis with main focus on the scope of future research. It follows the progress from the early beginning through the current state to the desired target. The aim of the doctoral thesis is to propose the suitable solution for automated storage/retrieval of cars using the stacker crane based technology. Specific existing location will be used as a reference point for showing that this solution is able to be adapted to the real conditions.

**Keywords:** Stacker crane, parking, garage, public tranportation, automation, Říčany, P+R

In my bachelor thesis I have focused on the transportation analysis in my region of Říčany. This region is quite unique because it is combining various types of transportation and the location within the whole country is very specific. First of all there is a combination of individual and public transportation that includes bus and train.

The main aim of the bachelor thesis was to analyse the flows of passengers and discover the possibility to ease up the transportation through the region. City of Říčany is presumed to be the main point for interchange of the above mentioned types of transport. There are several reasons for this. First of all the repeating congestions usually takes place near the southern and eastern city boarders and there is a big flow of cars that is either going through this area or they start the journey in here. If we leave aside the traffic that is starting directly in the city which we can consider as optional (meaning that the people using this kind of transport had already the possibility to choose between car, bus and train) the amount of traffic that is passing through and starting in the area of Říčany but not directly in the city is still very high.

During the time when I was writing the bachelor thesis the complete modernisation of the train track Praha-Hostivař – Strančice – Čerčany was in progress. The result of it was the massive increase of the track capacity and directly related was the increase of the train connections. The increase was up to five connections per rush hour and two connections per hour out of the rush hours. Another big advantage of the train connection is the time spent on the track. From Říčany station to Praha Hlavní nádraží station that is situated right in the city centre the trip takes only 26 minutes. That is in comparison to car or bus an outstanding performance.

Bus connections were modified in order not to have the same routing as the train and the main aim was to serve the area near the bigger train stations and deliver the passengers to the train. This approach was taken because of the capacity of the bus/train and also to eliminate the bus delay that could occur when hitting the congestion. Compare to train the possibility of a bus delay is considerably higher. The choice to go by bus to Praha remained but it was reduced significantly as the trip takes substantially more time and passengers are not delivered to the city centre but to terminus station of the metro.

In my diploma thesis I have focused on proposing the adequate solution for the region analysed in my bachelor thesis. The main aim was to decrease the amount of individual transportation based on using the cars and therefore cutting down the amount and magnitude of the congestions. Another aspect of this solution was to utilize more the available public transport capacities and in the best case scenario increase the demand for even more public transport capacity.

The main idea was to combine all three transport modes (car, bus and train) that are currently active in the region into one central interchange point. I have followed the result of the bachelor thesis that indicated that the best the approach to reach the desired goal could be a car parking facility. This also made me think about the overall concept of the solution and its design.

I have decided to design the park place of the same type (P+R – Park and Ride) that is in operation at many points mainly at the borders of Praha. The main issue was to pick the right place to ensure that the system will work to the designed purposes. I did some research focused on the places available near the train stations because these are the only point that are fixed. My research counted in with the five train stations (Praha Uhříněves, Praha Kolovraty, Říčany, Světice and Strančice). Two main candidates based on the space available were Praha Uhříněves and Říčany. In relation to the traffic and also to the accessibility of the place Říčany were the right spot. This location is combining all modes of transport that are not directly connected. Therefore the idea of having one central point for car storage/retrieval, bus and train station seems as a good approach for finding a suitable and effective solution.

In order to be as effective as possible I have chosen to go with the multiple level park garage connected directly to the other modes of transport. The idea of garage has been presented in two variants.

Both concepts were designed also in relation to bus transportation and on one level the adequate space is considered. It is not only for get on/off of the passengers but there are also stands for inactive buses (i.e. for the driver safety pause, waiting for a train connection etc.).

First variant is based on the usual concept of the park garage. The concept is that users are able to reach all available parking spot by car on their own. It means that the garage is equipped with ramps for reaching higher and lower levels. This concept has quite low space utilisation that is in direct relation to the need of operational parts. These operational parts are not able to be used for parking. The building is considered as modular based. It means that the numbers of levels are not limited and the building grounds are designed for the maximum amount of levels to allow future expansion of the parking places according to the needs. This is the main advantage of this solution. Of course the height of the building respectively the number of under and above ground levels needs to be in relation to the local authority regulations.

Second variant is based on the fully automated stacker crane in high bay warehouse concept. This is the main focus of my doctoral thesis so I will go more into deep with this idea.

History of intralogistic solutions based on the stacker cranes is quite rich. Automation itself is a great opportunity to optimize space utilisation, material flow, throughputs and of course to reduce human-based mistakes and costs.

Automation based on the stacker crane technology has a history of over than 40 years and the roots are spread all over the world but especially in Europe and Northern America.

Stacker crane is quite sophisticated unit. It consists of the base carriage, mast, hoisting unit and upper carriage.

Base carriage is the part that provides the support for the mast; one or two traveling motors are integral part of this structure. Rail (usually RN45) is used as the support for wheels. There are also traveling encoders for ensuring the exact position in the aisle.

Mast of the stacker crane is providing support for hoisting carriage and hoisting motor. The hoisting carriage is responsible for handling the material. Both are equipped with sensors and measuring devices to ensure the perfect position in order not to start the movement before the stacker crane and handling unit is on the right place.

Upper carriage provides the upper support for the mast. It is connected via the rollers to the upper guide rail. This solution provides the necessary stability for the stacker crane by reducing the unwanted movements of the mast. This also influences the ability of reaching higher traveling speeds.

One of the main benefits of stacker crane based solution is space utilisation. The maximum height of the steel structure called Silo or High Bay Warehouse (HBW) can reach up to 50 meters but more usual are maximum height of 40 meters. The height is also being influenced by local authorities in relation to surrounding buildings. Comparing to the standard forklift truck or VNA (Very Narrow Aisle) trucks the height can be more than tripled. Besides of the higher height the base area utilisation is also very good. This is based on the low stacker crane profile and therefore the aisle is very narrow. Usually there is only need for a safety distance to be added to the width of the transported handling unit.

Material flow is the next big advantage of the automation. Continuous and on time delivery of material without errors is quite hard to achieve the usual way using manpower. Also the higher amount the more manpower is needed, more money is spent and more mistakes can occur. Automation is able to work according to priority levels, respect the batch numbers, focus on sequencing. Therefore the overall throughput of the material can be much higher than using the manual operated solution.

Reduction of human-based mistakes and therefore improved efficiency of all actions is also an advantage. Even though the system is based on the mechanical and electrical parts the design that will count in the redundancy is the way to ensure the maximum system availability and performance.

If we take all these benefits into account we can get very effective solution for a special purpose that requires high space utilisation. The case of the parking garage directly connected to the Říčany train station.

Fully automated high bay warehouse based on the stacker crane technology for storage of cars is a unique solution. The main issue are the parameters of the handling unit that has to be either unified to ensure that all types of cars are able to enter the warehouse or diversified into sub-types based on the dimensions and weight. In my diploma thesis I have considered the unified unit. After graduation I started to work for a company that is constructing the warehouses of this kind. At current level of knowledge I can say that both approaches are possible. The final decision should be made based on more deep research of the stored cars structure.

Unified handling unit brings the benefit of variability but lowers the space utilisation. Also the steel structure demands are higher. Diversified handling unit brings the benefit of higher space utilisation and the demands for steel structure are lower. But the variability is lower because of limited number of the handling units of each type. This also means that the structure itself is not ready for the future change of demands.

Even though the universal structure could be less space effective and a bit more expensive I think that it is the way to follow. The benefits of this design prevail in comparison to diversified unit based design. This will also influence the design of the stacker crane. For universal handling unit the stacker crane hoisting unit could be simpler. No special equipment that will adapt the hoisting carriage to various types of handling unit is needed.

In this specific case there are special circumstances of the car flow. The biggest issue to solve is for sure the peak throughput of the system. This is in direct relation to the rush hours that occurs during the day. The system has to be therefore designed to withstand these peaks and be able to deliver the demanded performance. In general we can say that there will be two main peaks during the day. In the morning there will be high demand for input and in the afternoon there will be high demand for output. Both peaks will be high but the demand in the morning is considered to be the highest peak of the day.

In order to withstand these peaks I have designed in my diploma thesis multiple input/output points. The biggest advantage of these points is the universality. Nearly all of them are able to work both ways and cover the demand either for input or output. To ensure the best performance the automation work is not only dependent on the stacker crane. Other types of automation equipment are considered to be used to help with absorbing the peaks.

This kind of parking facility can reach up to twice capacity in comparison to the usual concept of the garage. It can also include the modern technologies such as delivery just in time to shorten the waiting time when changing from train/bus to car.

My intention in doctoral thesis is to design the fully automated solution of a facility that will include all modes of transport. Stacker crane technology based high density automated storage/retrieval system with integrated bus station/parking place and covered train station connection.

# High-speed Rail System Characteristic

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**Abstract**

Nowadays passenger and freight rail transport has not possibility for fully using its advantages in the Czech Republic – it does not come up to sufficient commercial speed in comparison with other modes of transport in potential attractive relations and it has almost full capacity in the competitive routes. The solution consists in constructing of high-speed railway lines which comprise so-called high-speed rail system with some modernized existing lines and connecting lines to so-called conventional rail network. First is defined the high-speed rail system concept in this paper, followed with description of the procedure preceding implementation of such railway line, and basic principles of the high-speed railway line route layout.

**Keywords:** traffic service in region, public mass transport, high-speed rail system, route layout

## 1. High-speed Rail System Definition

Guided transport systems can be grouped by their different features. In terms of physical features, two differing features can be mentioned that distinguish the two given systems that enable movement of a railway carriage on a long distance railway line – these are the adhesion guided transport systems and the guided transport systems based on the principle of the magnetic levitation (generally referred to as maglev). Guided transport systems will be mentioned as adhesion rail systems in the next text of this paper.

In terms of the highest trains' speed facilitated by the railway lines, it appears that the most suitable grouping is the one in terms of the Directive 2008/57/EC on the interoperability of the rail system [1], which set out differences between the conventional railway lines and the high-speed railway lines (HSRLs). The HSRLs include specially constructed HSRLs for speed up to 250 km/h and higher, specially modernised railway lines for speed in the order of 200 km/h, and specially modernised rails of unusual characteristics given by topographic, terrain or urban limitations, to which the speed must be adjusted in each individual case separately [1].

Considered as a new, high-speed railway line is therefore such adhesion railway line (usually with standard track gauge 1,435 mm) of which line speed is at least 250 km/h at the adequately long and useable distance; together with the modernised sections usually rated up to the speed of 200 km/h these railway lines then create high-speed rail network.

## 2. High-speed Railway Lines Basic Parameters

To determine basic parameters of the HSRL, it is first necessary to establish the reason for the HSRL construction and after that to determine which trains would be using the HSRL. Generally, it is possible to find at least few closely correlating arguments to support construction of the HSRLs (that is why several justifications usually come up almost simultaneously), and of which the following could be the ones applicable [2]:

- insufficient capacity of the conventional rail network (especially within large conglomerations with heavy suburban passenger transport)
- slow train speed (long travelling times) by the conventional network (the rail transport is not attractive either to the passenger, or to the transporters, i.e. it is not competitive in comparison with the road and air transport)

- heavy transport streams (having potential of further growth) of some connections, which are presently carried out by different transportation means
- unreliability of the conventional trains (failure to adhere to train schedule due to breakdowns and extraordinary situations), and provision of only low comfort level to passengers (again lack of the rail transport's attractivity and loss of customers)
- independence on non-renewable energy source – crude oil (this reason will become actual in the forthcoming decades; the crude oil crises in the $2^{nd}$ half of $20^{th}$ century contributed towards the development of HSRLs)

Selection of the train types and their parameters play a key role in terms of evaluation of the investment to be expended, including regular operating costs required for the maintenance and operation of the railway line, when usage of HSRL is considered – its attractivity to the carriers.

To be able to determine the basic design parameters of the HSRL, it is necessary to know at least the characteristics of the further mentioned individual train types (and not only of their driving units):

- max. speed, which the train is able to achieve
- max. acceleration to reach the train's max. speed and the braking-down distance from the highest speed
- max. longitudinal gradient of the railway line, on which the train is able to maintain its highest speed, alternatively max. speed, which the given train is able to maintain on such longitudinal gradient, and which is the highest applicable to the highest performance train assumed
- grouping of the train to the loading class (max. mass on the axis and the unit of the carriage length)
- max. length of the train

To determine the design parameters of the railway line it is not crucial as to how the specific category of the train will be marked or what will the exact route of the railway line be, but which characteristics will correspond to the given group of trains. On the basis of the knowledge of the described train types' characteristics and in conformity with the technical norms and legal regulations it is possible to determine the critical parameters of the HSRL layout as follows:

- min. radius of the horizontal curve
- max. longitudinal gradient of the railway line
- min. effective length of the running track in the HSRL operating control points
- min. length of the platform edge of the HSRL stations' platforms

There are technical and operating rules and parameters of the high-speed and also conventional railway lines in the EU countries – there are so-called the Technical Specification of Interoperability (TSI) applicable to the Transeuropean high-speed rail system and to the Transeuropean conventional rail system which all subjects on rail sectors (infrastructure owners, infrastructure managers, carriers, railway offices, projection offices, building companies etc.) have to respect.

Upon expert selection of the trains and determination of their parameters it is possible to approach the design of the HSRL routes' options. Once their layout is completed, it is necessary to perform the travel simulation of all train types in terms of the dynamics of their travel (affected especially by the longitudinal gradient of the individual track sections), and it is through this that calculation of the travelling time of the train and the traction energy consumption will be carried out, as well as verification that the line speed has been reached.

The bigger the trains' variety and the wider their parameters' range, the stricter the HSRL design criteria become; consequently, search for the optimal route becomes more demanding and its construction more expensive. Big difference between the max. speed of the fastest and the slowest train will manifest itself by the necessity of a large radius of the horizontal curves and increased wear of the railway superstructure. The traction characteristics of the train, considerably influenced by its mass and the power output of the drive-axle assemblies, will manifest itself directly in the max. longitudinal gradient of the railway line.

For the HSRL combined operation (passenger and freight trains) it is possible to determine the radius of the horizontal curves as approximately 7,000 m, and for the HSRL operation of only special high-speed units, the radius of the horizontal curve of approx. 3,000 m will suffice. The smallest admissible values of the horizontal curves' radius are with the slab (non-ballasted) track construction. The biggest HSRL longitudinal gradient with combined operation can be determined as 18 mm/m. Example of the HSRL intended only for the special high-speed units are the rails in France, where the TGV units overcome ascend of value of up to 35 mm/m, or in Germany between Cologne and Frankfurt, where the ICE 3 units manage the longitudinal gradient of up to 40 mm/m. Especially on the territory of the Czech Republic, characterised by the complex configuration of the terrain, scattered settlements and a unique natural and cultural heritage, even small changes of the limiting values of the HSRL routing parameters play a key role in the capital intensity of its construction.

## 3. High-speed Railway Lines Routing

In accordance with the reasons that lead to the proposal of the new HSRL and the train types, of which operation is assumed on the HSRL, the HSRL route connects important residential and industrial conglomerations as the sources and target journeys of the travellers (alternatively goods), replaces sections of the low line speed conventional rails, or increases the almost used up capacity of the existing rails. Routing of the new HSRL is constrained by the limiting design parameters and effort to minimise the investment costs of the construction and the future operating costs as well as efforts to make the route as short as possible. At the same time the HSRL routing is limited by the availability of the free space between the residential formations, industrial zones and transport constructions as well as necessity to protect the cultural and especially the natural assets of the territory.

### *3.1. City Traffic Service by High-speed Trains*

To the limiting conditions indicated in the preceding clause have to be added the problems with location of the passengers' boarding/exit/transfer nodes (i.e. railway stations or stops) and crossing of the trains from the high-speed rail network to the conventional one and the other way round. One of the biggest advantages of the passenger rail transport in comparison with the air transport is the fact that the train can bring the traveller directly into the city centre, where there is a natural concentration of all services, availability of transfer to interconnecting public transport systems, and about equal accessibility to any place in the city.

One of the options of the HSRL route and a city's connection is therefore termination of the HSRL at the periphery of the residential agglomeration into the conventional network (see Figure 1b), which will facilitate use of the existing railway to enable trains to consequently travel to the central station. However, this solution has two main snags, which must be examined for each specific case. Firstly it involves extending the trains' travelling time during the travel within the urban area on the existing rails (though reconstructed within the available means), especially for the travellers, who are passing through the given city, and secondly the complications with the saturated capacity of the existing railway lines, which occurs especially due to concentration of the urban passenger transportation. As advantageous (but at the same time costly) solution appears the construction of a new railway line, segregated from the other transport systems, through the city centre (i.e. at the different height level – above ground, or more often underground), building a station or a stopping place as close as possible to the city centre, or an important changing transport terminal. This option became useful for instance in Antwerp (Belgium) or in Berlin (Germany).

Another possibility as to how to provide link between the HSRL and the residential area is to build a HSRL bypass around the agglomeration (plus connecting, as and when possible at suitable places, the HSRL with the conventional rail network), and build on it a completely new railway station (see Figure 1a, 1c, 1d), which would be part of the transport terminal, connected to good quality network of other types of the public transport services, and provided with an ample parking space of the P&R type. The advantage of this option, in spite of the longer HSRL route when compared to the preceding option (bypassing the city instead of going through it) is usually shorter travelling time as the result of better design parameters of the railway line (higher line speed), lower investment costs (lesser share of tunnels and bridging structures can be expected on the border of the town residential zone and the rural area, and their lower capital intensity), and the possibility of cooperation with the Individual Automobile Transport. For instance this route was taken by France by implementing the Paris east bypass (LGV-Interconnection), bypassing Lyon with the Lyon-St Exupery (TGV) station, or the Avignon TGV station.

The attractiveness of high-speed rail system can also be increased by interconnecting stations built on HSRL with airport terminals (e.g. Paris – Charles de Gaule, Frankfurt a. M., Shiphol near Amsterodam). The advantage of such interconnection lies in the fact that on intercontinental flights and Transeuropean routes the passengers are carried by airplanes while after changing the airplanes for HSRL they can be easily carried to the centres of European metropolis with great comfort and in high speed. Regardless of the chosen means of transport, the journey is realized on the basis of a single ticket issued by the transporters involved in the cooperating system; the application of the airplane ticket on the train is considered as "flight at zero level". Another advantage rests in lowering of air space loading. For instance, the building of HSRL on the Paris – Lyon route originally posed a threat to air traffic in terms of competitiveness, but later on resulted in a mutually satisfactory co-operation.

### *3.2. High-speed and Conventional Railway Lines Connection*

During the HSRL routing it is necessary to approach its interconnection with other conventional rails with special consideration. These connections, ensuring trains' smooth crossing between both rail networks are on one hand advantageous for both rail networks, but on the other hand can be a source of complications. The contribution brought about by the connection of both rail networks rests in the fact that the travelling speeds of the conventional trains, which use the HSRL for part of their travel, increases, while at the same time the usage of the HSRL capacity increases as well. However, if the rail network interconnections are made in unsuitable places, they can become a potential source of an unreliable operation. Namely, big problems occur in cases when the train, which is supposed to depart to the HSRL at certain exact time, can not do so due to occurrence of delays in the conventional network. Travel of various types of trains onto the HSRL, which in addition are also leaving and coming onto the HSRL at different places, poses high demands on processing of the train traffic schedule, and that is why there mostly is not big enough margin to shift the train route during the dispatch control of the operation. The train traffic schedule design simplifies when certain types of trains are routed in a certain part of the day only (e.g. the passenger trains mostly during the daytime, the freight trains at night time). (Týfa, 2013)

The link between the train traffic schedule and the HSRL route (travelling time, determined train traffic schedule, and track capacity requirements) causes an actual problem in creating efforts for the HSRL parameters to conform rigorously to so-called system travelling times of the integral train traffic schedule in the long distance rail transport. This requirement in some connections leads to belief that in these sections it is not the aim to achieve the technically lowest travelling times of the high-speed trains, and so it may at first glance appear that all that is required to be connected into the HSRL network to modernise the existing railway line. However, such doing holds further mentioned pitfalls:

- HSRLs are railway lines primarily intended for the high-speed trains, which create own European link system, and therefore they are the changing links between the trains of this type that must be primarily monitored. Creation of the individual high-speed lines' tact is naturally desirable, as it leads in terms of the passengers to increasing attractiveness.
- The high-speed trains are supposed to compete with the road vehicles travelling on highways, and also with the airplanes – both groups of the transport means are trying to shorten as much as possible their driving and travelling times.
- Construction of any new transport infrastructure is a matter of several years, built at high financial costs, creating a perceivable intervention in the landscape, and its assumed lifespan is at least 100 years. That is why it is necessary to always create certain reserves in the newly built rails' parameters, with a foresight by looking into future, as the carriage stock is developing faster than the construction of the railway lines and the organisation of the rail transport operation might change even more dynamically.

## 4. Conclusion

With the development of technology, commerce and tourism in the 2nd half of the 20th century, most countries of the world experienced fast growing demand for transport and increasing demands of the travellers and transporters for transport reliability. The automobile and the air transport operators adapted to the requirements in a versatile manner. The rail transport also had to start offering their customers higher travelling speed, reliability, sufficient range of connections, comfort and complex range of services. During this revival of the rail transport it was consequently recognised among other things that certain track sections' capacities are not adequate, and also discovered that their routing and technical parameters are inadequate as well. This gradually led in many countries round the world to radical modernisation of important rail routes and development of new HSRL.

The Czech Republic occupies a strategic position in the centre of Europe, which predestined it to be also the centre of big events and a crossroad of important routes. But if it does not react fast to the changes taking place in the rail transport in the neighbouring countries (especially in Germany and Austria), which are, among other things, substantially increasing the qualitative and capacitive level of their railway line infrastructure, the natural potential of the advantageous position will remain unused.

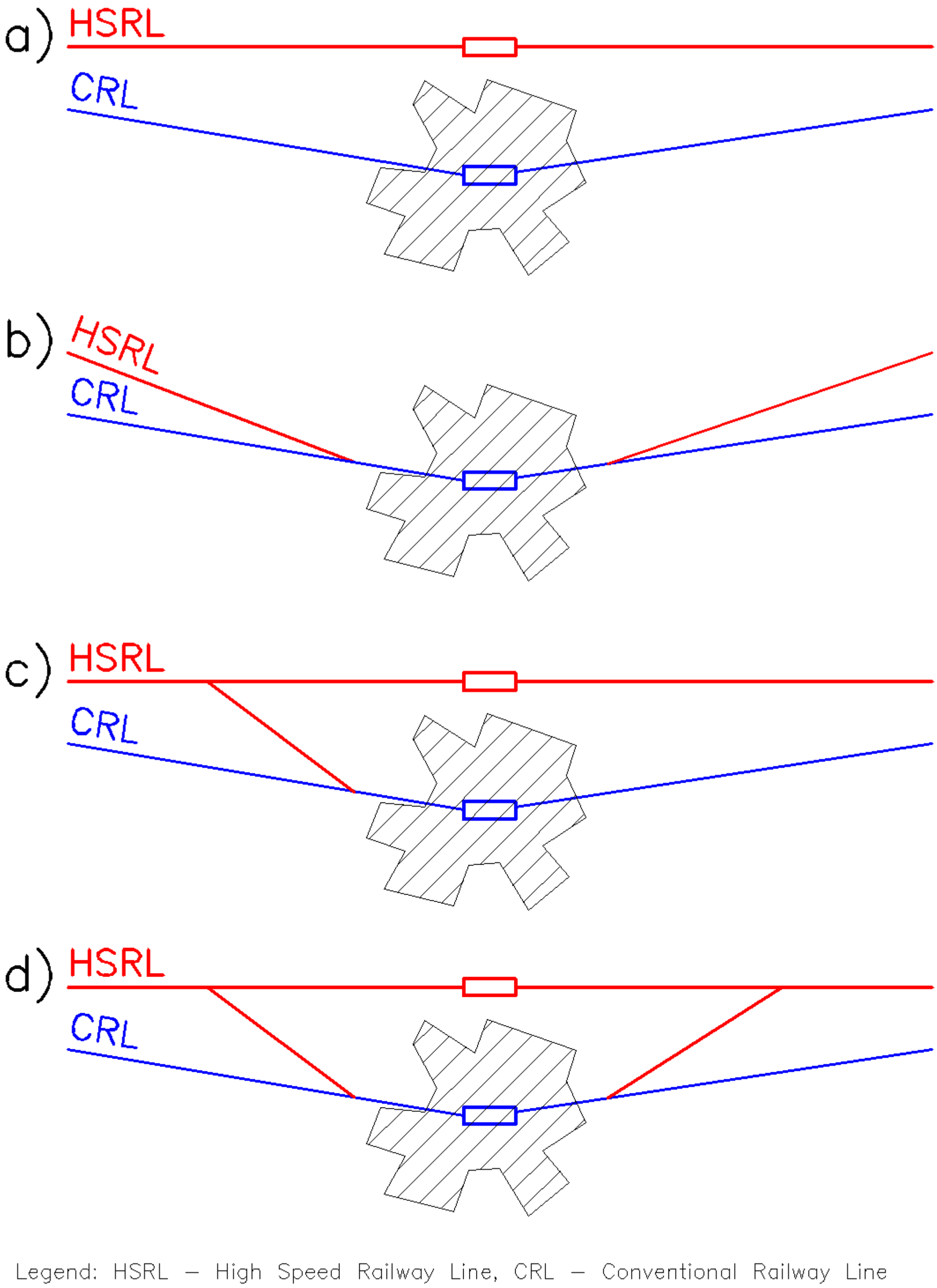


Fig. 1. Relation between city and HSRL: (a) HSRL bypass around the agglomeration with a new railway station on it; (b) Termination of the HSRL at the periphery of the residential agglomeration into the conventional rail network; (c) HSRL bypass around the agglomeration with a new railway station on it, plus connecting the HSRL with the conventional rail network on one side of the city; (d) HSRL bypass around the agglomeration with a new railway station on it, plus connecting the HSRL with the conventional rail network on the both side of the city.

## Acknowledgements

The paper was supported by the MSM grant no. 6840770043.

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# Examining Changes in Runoff in Urban Areas Caused by Transport Infrastructure

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**Abstract**

Changes in runoff conditions that are caused by transport infrastructure, are becoming an increasing degree of urbanization with the most acute problem, including in relation to the potential global climate change. Taking into account the conservative approach practice (investors, managers, operators, designers, ...), it is appropriate time to analyze the situation, identify specific problems and opportunities of the optimal integrated solution including the possible application of compensatory measures. All of this with regard to the low demand of sustainable development.

**Keywords:**sustainable development, urban areas, road construction, hydrologic parameters and conditions of the area, the structure of sub-basins, natural flow regimes, modeling the behavior of complex dynamic systems

## 1. INTRODUCTION

Examining changes natural runof in urban areas caused by transport infrastructure, is becoming important, especially, because of there quirement of low sustainability urbanized area. Functionality for highway construction and functionality urbanized area, which is located in building trafficis important to seek a balance of their relationship, the balance of relations between elements of the urbanized area. This interaction, in practice very diverse andexisting, includes many sub-problems. It iscurrent, and you may already acute, these issues seriously, and try to understand them more and be able to deal masonably well. This paper describes changes in runoff conditions that are caused by transport infrastructure, are becoming an increasing degree of urbanization with the most acute problem, including in relation to the potential global climate change.

### *1.1. History*

Historical development of technical solutions road construction and development urbanized a read not always correspond perfectly and corresponds with the requirements for seamless land use in the long term, in terms of sustain able development in relation to the development of predictable conditionsin urban areas. Big problems see in gasin areas where there has been andt here is extensit mining activities. Miningunderground and on the surface also affects transport systems of the above aspects. A negative impal on the construction and operation of a private road construction. It also affects tracing highway constructionin the area.

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### *1.2. Conservative wiev*

The vast majority of authors and thein public ations deals with protection of transport buildings, transport structures and does not address other contexts, eg by changes in runof in the area[1], [2]. It is therefore straight forvard to ensure the functionality of road construction in the area, without examined, as willan urbanized area as a whole. External sources of information (eg [4], [5]) then placing particular emphasis on early warning systems and public institutions, so as to prevent material damage (damage to process equipment, etc.) and loss of life. In the developer countries of WesternEuropeare, developer specialized systems to appropriate visual monitoring of problem are as (both in ruraland in urban areas and municipalities). In particular, the development focuses on creating a very sophisticated systems [4], [5], [6], [7], but too narrowly focused. In a simplified case, we can say that it is a similar too NDIC, the ´´National Traffic Information Centre". Important partial results of such sophisticated systems, it can be appropriate to make even the people who are presentand thusat risk such astherisk of regular or frequent occurrences of floods (including TOR., ‚Flash floods"). However, other problems other interaction urbanized area and transport structures deserve attention.

### *1.3. Solutions*

For example a very important phenomen on, which is more desirable deal is widely known phenomen on acondition wherea network of local rous functions as aspecial kind of sanitation. Traffic Engineering and urban don´t see problems do not enough attention. It turns out that many of these problems and risks is relativem walk able solvable. For example, whether or not properly designed compensatory measures can be negative manifestations of these phenomen and either gatedoor avoided all together. This phenomen on where a network of local rous functions as aspecial type of drainage, can act both positively and negatively. The positive impact of action in combination with variol assistive devices: seeping depressed areas, dry polders, etc. Thus, for example, can have a positive effect on relieving uniform drainage from rainwaterorstorm water drals built with divisions themselves. One of the many manifestations of negative effects of roads (paved area with absence but road surface has little hydraulic resistance of a network of streetsbordered by curi thein wise creates a network of open channels...) is the greater burden of the combined sewerage network, built with divisions or storm drains. We verify that this is a phenomenon where,, a network of local rous functions as aspecial kind of drains"efficiently and effectively exploreusing SW-equipment company AQUION, specifically using Siteflow that can simulate variol situations such model based on its particular suitable modifications and adjustments. So we have a tool to examine possible solutions for a representative set of model specific situations (at the same time also for a representative set of loadinduced by the corresponding values of the design of rain, etc.).

We are exploring whether the applicability of MDM (modified dynamic model) [3], a tool to simulate the behavior of komplex dynamic systems. In our case, for example, based on the structureand connections as shown in Fig.1.The figure 1 shows that can examine both road and rail construction and thus the construction of various other modes. From Fig 1 it is obvious komplex structure of relations, enters a largernumber of elements.

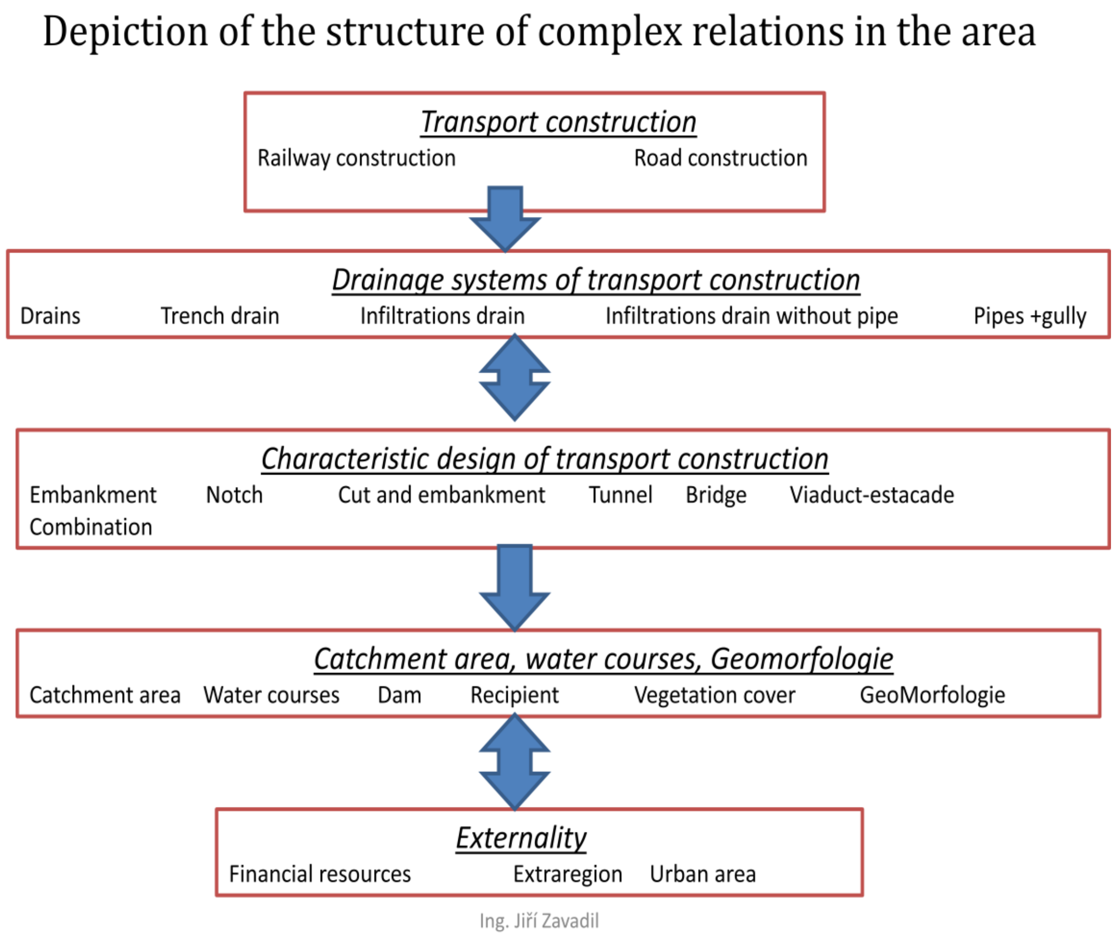


Fig. 1: Structure of relationshipshighway constructionin urban areas- the basic model in Czech language

It is clear that the assessment of highway construction only in terms of their protection can be evaluated as incomplete and inadequate today's situation continued urbanization of the territory. It is important to evaluate the historical intervention in the road construction and objective assessment of whether the design of our ancestors were sufficiently prudent and sustainable long-term development is satisfactory. Another sub-task is to evaluate current and frequently used road construction drainage systems in terms of sustainable development. A study of foreign materials and documents, it is clear that foreign designers, investors, etc., are far more willing to accept the application of sophisticated and innovative solutions.

Generally conservative approach already appears as anachronistic. You can see in Fig 2,3 realiyace optimalized track rail corridor, it is obvious conservative approach to the implementation of the railway track drainage (eg known that uncovered and unkempt railway railway ditches, both paved and unpaved, after one year lose their functionality). Basic inventory status then usually begins by clarifying type solutions, solutions, which is mainly due to normative or even corporate documents, regulations fire regulations, etc. In this respect, it can be concluded preliminary partial in the sense that not all used in practice and occurring type solutions are appropriate to the needs of unification and degree of understanding of the interaction of transport constructions and other elements of the urban area, in terms of low sustainable development. Traffic building water managers are often referred to as the cause of the so-called "drain chaos" in the country. Therefore, it is important to accurately define this term. This is not possible without rigorous. It shows the potential of systemically examine this set of phenomena including through MDM (modified dynamic model) [3] This is already happening, and even partial results are not uninteresting. Systemic and objective (objectified) examination of the interaction phenomena and their simulation allows to obtain instructions and solutions identified, objectively existing problems. It is important to ensure that when a sufficient extent and quality of representative input data (input data are provided by the registration sheet, which is adapted to the treated subject and for specific sub-tasks, making the registration certificate is usually carried out on the basis of expert questionnaires processed by a representative sample of respondents). Examining changes in runoff caused by transport infrastructure can then be made using MDM software programs for the specified model real situations. The software then allows the objectified examine the development of the individual elements of the analysis system see Fig. 1 over time. The development of these standard elements and their solutions can be monitored over time. It is therefore relatively quickly detect potential adverse developments or even degradation of some elements of the investigated system, etc. Similarly, you can define the functional relations (development value of bonds) between elements of the system (model) and to determine the conditions of acceptable operation and functioning of the links themselves elements of the studied system, actively and positively affect their development or by established externalities.

Fig. 2:Picture of the implementation of optimization railcorridor

Very important is also using expert analysis and local investigations to identify themselves constructions sites and causes of failures of highway constructionin relation to specific conditions. Can ensure verification of outputs MDM applications. The evaluation of recurrent typical failures on road construction, it is then possible to reliably determineand remedy the desiredrange of measures including unified compensatory measures.

*1.4. Conclusion*

Shows the efficient use of the available tools addressing current issues such as MDM, etc. Siteflow in other technology sectors, where theyetfor various reasons did not. It is the very real looking and fading unconventional effective and efficient enough to interdisciplinary problems of urbanized area and to better guarantee its sustainable development. In detail it is possible to use such modified SW-tools successfully solve problems of un wanted influences of buildings on runoff in specific situation surbanized area (but always carefully based on localsurveys and condition survey of the solid section of road construction).

Figure 3: Implementation of the culvert under the railway apparently systematic and conservative solutions investments managers of highway construction. The construction does not fulfil the purpose for which it is designed

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# DEPARTMENT OF APPLIED INFORMATICS IN TRANSPORTATION

# K614

The Department of Applied Informatics in Transportation ensures education concerning computer facilities, provides with knowledge from the field of information systems, telecommunication technologies and services of both fixed and mobile telecommunication networks. The mentioned topics are advanced at bachelor, master, and doctoral educating programs.

Fields of department's research activities:

- Creativity models and transportation systems design - Research of non-linear thought processes as analogous and metaphoric cogitation that are neurologically confirmed and dispose of potential for explanation of many drivers´ cogitation aspects and behaviour.
- Robotics, cognitive robotics, mobile robots, electrical engineering - The field of robotics, especially with respect on mobile robots and possible applications in transportation, mutual communication, self-organization of mobile robot groups. Modelling of cognitive system abilities, cognitive models verification on robots, applications in the field of thought processes modelling of transport infrastructure users, modelling of receptive abilities and limitations.
- Simulation technologies for transport modelling HW and SW - System support and development of untraditional simulation technologies applicable in the field of transport systems modelling as distributed simulation technologies application, distributed calculations on graphical adapters, simulation in heterogeneous computer environment (from the HW and system technologies viewpoint). In terms of simulation technologies, the discrete simulation and soft-computing field are considered. Further, the department focuses on building of HW infrastructure for simulation and compute support of activities in other spheres.
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- Artificial intelligence and cognitive sciences, human operators' mental models - Research of artificial intelligence applications (excepting robotics) in transportation, simulation, and advanced creative though processes modelling. Developing new approaches to brain functions modelling. Use of these models for transport modelling and analysing manners how drivers solve unexpected and complicated traffic situations. Optimizing methods and symbolic regression methods by means of genetic algorithms and genetic programming algorithms. Regression models of some more complex transport processes.

# Complex System Analysis by Evolutionary Systems

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**Abstract**

This document discusses ability of advanced evolutionary algorithms combining Genetic Programming Algorithms with Evolutionary Strategies to support analysis of complex systems. The paper brings discussion of GPA-ES algorithm behaviour, its applicability to symbolic regression of deterministic chaos systems and its application to EEG signal modelling.

**Keywords:** genetic programming algorithm, evolutionary strategie, symbolic regression, determiinistic chaos systems, EEG signal

## 1. INTRODUCTION

Transportation sciences studies systems composing from many elements influenced by large groups of humans. Resulting behaviours and features are complex, hard to analyze and it is possible to recognize their chaotic properties frequently. It makes them hard to any analysis and modelling. Especially when in many cases these systems must be modelled by black-box or grey-box techniques. Presented paper discusses ability of GPA-ES algorithm to analysis of these systems. This algorithm is developed with respect of large or even complex system analysis requirements, as it will be discussed latter.

The second part of the paper introduces requirements on symbolic regression algorithm and then it discusses properties and behaviours of GPA-ES algorithm. Then the third part of the paper is devoted to application of the algorithm to the symbolic regression of deterministic chaos systems and the fourth part of the paper then brings results of the EEG signal non-standard analysis with the aid of the GPA-ES algorithm.

## 2. GPA-ES ALGORITHM

The presented GPA-ES algorithm [1] is combination of Genetic Programming Algorithm with Evolutionary Strategy. Evolutionary Strategy is used in the each cycle of GPA work for each individual of its population for optimization of parameters of each model developed by this GPA to optimize developed system or model parameters. Only this computationally expensive way gives certainty that GPA algorithm compares models with well fitted parameters, it means, it compares them without strong influence of noise caused by random errors caused by ill-identified parameters. The magnitude of the fitness function for each individual determines their position to future evolutionary operations – mutation and cross-over ones. Other words, hybrid GPA-ES algorithms are more efficient in symbolic regression of complex systems than original GPAs not looking that there is large computational effort consumed by created structures parameter estimation. Similar ideas tended to development of different combinations of algorithms like Analytic Programming [2] combining Differential Evolution (AP uses standard genetic programming and then interprets resulting string on the place of tree developments applied in GPAs) to structure development with Evolutionary Algorithm in the form of Self Organizing Migrating Algorithm (SOMA).

The GPA-ES algorithm is suitable to so-called Precise Symbolic Regression (PSR). When the sizes of GPA and ES populations and numbers of their iterations are small, the founded solution is approximate – imprecise. Above some limit given by complexity of the solved problem, the structure and parameters of regressed solution equal to original model are reached. In such situation it is possible to speak about PSR. Unfortunately, the required overhead of populations is big and thus it is hard to discover precise models for complex systems when the computational power is limited. Precise regression is also inapplicable in combination to small population application of GPA-ES algorithm – the most efficient operation mode of this algorithm, as it will be discussed latter.

In the previous works as [3 and 4], there is described PSR of differential equations describing deterministic chaos systems like Lorenz attractor, Rőssler attractor, Rabinovich-Fabrikant equations and Van der Pol oscillator. These deterministic chaos systems are useful to verify the algorithm because they contain typical nonlinear structures frequently occurring in the other deterministic chaos systems. Deterministic chaos systems are sensitive to influence of computational errors, initial parameters determination and the other properties complicating symbolic regression.

### *2.1. The GPA-ES algorithm structure*

The above mentioned GPA-ES system combines Genetic Programming Algorithm with Evolutionary Strategy one into structure outlined in Fig. 1. GPA-ES algorithm was used to precise symbolic regression of deterministic chaotic systems from the previously computed data sets. These systems include Lorenz attractor, Rősler attractor, Van der Pol oscillator, Rabinovich-Fabricant system and others. Symbolic regression all of these systems pointed that the sizes of GPA and ES populations are not so significant for algorithm efficiency as total number of fitness function evaluations expressed by equation (1)

$$ev = f\,(GPAind, ESind, GPAcycl, EScycl) \tag{1}$$

Where

GPAind denotes number of individuals in GPA population
ESind is the number of individuals in ES population
GPAcycl is the number of GPA cycles
EScycl is the number of ES cycles
f is the non-linear composition function, in the rough approximation it might represent product $\Pi$ of all parameters.

Good approximation of f is (2) with five control parameters c1 and c2 denoting initial point and k1 to k3 representing sensitivities. This estimation was obtained on the base of both large and small population experiments with precise symbolic regression of Lorenz attractor described below.

$$ev = k_1(c_1 - k_2 GPAind)^2 * (c_2 - k_3 GPAing)^2 \tag{2}$$

The most significant parameters are GPAind and ESind, while ES cycles number must be adequate to number of constants (and it is chosen to be constant) in GPA individuals to reach their reliable optimization and influence of GPA cycles number depends on number of GPA individuals and concluding evolutionary pressure, as it will be discussed latter.

This relation might be illustrated by Fig. 2, where relation of GPA cycles on sizes of GPA and ES populations is illustrated for Lorenz attractor system variable *x*. Lorenz attractor system was originally introduced in the work [10] and it is described by three differential equations (3):

$$\begin{aligned} x'[t] &= \sigma\,(y[t] - x[t]), \\ y'[t] &= x[t]\,(\rho - z[t]) - y[t], \\ z'[t] &= x[t]\,y[t] - \beta\,z[t] \end{aligned} \tag{3}$$

The increase of required iterations for given preciseness (sum of error squares) in the case of the largest populations GPAind=ESind=1000 is probably caused by slower propagation of information in large populations. It is also possible to see, that the number of GPA cycles does not decrease as fast as the number of individuals in GPA and ES populations increase. This observation introduces the study of small GPA population behaviors in GPA-ES algorithm:

Computational complexity of GPA-ES is expressed as (4),

$$O(GPAES) \cong pqnm\log m + pqn\log n \tag{4}$$

Where

n is number of GPA individuals
m is number of ES individuals
l is complexity of structures created by GPA
k is average number of constants in GPA genes, where $k = 2^{l-2}$
p is number of GPA populations
q is number of ES populations

Relatively time-consuming experiments were executed when the problem of symbolic regression of Lorenz attractor system equations (3) was solved, where the sizes of populations were chosen for GPA from 3 individuals up to 13 individuals. Because the behaviour of evolutionary algorithms is stochastic, each experiment must be repeated many times. In comparisons to all previous experiments, see e.g. [3-4], the limit of GPA algorithm iteration number was increased to 14000 cycles, while the number of ES algorithm iterations has remained on the magnitude 40, as well as the sizes of ES populations has remained to magnitudes 10, 40, 100, 400 a 1000. Small GPA populations really increase the population pressure and thus efficiency of computation, as it will be also discussed in the following chapter. On the other hand, the small ES populations bring risk of efficiency decrease, because they give no evidence of reliable determination of constant magnitudes and thus they significantly complicate the GPA algorithm work. This algorithm then makes unsupported eliminations of individuals with imprecisely identified parameters and replaces them by individuals with wrong structure (problem of mutual masking of parameters and structure influence) frequently.

Another and from the practical viewpoint possibly more significant problem of the small populations represents the decrease of parallelization efficiency. When the number of individuals dedicated to block solved by single processor core is small (in the presented cases it frequently contains the only individual), strongly decreases efficiency of parallel algorithm with respect to increasing proportion of overheads related to starting and stopping of threads. Increasing number of iterations also increases the computational time by increasing of amount computations which cannot be parallelized. Thus, it is not possible to use computational power of supercomputers but it is need to wait for results obtained from single-processor machines.

Previous results avoid the question, if the number of iterations is suitable measure of computational efficiency. The equation (5) tells that the small populations should be more efficient because the used sorting algorithm must be more efficient on small populations and thus the crucial question is if the increase of iteration number is not significantly bigger than the decrease of population sizes. From this reason, the number of fitness function evaluations should be better to use measure (5):

$$c = mnpq \qquad (5)$$

For Lorenz attractor equations reconstruction experiments by Symbolic Regression it is possible to obtain the following Figures 3-5.

The view on GPA-ES algorithm through the (6) measure is totally different from the view on the base of total iteration number and it is possible to identify that the size of GPA population is not significant for the time of problem solution except population of 3 individuals where is the average number of iterations of Y a Z variable is close to its limit of 14000 iterations and thus the obtained result is not precise. There is also interesting dependency on ES population size with optima about 4 individuals for all three variables but it is hard to generalize this result for small number of constants in Lorenz attractor system equations and their simplicity. E.g. the first experiments points that for Rössler system symbolic regression are the optimal population sizes between 40 and 100 individuals. With respect to the average number of needed iterations 12000 and 7000 respectively, this case is also small population one.

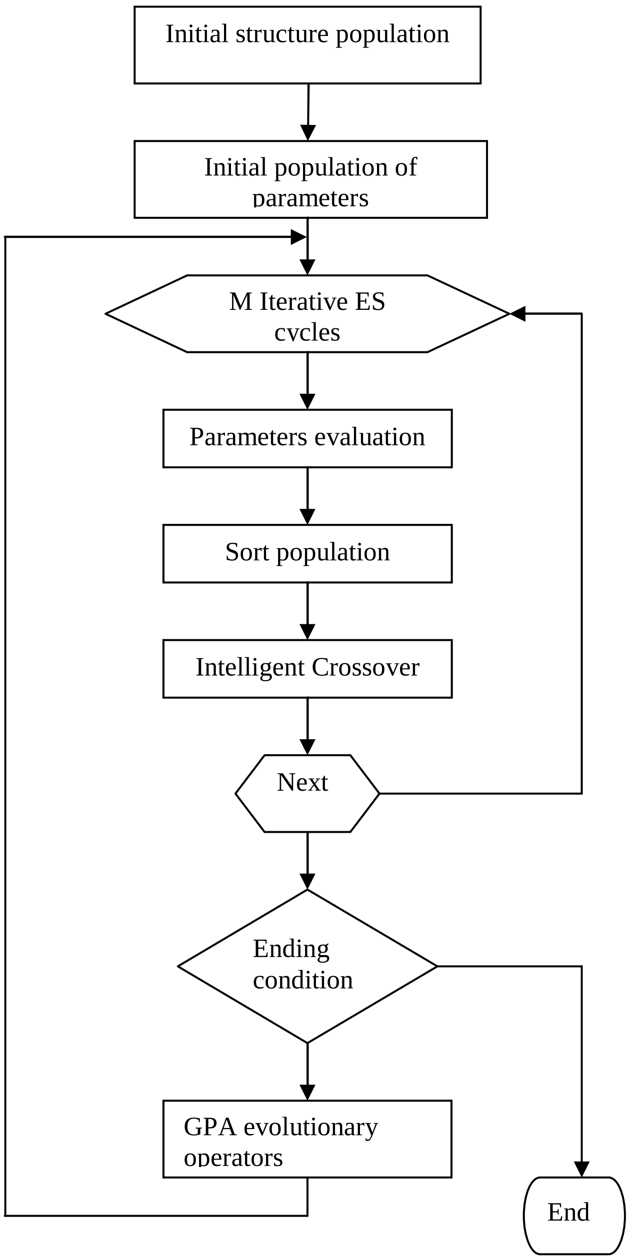


Fig. 1. Structure of GPA-ES algorithm where M is the number of inherited Evolutionary Strategy cycles.

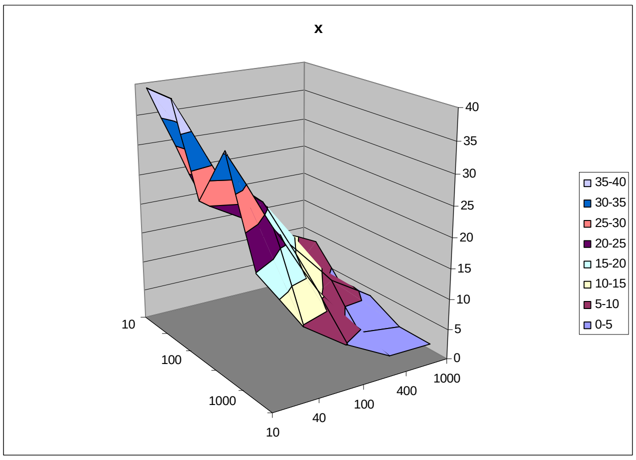


Fig. 2. Dependency of required GPA iterations number on GPA and ES population sizes for precise symbolic regression of Lorenz attractor variable x.

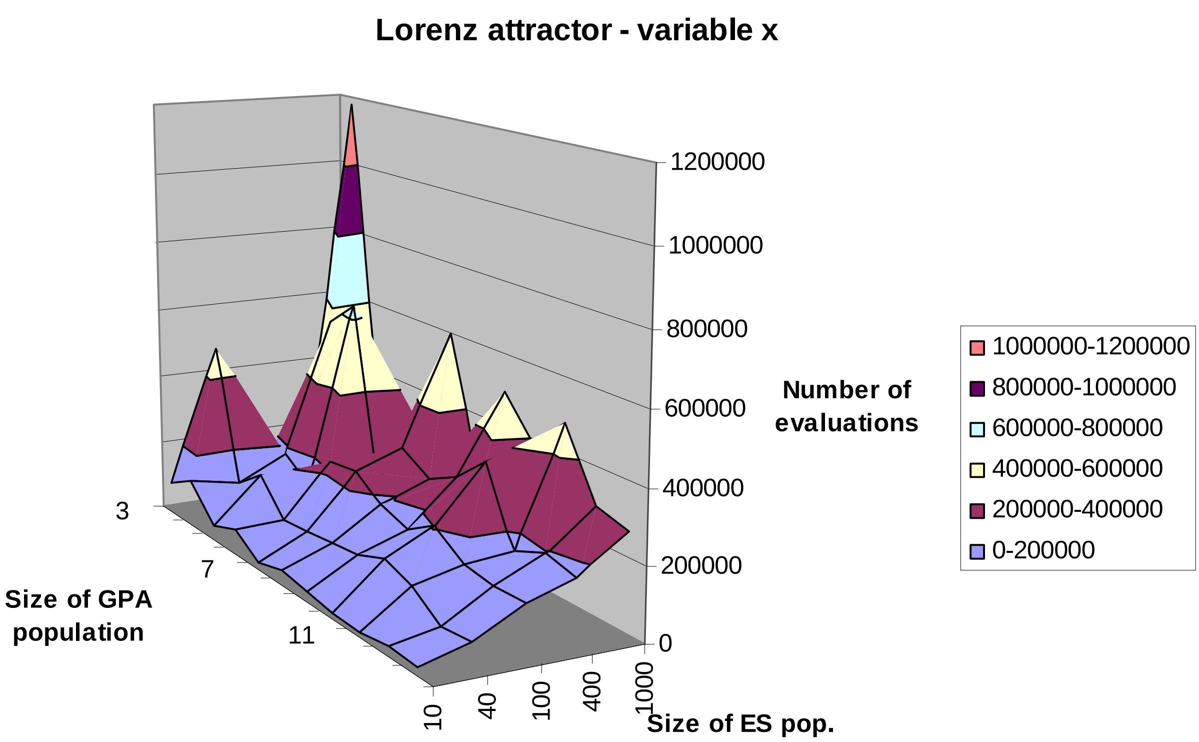


Fig. 3. Dependency of average number of fitness function evaluations on the population sizes in the case of symbolic regression of x variable of Lorenz attractor system

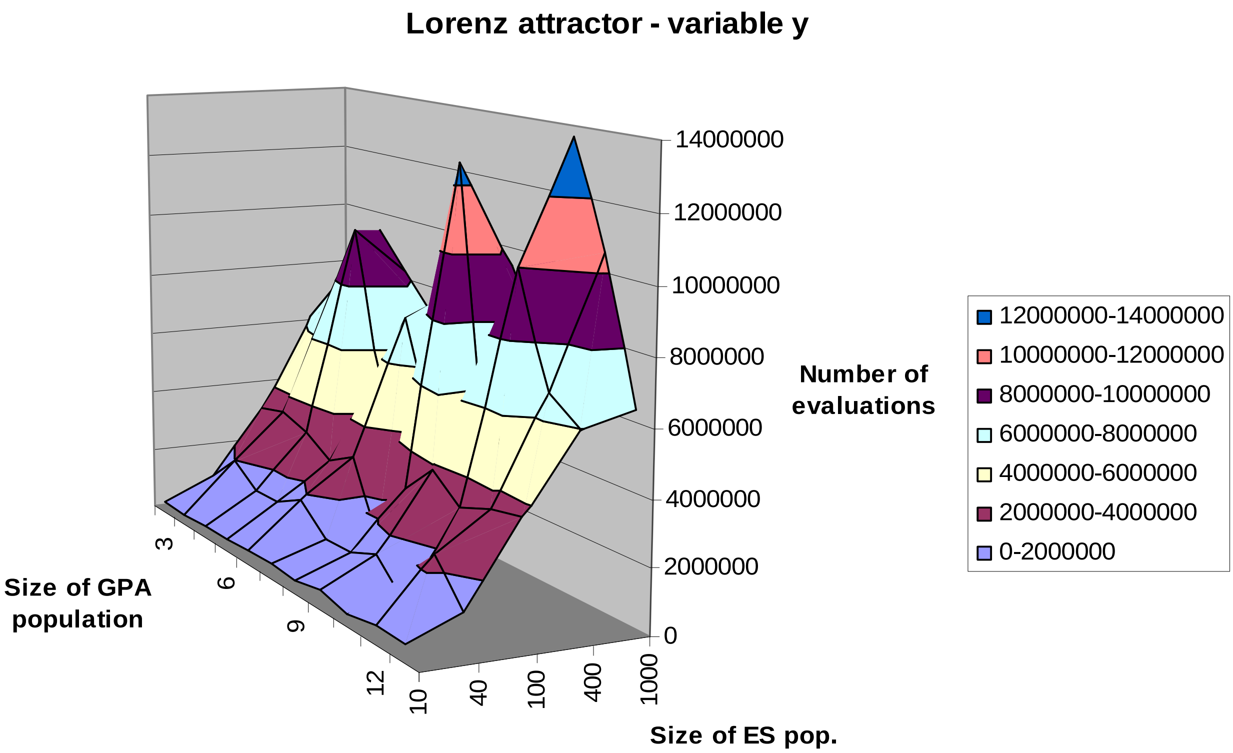


Fig. 4. Dependency of average number of fitness function evaluations on the population sizes in the case of symbolic regression of y variable of Lorenz attractor system

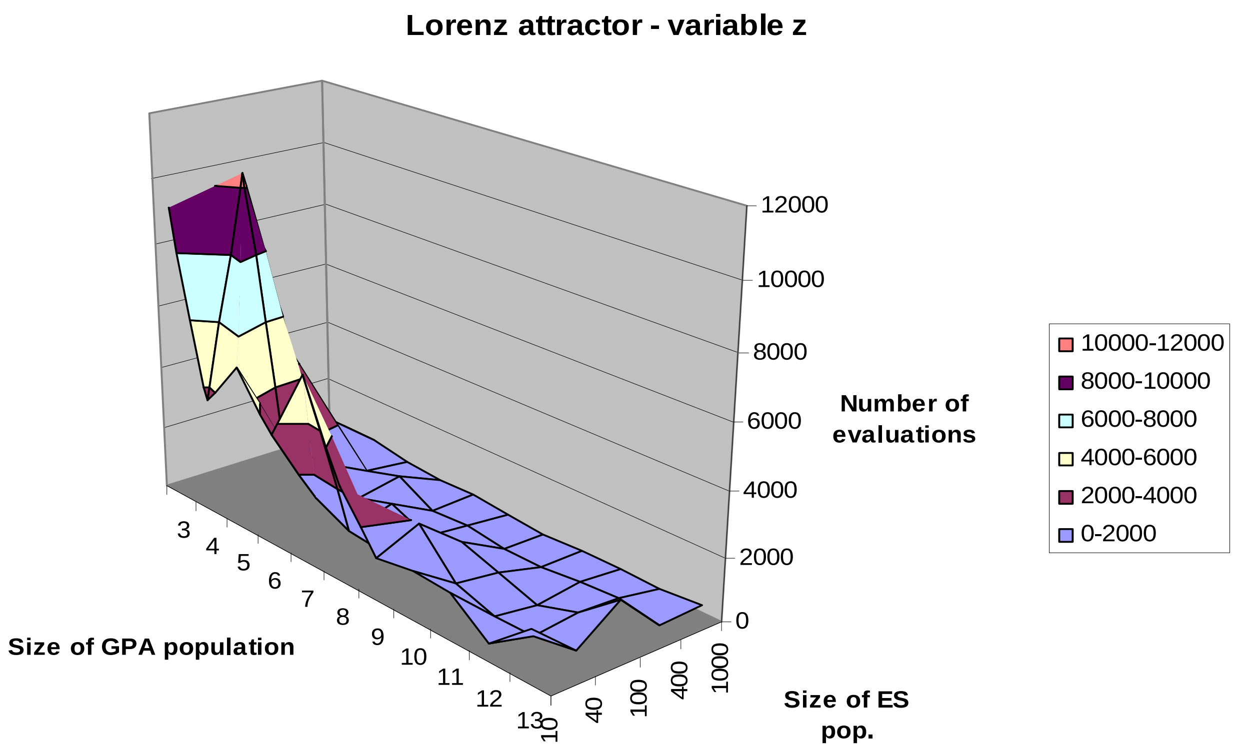


Fig. 5. Dependency of average number of fitness function evaluations on the population sizes in the case of symbolic regression of z variable of Lorenz attractor system

## 3. SYMBOLIC REGRESSION OF DETERMINISTIC CHAOS SYSTEMS

GPAs are able to make symbolic regression of models in both basic forms – as functions of time and as functions of state and input variables. The only difference is in the used form of training data and operator (building block) set. The only small problem occurs when the input data structure allows developing of both models. In such situation state space expands and symbolic regression is less efficient. Because the evolutionary algorithm remains without any change, deterministic chaos systems were used for the algorithm verification. These systems are in the form of functions of previous states (6). The next chapter will discuss application to EEG signal modeling, which is represented in the form of time function (7).

$$x^{/}(t) = f(x(t), u(t)) \tag{6}$$

$$x(t) = g(t) \tag{7}$$

Above mentioned well known systems of deterministic chaos defined on continuous time domain and real value space are described as (3) for Lorenz attractor, (8) for Rőssler attractor, (9) for Van der Pol oscilator and (10) Rabinovich-Fabricant system.

$$\begin{aligned} x' &= -y - z \\ y' &= x + ay \\ z' &= b + z(x - c) \end{aligned} \tag{8}$$

$$\begin{aligned} x'_1 &= \mu * (\mathrm{x}_1 - 1/3 * \mathrm{x}_1^3 - \mathrm{x}_2) \\ x'_2 &= \frac{x_1}{\mu} \end{aligned} \tag{9}$$

$$\begin{aligned} x' &= y(z - 1 + x^2) + \gamma x \\ y' &= x(3z + 1 - x^2) + \gamma y \\ z' &= -2z(\alpha + xy) \end{aligned} \tag{10}$$

In these equations, typical structures listed in (11) are identified:

$$[x^2, x^3, xy, x^2 y, x - y, xyz] \tag{11}$$

To compare real computational complexity of their regression by GPA-ES algorithm, the table of 36 samples for each above listed function and for variables x, y, and z was prepared. With respect to presence of such functions as (7), this list is short, but sufficient for symbolic regression by the used algorithm. The following Table 2 presents numbers of evolutionary cycles needed to regress above listed functions with sum of error squares smaller than $10^{-6}$. For presented test, the size of GPA population was 100 individuals and size of ES populations was 1000 individuals.

Table 1: Numbers of evolutionary cycles of GPA-ES algorithm for specified functions symbolic regression

| Function | Average number of needed iteration cycles | Number of fitness function evaluations |
|---|---|---|
| $x^2$ | 39 | $3{,}9e10^6$ |
| $x^3$ | 147 | $1{,}47e10^7$ |
| $xy$ | 3 | $3e10^5$ |
| $x^2y$ | 41 | $4{,}1e10^6$ |
| $x-y$ | 3 | $3e10^5$ |
| $xyz$ | 8 | $8e10^5$ |

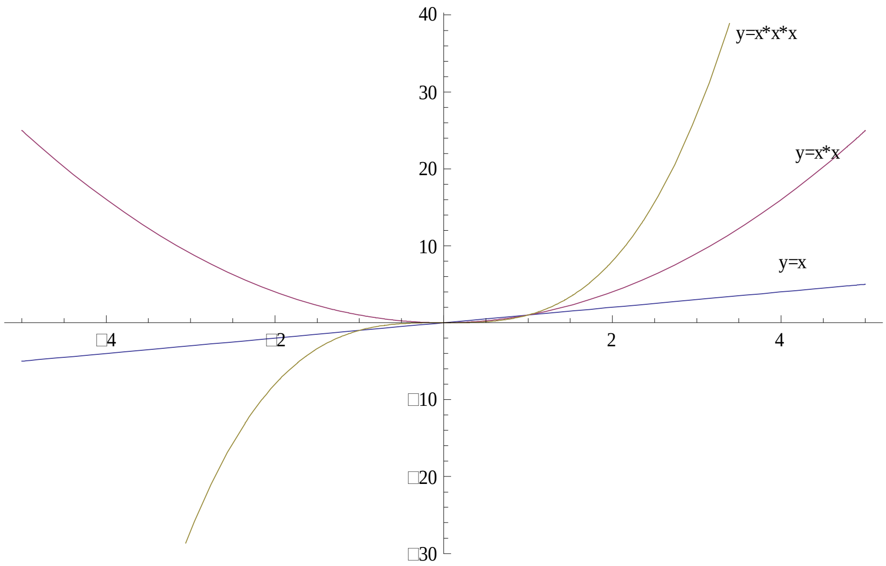


Fig. 6. Discussed functions y=x, $y=x^2$ and $y=x^3$ illustrating problem of movement from original imprecise approximation by monotonously increasing function y=x into better form $y=x^{\cdot 3}$ across function $y=x^2$, which is not monotonous.

Table 1 points that some pairs of equivalent complexity structures might tend to different computational times (and numbers of evolutionary cycles) as in the case of pairs xyz and $x^3$ or xy and $x^2$ , where the computation in one case might be more than 10 times faster than in another case. Small probability of occurrence of structures and in initial population might be computed by Markov chains [16]. Evolutionary operators as mutation and crossover ones tend to analogical results in the case of mutation. Crossover operator gives higher probability to broke structure close to final one than to update it to searched structure. There is also another problem – there is larger similarity between functions y=x and $y=x^2$ than between y=x and $y=x^3$ or between $y=x^2$ and $y=x^3$ as it is illustrated by Fig. 6. This fact decreases probability of movement from y=x to $y=x^3$ because this change requires typically two mutations and the first one must produce function $y=x^2$, which gives worse fitness than original y=x in the case of reaching final $y=x^3$. This modification of the GPA-ES algorithm is able to increase the speed of its convergence (to decrease needed number of GPA-ES algorithm evolutionary steps) 2-10 times.

## 4. NON-STANDARD ANALYSIS OF EEG SIGNAL

Used dataset contains data files collected on 7 drivers (used dataset will be extended, when the first hypothesis will be formulated and verified) and data describing driver vigilant state are represented by 9600 samples. Data representing tired state of them are represented by files containing from 20000 to 45000 data samples. Each sample is a single line in matrix of 36 columns. Full data were recorded during 24 hours taking experiments, but experimental data used in the presented experiment are only small parts of these data selected by physician – neurologist.

EEG marker approach is based not on the comparison of α, β, and γ wave amplitude proportion, but on the analysis of occurrence of typical patterns, groups of waves. Presented work expects that it is suitable to describe these data by difference equations like (13) or (14), but for comparison, black-box model in the form (12) is regressed by GPA-ES algorithm too.

Description by differential equation is better than description by black-box model (description by input and output signal) in 83% percents of test cases. Problem is that this description is more complicated. There is also the problem that approximation error of some samples is too big and so, they cannot be used for reliable analyses.

Black box model of vigilant driver contains the following expressions, typically:

Table 2: Typical expressions in black-box model of vigilant drivers EEG signal (as functions of time). Cx represents x-th constant, t denotes time.

| |
|---|
| C1+t) Sin[c2+t] Sin[(c3+t+Sin[t]) Sin[c4+t]] |
| C1 t(c2+c3 Sin[c4 t])+c5 t Sin[c6+c7 t] |
| (c1+t) (c2+t)+ c3 (c4+t) Sin[Sin[(c5+c6t)]] |
| (c1+t+c2 t) (c3+c4 t+c5 Sin[t]+Sin[c6 t]) |
| C1+(c2+t) (c3+c4 t)+c5 Sin[(c6+c7t)] |
| (c1+t+c2 Sin[c3 t]) Sin[c4 Sin[c5+Sin[c6 t]]] |
| Sin[c1 t] (c2+Sin[c3+c4 t]) |
| C1+c2 t Sin[c3 t] Sin[c4 (c5+t)] |
| C1+Sin[c2 t]+Sin[c3 Sin[Sin[c4 Sin[t (c5+t)+c6]]]] |
| C1+ Sin[Sin[c2]Sin[c3] Sin[c4 t]] + Sin[c5 Sin[c6 t]] |
| C1+t+c2 (Sin[c3 t]+Sin[t+c4 t])+Sin[c5+c6 (c7+c8 t)] |
| C1+$t^2$+(c2+c3 t) (c4(c5+t)+Sin[c6+t]) Sin[c7 (c8+t)] Sin[c9 (c10+t)] |
| C1(c2+Sin[c3(c4+t)])Sin[Sin[Sin[c5(c6+t) (t+Sin[c7+t])]]] |
| C1+c2 Sin[c3 t]+Sin[c4+t] |
| (c1+c2 t) (t (c3+t)+Sin[c4 t])+Sin[c5 Sin[c6 t]] |

It is possible to identify typical building blocks in the Table 2 which are presented in the following Table 3:

Table 3: Typical building blocks in vigilant diver EEG represented as function of time. Symbol Cx denotes x-th constant. None of these functions is integrable.

| |
|---|
| Sin[Sin[Sin[c1 (c2+t) (t+Sin[c3+t])]]] |
| c1 (c2+t) Sin[Sin[(c3+c4*t)]] |
| Sin[(c1+t+Sin[t]) Sin[c2+t]] |

It means that EEG signal similarly as another complex signals observed in nature or transportation systems are described by composed function. The common features of these function is the increase of their complexity with increased degree of derivation and usually they are not integrable. Functions like (12) also have continuous spectra, not only strict frequencies like e.g. Sin(x) function. These facts give Fourier transform inapplicable.

$$y(t) = c_1 \sin(c_2 \sin(c_3 t + c_4) + c_5) \qquad (12)$$

There was provided also comparative analysis searching models in the form (6), but with the similar computational effort (it means with equal limit of GPA and ES cycles and equal population sizes) the obtained models give hundred times greater error than EEG signal models of the form (7). These models were discussed in [6] and their typical shape is displayed at Fig. 7.

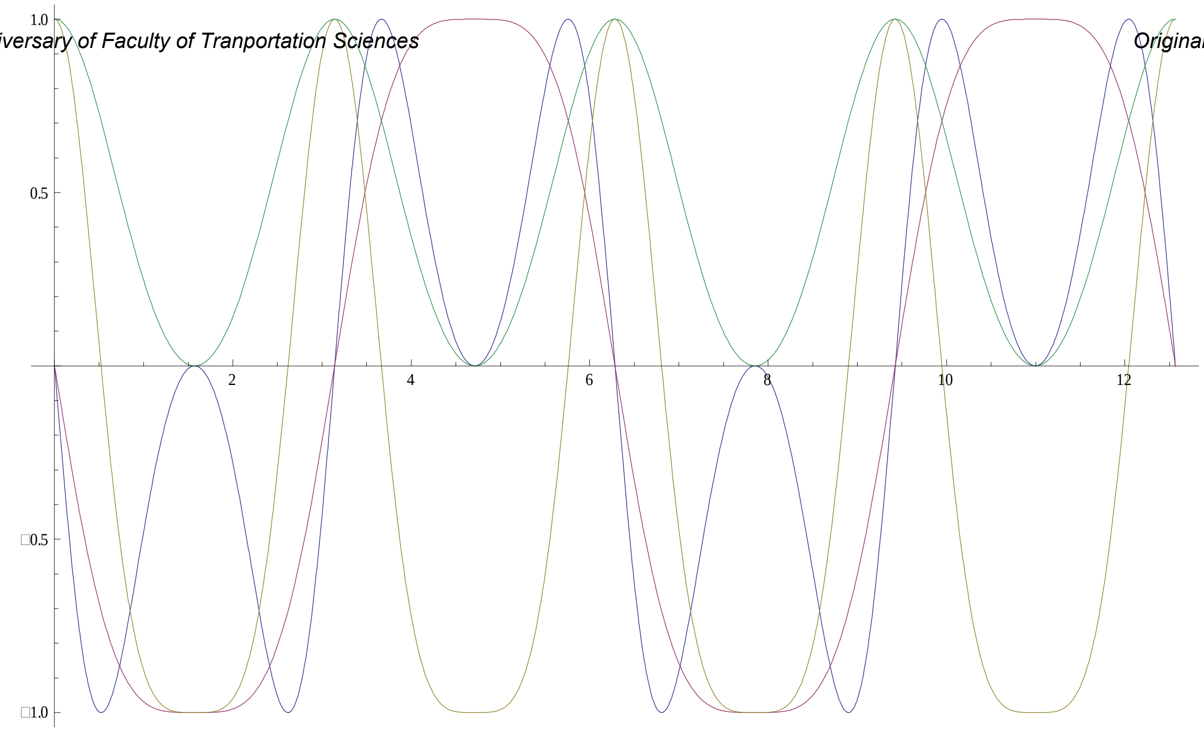


Fig. 7: Example of possible shapes described by function (12).

## 5. CONCLUSION

The development of GPA-ES evolutionary algorithm allowed to make not only efficient symbolic regression of deterministic chaos systems, but also to find novel description of EEG signal. Analysis of complex systems and signals produced by them is difficult for number of dimensions and needed amount of training data. These facts tend to extreme computational complexity and to requirements to efficient and parallel implementation of the used algorithms.

On the base of the above presented work the future works on identification of complex biological and transportation systems without analytical model will continue as well as works on novel EEG signal models and study of behaviours and features of signal description on the base of above mentioned composed functions.


## Acknowledgements

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# Authentication and Fiat-Shamir Protocol

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**Abstract**

The authentication system is an integral part of information systems. It allows access to data and functions of information system only to authorized persons. The paper presents protocols using zero-knowledge technique which make possible pass out of process authentication on condition only prove knowledge of password (or some secret) without leak of them. The paper presents attacker resistance of selected protocols when attacker attempt at fraud and the paper presents experimental measurements of the duration of authentication.

**Keywords:** authentication, zero-knowledge technique, protocol zero-knowledge, attack

## 1. Introduction

To access non-public information to authorized persons in the information systems is used identification, authentication and followed authorization. During user authentication is verified whether the same person whose identity is proven. Authentication must be completed so that the user had access to non-public information. Based on the findings and user authentication is done by authorization, which allowed him access to information, which is entitled to the position of his office, membership of a group, etc.

Verification of for authentication the person can be based on knowledge of "something", having "something" or the user's biometric characteristics. These three possible approaches can be combined but authentication is in practice very often realized only with a password (authentication based on knowing the password). Many information systems are based on the fact that the user knows the password also service provider. When logging in the user entering the password that is sent to the server side (such as plain text or its hash, etc.) where it is verified. If it is not sufficiently secure transmission of passwords over the network, can be obtained by unauthorized persons and later misused. Even the service provider itself could exploit the password that could be tested if not also work for access to another service provider.

## 2. Attacks when Authentication by Password

Authentication by using a username and password belong to the authentication’s category of "knows something". Username is often public information available but the password should be known only authorized user. However, there are risks that the password will be revealed by an attacker. If this happens nothing prevents an attacker to impersonate someone else and generated greater or minor damage.

### *2.1. Observation of Password*

The attacker does not see the password while being physically present but he can use properly positioned camera. In addition to visual recording the attacker can use an audio recording from a microphone that picks up the sound of clicking keys.

### *2.2. Capture of Password*

Capture of password on hardware level requires physical access to the user's computer. Equipment to detect keystrokes can be placed directly into the keyboard or at the end of the data wires. Using the wireless keyboard without strongly enough a secure transmission also allows the attacker to find out the password to a shorter distance.

Trapped by the password is widespread in the software level using the installed malware (spyware or Trojan horse). The task of this malicious program is to collect information about user's computer - among other data, and the password - and later all this information accessible to the attacker.

Very culpable password handling is its transmission across the network in an open form (such as plain text) using an insecure protocol because if the attacker on the same network he can capture traffic and find the login information. But even the use of hash functions (MD5, SHA1, LM hash, NT hash, etc.) through the network sends only the password fingerprint (hash), it is not safe enough because they are accessible on the Internet called "rainbow tables" which contain a variety of hash functions has generated a pair (hash of password and the password as plain text).

### *2.3. Guess or Breaking the Password*

At appropriate cases, an attacker can use a dictionary attack. This attack is based on testing of pre-created word dictionary whose contents can generate hundreds of thousands of words. Attack with this method can have "online" or "offline" form. Dictionary attack can be distributed when other workstations are involved in the attack.

Distributed attack, however, mainly used in the attack brute force is not used when no pre-formed dictionary, but gradually tested all combinations of characters. Again, it is possible "online" and "offline" form of this attack.

### *2.4. Receive a Password by Fraud*

This group of attack includes method of social engineering. Under various fraudulent pretenses attacker attempts to contact the user and the password from him elicit. To obtain password by phishing it is often used e-mail when it is sent an e-mail to user that looks like an official report (e.g. of his bank). These fraudulent messages contain links to Web sites that look like real internet banking website and any credible reason to link the user to use and applied to his account. Improvement of this attack is called "Man-in-the-middle" attack where the fraudulent server all the data entered by the user forwards to the official site and all requests from the official site back forwards the user. The user and the real bank site communicate via an intermediary without knowing it.

### *2.5. Stealing of Password*

Because so many services to which the user must login if he wants to use it leads to the fact that the user always uses the same password. Disclosure of this password allows an attacker to harm in more places. However, if the user selects different passwords, it is a problem with remembering them, so the user can write password somewhere, which reduces security.

Stolen password can also occur through theft of the password file from the server of service provider. Subsequently, the file may be subject to dictionary attack, brute force attack or of attack by and "Rainbow tables". The user should also be careful when using web browsers in the mod "remember the password on server" because if the attacker access to his computer it is risk of disclosing.

## 3. Zero-Knowledge Technique

Typically when authentication using a password, the user must enter the password, making it reveal and service provider authenticates the specified password simply by comparing themselves and stored passwords. If it is not secure enough for its transmission network, can be obtained by unauthorized persons and later misused. It can be problematic and partial applications for user authentication using a central authentication system.

That's why the secret remained secret was founded zero knowledge technique. When using a protocol based on zero knowledge to authenticate itself it is not divulged secrets or not to provide information that could be used for its detection (or can be used but the revelation would be very difficult and inefficient in the current state of knowledge and technical resources).

The mechanism of zero knowledge is used between two parties, party A and party B. Party A knows its secret, and proves its knowledge to the party B, which verifies the proof and decides whether the party A really knows the secret. Such a mechanism must satisfy three basic features:

- completeness – if the proof of party A is true then party B should it accept with a high probability
- soundness – if the proof of party A is false then party B would have had to reject it with high probability
- zero knowledge – party A will not provide any information about his secret to party B

*3.1. Fiat-Shamir protocol*

This protocol is referred as the basic zero-knowledge protocol. Its publication is dated to 1986 and its authors are Amos Fiat and Adi Shamir.

First, initialization must be done:

1. trusted authority T selects and publish the number $n = p \cdot q$ , while p and q are primes and are kept in secret
2. party P ("Prover" – who prove his affirmation) chooses its secret a number *s*, that is relatively prime with *n* (gcd(s,n)=1, the greatest common divisor is 1), while for *s* is valid $1 \le s \le n-1$. Party P calculates $v = s^2 \bmod n$ and the number *v* registers at trusted authority T as its public key.

Table 1 Table 1 A round in the Fiat-Shamir protocol

| | | P | V |
|---|---|---|---|
| 0 | | *s*, *n*, *v* | *n*, *v* |
| 1 | P randomly selects r | *r* | |
| 2 | $P \to V : x = r^2 \bmod n$ | *x* | *x* |
| 3 | $P \leftarrow V : e \in \{0,1\}$ | *e* | *e* |
| 4 | $P \to V : y = r \cdot s^e (\bmod n)$ | *y* | *y* |
| 5 | V accepts proof only if $y \ne 0$ and $y^2 \equiv x \cdot v^e (\bmod n)$ | | |

Fiat-Shamir authentication protocol fulfills all three characteristics (see above):

- completeness – if the party P knows the password s, then it is not problem send to party V number $y = r$ or $y = r \cdot s (\bmod n)$ so when the whole protocol repeated $t$ times the proof the party V accepted with probability 1
- soundness – if the party P knows the password during protocol send $y = r$ or $y = r \cdot s (\bmod n)$ so that the party V refuses to proof with probability 1/2. If the whole protocol repeated $t$ times, it is probability $2^{-t}$ that the party P come out this fraud.
- zero knowledge – the answer of party P $y = r$ is fully independent to the mystery *s*, as well as the response $y = r \cdot s (\bmod n)$ provides no information about the secret *s* because the number *r* is randomly generated and for party V unknown because the implementation of the protocol $e = 1$.

**4. Attack Sensitivity of Zero-Knowledge Protocols**

*4.1. On-line Brute Force Attack on Fiat-Shamir Protocol*

The probability that the attacker guess the password is

$$P(password) = \frac{1}{n-1} \qquad (1)$$

If the attacker had a chance to make $t$ attempts to brute force attack while suffering from memory loss (would not remember what number have already tried) it may occur following a successful of attack variants (0 means failed, 1 means success) provided that each verification is outcome (the verifier sends only $e = 1$).

Table 2 The probability of a successful brute force attack

| Experiment No. | A successful of attack variant | The probability of success |
|---|---|---|
| 1 | 1 | $\frac{1}{n-1}$ |
| 2 | 0 1 | $\left(1-\frac{1}{n-1}\right)\frac{1}{n-1}$ |
| 3 | 0 0 1 | $\left(1-\frac{1}{n-1}\right)^2\frac{1}{n-1}$ |
| ... | | |
| t | 0 0 0 0 ....0 1 | $\left(1-\frac{1}{n-1}\right)^{t-1}\frac{1}{n-1}$ |

Probability of guessing password in $t$ experiments tested unrecorded numbers and verifying each password is only one repetition is

$$P(password, t) = \frac{1}{n-1}\sum_{i=0}^{t-1}\left(1-\frac{1}{n-1}\right)^i \quad (2)$$

If the attacker used an on-line brute force attack he would be found that chose a wrong password only if the verifier sends $e = 1$. Whereas that the probability of sending a verifier $e = 1$ is $\frac{1}{2}$ which is the same as the probability of sending $e = 0$, we can assume that, on average, each chosen password verification took 2 repetitions authentication. It follows that the maximum number of attempts to detect password would be $2(n-2)$ (after $n-2$ failed attempts to have only one remaining untested number and it is certain that it is just the right password).

Of course, for efficiency reasons the attacker remembers the numbers that have unsuccessfully used as a password, so when average of 2 repetitions to verify a single password it is probability of password guessing $t$ attempts

$$P(password, t) = \frac{t}{2(n-2)} \quad (3)$$

*4.2. Eavesdropping and Subsequent Fake Transaction Fiat-Shamir Protocol*

During the interception of unencrypted communications between the prover and verifier the attacker can obtain a unique trio $(x, e, y)$, $x \in \langle 0; n-1 \rangle$, $e \in \{0, 1\}$ and $y \in \langle 0; n-1 \rangle$, $y$ depends on $x$ as well as $e$, in the next text it will be expressed as $y(x, e)$.

Because the authentication protocol implements t-times attacker needs to be 100% confident of successful eavesdropping triads $(x_i, e, y_i(e))$ where $i = \langle 1, t \rangle$ and $e \in \{0,1\}$.

The probability that during one execution authentication protocol verifier generates $e = 1$ is the same as that generated $e = 0$

$$P(e=1)=P(e=0)=\frac{1}{2} \tag{4}$$

The probability is that during one performance prover send authentication protocol specific $x_0$

$$P(x_0)=\frac{1}{n} \tag{5}$$

The probability is that during one performance prover send authentication protocol specific $x_0$ and verifier generates $e=1$ (as well as for $e=0$)

$$P(x_0, e=1)=\frac{1}{2}\cdot\frac{1}{n} \tag{6}$$

Probability that an attacker detects when $t$ repetitions as the authentication protocol for $x_0$ both $y(x_0, e=1)$ and $y(x_0, e=0)$

$$1-\left(\frac{n-1}{n}\right)^t - 2t\cdot\frac{(2n-1)^{t-1}}{(2n)^t} \tag{7}$$

## 5. Duration of Authentication Process

The total time of authentication is generally broken down into sub-periods - the period of calculation on the prover ($calculation\_time_P$), the period of calculation on the verifier ($calculation\_time_V$) and the prover and the verifier communication time ($communication\_time_{PV}$).

$$authentication\_time = calculation\_time_P + communication\_time_{PV} + calculation\_time_V \tag{8}$$

These three times are the sum of partial times

$$authentication\_time = \sum_{i=0}^{j} ctP_i + \sum_{i=0}^{k} ctPV_i + \sum_{i=0}^{l} ctV_i \tag{9}$$

where $ctP_i$ is the $i$-th period of calculation on the prover, $ctV_i$ is the $i$-th period of calculation on the verifier an $ctPV_i$ is the $i$-th prover and the verifier communication time.

For those protocols that need to be repeated several times (generally times) to reduce the probability that the attacker successfully authenticates by fraud

$$authentication\_time = t\cdot\left(\sum_{i=0}^{j} ctP_i + \sum_{i=0}^{k} ctPV_i + \sum_{i=0}^{l} ctV_i\right) \tag{10}$$

Total time for each authentication protocol is based by the complexity of the calculations, on the part of verifier as well as on the part of prover. The total authentication time also affects the volume of data exchanged between the verifier and the prover.

For the authentication protocols that must be repeated several times to reduce the possibility that an attacker authenticating by fraud, their disadvantage is a longer duration of authentication. On the extension of the authentication, however, be viewed in the context of the overall transaction time. If every user request took in the order of seconds is acceptable if the authentication will take e.g. the order of tenths of a second. So it is an important proportion

$$\frac{authentication\_time}{transaction\_time} \qquad (11)$$

For the experimental measurements of the duration of authentication depending on the number of repetitions of authentication protocol, and various telecommunications access solution I programmed Fiat-Shamir protocol in Java. Client code was executed on a notebook Dell Latitude D830, Intel Core 2 Duo 2.4 GHz, 1GB DDR2 RAM and the verifier code on the server Dell PowerEdge SC1425, Xeon 3.2GHz, 1GB DDR2 RAM. As a telecommunications access solution for the client was used:

- Fast Ethernet (100Mb/s) when the client and server were in the same network
- Wi-Fi IEEE 802.11g when client was once in the same network with the server (LAN) and ones in another network (WAN)
- HSPA 3G by mobile phone operator Vodafone and O2.

Each measurement was repeated 200 times. During the measurement has been tested also telecommunications links - packet loss and packet delay.

Table 3 results of measurements on localhost

| number of repetitions | 1 | 2 | 4 | 8 | 16 | 32 |
|---|---|---|---|---|---|---|
| average [ms] | 3 | 4 | 5 | 9 | 14 | 25 |
| variance [ms$^2$] | 56 | 55 | 70 | 88 | 66 | 109 |
| standard deviation [ms] | 7 | 7 | 8 | 9 | 8 | 10 |
| average deviation [ms] | 5 | 6 | 7 | 8 | 4 | 9 |
| median [ms] | 0 | 0 | 0 | 15 | 16 | 31 |
| minimum [ms] | 0 | 0 | 0 | 0 | 0 | 15 |
| maximum [ms] | 62 | 40 | 62 | 78 | 78 | 110 |

Straight line created by linear regression of average durations has the equation

$$AD = 0{,}7 \cdot NoR + 2{,}97 \qquad (12)$$

where is average duration, and is number of repetitions of protocol.

Table 4 results of measurements on Ethernet LAN

| number of repetitions | 1 | 2 | 4 | 8 | 16 | 32 |
|---|---|---|---|---|---|---|
| average [ms] | 191 | 344 | 567 | 903 | 1 589 | 2 896 |
| variance [ms$^2$] | 634 | 4 807 | 3 567 | 1 543 | 1 804 | 1 833 |
| standard deviation [ms] | 25 | 69 | 60 | 39 | 42 | 43 |
| average deviation [ms] | 17 | 63 | 46 | 29 | 33 | 34 |
| median [ms] | 187 | 367 | 578 | 891 | 1 594 | 2 891 |
| minimum [ms] | 140 | 235 | 422 | 765 | 1 469 | 2 796 |
| maximum [ms] | 282 | 515 | 703 | 1 032 | 1 703 | 3 016 |
| | | | | | | |
| ping - minimum [ms] | 0 | 0 | 0 | 0 | 0 | 0 |
| ping - maximum [ms] | 0 | 1 | 0 | 12 | 7 | 0 |
| ping - average [ms] | 0 | 0 | 0 | 0 | 0 | 0 |

Straight line created by linear regression of average durations has the equation

$$AD = 85{,}7 \cdot NoR + 181{,}6 \qquad (13)$$

Table 5 results of measurements on WiFi LAN

| number of repetitions | 1 | 2 | 4 | 8 | 16 | 32 |
|---|---|---|---|---|---|---|
| average [ms] | 202 | 362 | 595 | 995 | 1 790 | 3 262 |
| variance [ms$^2$] | 1 606 | 6 525 | 7 800 | 25 477 | 119 519 | 267 370 |
| standard deviation [ms] | 40 | 81 | 88 | 160 | 346 | 517 |
| average deviation [ms] | 30 | 67 | 47 | 113 | 258 | 364 |
| median [ms] | 187 | 375 | 593 | 938 | 1 640 | 3 047 |
| minimum [ms] | 171 | 250 | 437 | 782 | 1 547 | 2 891 |
| maximum [ms] | 344 | 672 | 1 094 | 1 562 | 2 860 | 4 891 |
| | | | | | | |
| ping - minimum [ms] | 0 | 0 | 0 | 0 | 0 | 0 |
| ping - maximum [ms] | 115 | 116 | 84 | 149 | 123 | 132 |
| ping - average [ms] | 4 | 6 | 3 | 7 | 6 | 6 |

Straight line created by linear regression of average durations has the equation

$$AD = 97{,}5 \cdot NoR + 176{,}5 \qquad (14)$$

Table 6 results of measurements on WiFi WAN

| number of repetitions | 1 | 2 | 4 | 8 | 16 | 32 |
|---|---|---|---|---|---|---|
| average [ms] | 236 | 462 | 747 | 1 177 | 2 017 | 3 628 |
| variance [ms$^2$] | 4 259 | 98 810 | 76 726 | 62 836 | 123 134 | 45 954 |
| standard deviation [ms] | 65 | 314 | 277 | 251 | 351 | 214 |
| average deviation [ms] | 54 | 136 | 118 | 89 | 148 | 118 |
| median [ms] | 258 | 391 | 688 | 1 172 | 1 968 | 3 578 |
| minimum [ms] | 79 | 187 | 391 | 875 | 1 594 | 3 296 |
| maximum [ms] | 719 | 4 000 | 3 703 | 4 094 | 4 922 | 5 406 |
| | | | | | | |
| ping - minimum [ms] | 3 | 3 | 2 | 2 | 3 | 1 |
| ping - maximum [ms] | 39 | 363 | 448 | 705 | 424 | 25 |
| ping - average [ms] | 4 | 8 | 7 | 7 | 8 | 4 |

Straight line created by linear regression of average durations has the equation

$$AD = 106{,}8 \cdot NoR + 256{,}5 \qquad (15)$$

Table 7 results of measurements on HSPA 3G Vodafone

| number of repetitions | 1 | 2 | 4 | 8 | 16 | 32 |
|---|---|---|---|---|---|---|
| average [ms] | 558 | 948 | 1 621 | 2 818 | 5 159 | 10 085 |
| variance [ms$^2$] | 3 200 | 17 009 | 21 329 | 22 475 | 8 957 | 384 735 |
| standard deviation [ms] | 57 | 130 | 146 | 150 | 95 | 620 |
| average deviation [ms] | 45 | 114 | 85 | 87 | 73 | 405 |
| median [ms] | 571 | 929 | 1 625 | 2 797 | 5 156 | 9 860 |
| minimum [ms] | 437 | 750 | 1 344 | 2 562 | 4 922 | 9 437 |
| maximum [ms] | 797 | 1 515 | 3 079 | 3 672 | 5 531 | 12 406 |
| | | | | | | |
| ping - minimum [ms] | 40 | 43 | 40 | 41 | 41 | 40 |
| ping - maximum [ms] | 1418 | 92 | 67 | 87 | 1456 | 1440 |
| ping - average [ms] | 70 | 52 | 49 | 51 | 65 | 57 |

Straight line created by linear regression of average durations has the equation

$$AD = 304{,}6 \cdot NoR + 33{,}5 \qquad (16)$$

Table 8 results of measurements on HSPA 3G O2

| number of repetitions | 1 | 2 | 4 | 8 | 16 | 32 |
|---|---|---|---|---|---|---|
| average [ms] | 886 | 1 312 | 2 237 | 4 144 | 7 784 | 14 197 |
| variance [ms$^2$] | 31 076 | 50 656 | 50 278 | 109 395 | 470 994 | 664 672 |
| standard deviation [ms] | 176 | 225 | 224 | 331 | 686 | 815 |
| average deviation [ms] | 123 | 157 | 166 | 261 | 526 | 610 |
| median [ms] | 844 | 1 281 | 2 218 | 4 071 | 7 656 | 14 203 |
| minimum [ms] | 640 | 969 | 1 657 | 3 453 | 6 532 | 12 453 |
| maximum [ms] | 1 813 | 3 172 | 3 328 | 5 344 | 10 907 | 17 125 |
| | | | | | | |
| ping - minimum [ms] | 57 | 53 | 54 | 54 | 54 | 53 |
| ping - maximum [ms] | 328 | 776 | 1192 | 1195 | 714 | 1427 |
| ping - average [ms] | 98 | 84 | 79 | 84 | 84 | 75 |

Straight line created by linear regression of average durations has the equation

$$AD = 431{,}5 \cdot NoR + 562{,}2 \qquad (17)$$

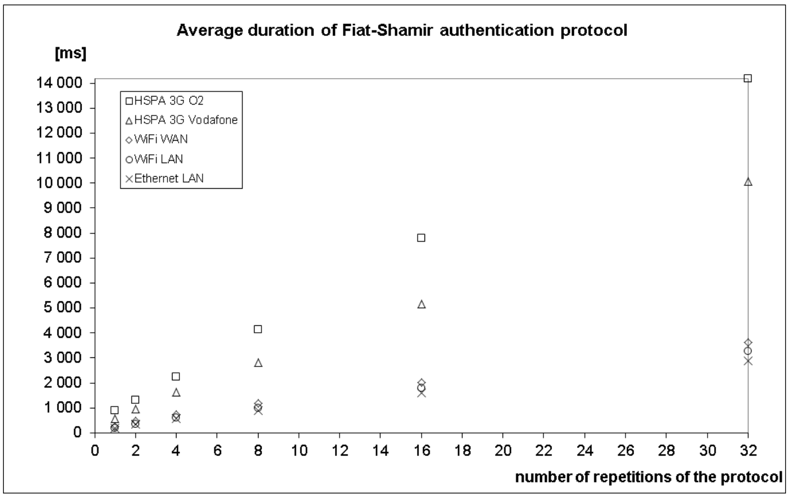


Fig. 1 graph of measured time authentication using Fiat-Shamir protocol for different numbers of repetitions and client’s access point

The measurement was repeated 200 times and the average duration authentication in the worst case was 14 seconds (for client connections via 3G mobile network operator O2). In the best case, the client and the authentication server is not operated on a local computer, authentication time was 2.9 seconds.

The measurement results clearly show that the duration authentication protocol Fiat-Shamir is strongly influenced by the used communication interconnection between the client and the server, or more precisely, the weakest link in the communication chain.

## 6. Conclusion

The paper was presented authentication protocol based on zero knowledge techniques. One of these protocols - Fiat-Shamir protocol - was studied in this work in terms of sensitivity to potential attack. Because the password itself is never transmitting there are no risk of interception and subsequent abuse. During the transfer, the verifier obtains proof of knowing the password the prover, while at the evidence can in polynomial time to verify its accuracy, but the potential attacker obtains of password only such information by which cannot find a polynomial time solution, so in essence of user's password no knowledge gain. The rate of vulnerability of authentication protocols using zero knowledge is dependent on the size of the selected parameter. Due to the advancement of information technology can be achieved largely resistance to vulnerability studied attacks.

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# Modeling of Departure of Vehicles from Light-Controlled Intersections

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**Abstract**

Departure of vehicles from a light-controlled intersection is one of the characteristics which allows us describe behavior of a traffic flow. In order to manage traffic on light-controlled intersections or in the entire traffic networks, it is imperative to describe this behavior with the most accurate mathematical apparatus. Computation of traffic management is determined by a model, according to which vehicles on an intersection set into motion upon the green signal, although in order to reflect today‘s traffic conditions, I prefer to propose using the red-yellow signal. This model is called the departure model. It is defined by the time necessary for a vehicle standing in a queue to cross a reference point after the onset of the green signal. One of the aims of this article is to describe and verify a new mathematical apparatus for departure of vehicles from an intersection – departure model, which would take into account both the preceding vehicles and other parameters influencing departure of vehicles from an intersection. This model is called the basic model. It focuses on simple situations, when a vehicle departs from an intersection without being detained by other vehicles or pedestrians. Additional aim of in this article is to create and describe the methodology for a departure model, which could be used for any intersection, i.e. a set of models from which the most suitable one would be chosen for a given intersection. This model is called the expanded departure model. In order to arrive at such a complex solution, it is suitable to create a model based on a mathematical apparatus of mixture distribution.

**Keywords:** intersection, departure model, departure headways, mixture distribution

## 1. INTRODUCTION

Departure of vehicles from the preshifting area (departure model) is not a new research area. Already in 1947 Greenshields computed the first departure model. This departure model is often defined as time necessary for individual vehicles standing in a queue to leave the preshifting area (i.e. from the point where it already stands in the queue until the STOP line or until another reference point) after the onset of a green signal. This approach no longer yields accurate results today, because many vehicles, especially in Prague, set into motion already after the onset of the red-yellow signal. Naturally, a lot has changed in transportation since 1947, such as the motor pool or degree of motorization. It is also for this reason that new departure models started to be gradually introduced.

Each new departure model was designed to surpass the previous ones in accuracy. This was done more or less successfully, thanks to the real data collected on specific intersections. Examples are works by Webster (1959), Fisher (1968), Lee (1986), Niittymaki (1996) [2], or Li (2006). Examples in the Czech Republic are departure models by Medelská (1972) [1], ÚSMD (1979), or Anoškin (1993) [5]. These models are most often expressed in terms of the departure headways or entrance times in the form – for example as in Table (see Table 1).

Table 1. Departure headways and Entrance times of the Anoškin model

| *Anoškin* | Position of a vehicle in a queue | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Departure headways [s] | 1,20 | 2,40 | 2,30 | 2,30 | 2,20 | 2,30 | 2,20 | 2,20 | 2,20 | 2,20 |
| Entrance times [s] | 1,20 | 3,60 | 5,90 | 8,20 | 10,4 | 12,7 | 14,9 | 17,1 | 19,3 | 21,5 |

Many departure models exist today. They are based primarily on the expression of measured data in a form of an average value of the departure time for a given position of a vehicle in a queue on a given intersection. Some models, such as Medelská (1972) [1], approximate the average value with the help of a mathematical function, for example second degree polynomial equations (Eq. 1).

$$x^2 + bx + c = y \quad (1)$$

Some models are based on the reaction of the driver, characteristics of the vehicle, and others. Their drawback is that the same variables hold for all the vehicles in the queue (for example in King 1977 [7], Eq. 2).

$$T = \sqrt{2\{[S + H(n-1)]/a\}} + RTS + (n-1)RTV \quad (2)$$

where $S$ is distance of the first vehicle from reference point, $H$ is distance between vehicles, $RTS$ is reaction time of first vehicle on the green signal, $RTV$ is reaction time of each next vehicles, $a$ is acceleration of vehicles and $n$ is order of vehicles in queue.

The goal is to take into consideration some influences impacting the departure time of a vehicle: type of the vehicle, direction of the departure, number of entrance lanes (Al-Ghamdi 1999 [6] or Tong 2002 [8]), influence of the morning or afternoon rush hour etc. It is generally necessary to find the extent of these influences on the departure with the help of statistical methods.

Application of any of the above mentioned models revealed considerable faults in estimation of departures of vehicles. This is why a new departure model was proposed. This model is based on a relatively strong mathematical apparatus called mixture distribution, which guarantees the general and robust solution. To my best knowledge, no research, which would address the problem of the dependence of the model on time and location, has been thus far conducted. These circumstances can differ considerably and thus devaluate fix solutions related to a given time and place.

## 2. Model of mixture of distribution and its application in departure model

The model, which I present in this text, contains a whole set of "fix solutions" (I have already earlier proposed a basic version of a departure model, based on parameters influencing the departure of a vehicle), which are automatically selected according to a particular situation. If every intersection or location had its own fix characteristic, which would differ from others, the proposed model would be too complicated and probably not usable. The solution is based on the assumption that changes in both the time and space lead to situations, which do not diverge, but rather merge into each other. A specific basic set of situations, on which the model will be learnt, can thus be created. Based on the measured data, the part of model (component or combination of components), which best corresponds to a given situation, will be activated.

Model of mixture of distributions is a set of models (components), usually of regression nature, and a random process, which can be referred to as "pointer". It is a process, which is discreet in time and values and which can be either static or have a form of Markov chain. Its values point in individual instances to the active component. Therefore, we are considering a set of models and a pointer, which identifies the right model. The right model is the one, which best confirms to the measured data. The benchmark for the corresponding of the data and the model is the likelihood function. First, it is necessary that the model learns. That is achieved with the help of data collected on a large number of representative intersections. Once the model was learnt, its function is as follows: based on the incoming data, the model determines a component of weighted combination of several components, which best corresponds to the data. Subsequently, it calculates the optimal prediction of departure times based on the chosen components of combination of components. Should the situation on the intersection change (due to the time or location in which the model would be applied), new incoming data activate a different component or a group of components, which will best correspond to the data. This is how adaptability of the proposed model is achieved.

An example of real system, which is suitable for a description with a mixture-model, is a situation in urban traffic. Let us take an early morning, late morning, afternoon, evening and night traffic in a city. Each of these regimes has different characteristics and we could switch among their sub-models (components) according to time. However, a mixture-model reacts to actually measured data sample and, according to it, it looks for the most suitable sub-model or a combination of sub-models for an ideal description of the given situation. Hereby, it generates the best description of the system in its actual mode. This selection of relevant model can be understood as a classification, which regardless of the time instant determines in which regime the traffic finds itself at the given moment. Although in the evening traffic should subside, the collected data can suggest that for some reason (accident, demonstration etc.) the traffic behaves as if it was a midday.

I try to be more specific by indicating basic results of derivation the estimation and classification algorithm for dynamic mixtures. The goal is not to present the results in detail, but to show the main tools used and to comment on them.

### *2.2. Theoretical background - Models*

A mixture-model consists of a set of models that describe individual system modes, so called components, and a discrete stochastic process c_t whose items at each discrete time instant t point to the active component. The components can be modelled by normal regression models, the pointer model is considered in the form of Markov process, described by a table of transition probabilities.

Component models are mostly introduced as normal linear dynamic regression models expressed in the form of a conditional probability density function (pdf)

$$m_{c;t} = f_c(d_t|\phi_{t-1}, \Theta_c) \qquad (3)$$

for $c = 1,2,\cdots,n_c$ where $f(\cdot\,|\,\cdot)$ denotes a conditional pdf, $d_t$ is the measured data vector, $\phi_{t-1}$ is a regression vector influencing the data $d_t$, $\Theta_c = \{\theta_c, r_c\}$ are unknown parameters of the $c$-th component, $\theta_c$ are regression coefficients and $r_c$ is the noise covariance matrix. Apostrophe denotes a transposition.

Pointer transition model describes the evolution of the pointer, indicating at time t the active component

$$f(c_t|c_{c-1}, \alpha) = \alpha_{c_t|c_{t-1}} \qquad (4)$$

Where $c_t$ is the current pointer entry, $c_{t-1}$ is the value of the last pointer entry and $\alpha$ are pointer model parameters - the table of transient probabilities. It holds: all entries of $\alpha$ are non-negative, and it holds $\sum_{c=1}^{n_n} \alpha_{c|c_{t-1}} = 1$, for $c_{c-1} = 1,2,\cdots,n_c$.

For a description of the model parameters $\Theta$ and $\alpha$, he conjugate priors, corresponding to the normal distribution of components and multinomial distribution of the pointer model, are chosen

$$f(\alpha|d(t-1)) \sim D_\alpha(v) \qquad (5)$$

$$f(\Theta|d(t-1)) \sim G_\Theta(V, \kappa)$$

Where $D_\alpha(v)$ denotes Dirichlet and $G_\Theta(V, \kappa)$ Gauss inverse Wishart distributions and the symbol $\sim$ assigns a specific distribution. More details about the conjugate priors can be found in [14].

### *2.3. Estimation*

The basic point for all derivations is the joint pdf $f(c_t, c_{t-1}, \alpha, \Theta|d(t))$ describing all unknown variables. This joint pdf can be decomposed as follows

$$f(c_t, c_{t-1}, \alpha, \Theta|d(t)) \propto w_{c_t|c_{t-1}} D_\alpha\left(v_{t-1}^{[c_t, c_{t-1}]}\right) G_\Theta\left(V_{t-1}^{[c_t]}, \kappa_{t-1}^{[c_t]}\right) \qquad (6)$$

where the weights are

$$w_{c_t|c_{t-1}} = f_{c_t;t}^{d} \hat{\alpha}_{c_t|c_{t-1}} f_{c_{t-1};t-1}^{c} \qquad (7)$$

Here

$f^d_{c_t;t} = f_{c_t}(d_t|d(t-1)) = \int_{\Theta^*_{c_t}} m_{c_t;t}\, d\Theta_{c_t}$ is the data predictive pdf for the component $c_t$, $\Theta^*_{c_t}$ is the definition region of the parameter $\Theta_{c_t}$.

$\hat{\alpha}_{c_t|c_{t-1}} = E\left[\alpha_{c_t|c_{\{t-1\}}}\middle|d(t-1)\right]$ is the point estimate of the transition probability from the state $c_{t-1}$ to the state $c_t$ based on the data up to time instant $t-1$, $E[\cdot\,|\,\cdot]$ is a conditional expectation,

$f^c_{c_{t-1};t-1} = f(c_{t-1}|d(t-1))$ is the (prior) pdf describing the pointer values at time $t-1$ with the data measured up to time $t-1$.

The symbols $D_\alpha$ and $G_\Theta$ denote Dirichlet and Gauss-inverse-Wishart pdfs, describing respective model parameters, with partially updated statistics $\nu^{[c_t,c_{t-1}]}_{t-1}$, $V^{[c_t]}_{t-1}$ and $\kappa^{[c_t]}_{t-1}$. By partially updating statistics we mean, the statistics that for each component $c_t = 1,2,\cdots,n_c$ and each previous component $c_{t-1} = 1,2,\cdots,n_c$ are updated as if both $c_t$ is and $c_{t-1}$ were surely the active components. The final update is performed in the approximation step, which follows. For more details about updating the statistics for estimation of normal and multinomial model see [14].

Let us now stop for a while at the weights $w_{c_t|c_{t-1}}$ defined in (7). They express the actual probability (i.e. taking into account the current data $d_t$) of transitions from the state $c_{t-1}$ into the state $c_t$. They are composed of (from behind): the prior description of the pointer $f^c_{c_{t-1};t-1}$ multiplied by the estimate of the transition table. This product forms the pointer prediction for time $t$, based on information brought by the data up to time $t-1$. It is

$$f^c_{c_t;t-1} = \sum_{c_{t-1}=1}^{n_c} \hat{\alpha}_{c_t|c_{t-1}}\, f^c_{c_{t-1};t-1}. \tag{8}$$

The first term in the weights (3) is the data predictive pdf $f^d_{c_t;t}$ which expresses a probability that the current data item could have been generated from individual components $c_t = 1,2,\cdots,n_c$. In this way, this pdf takes into account also the actual data item.

Now, let us define weights $w_{c_t} = \sum_{c_t=1}^{n_t} w_{c_t|c_{t-1}}$ that express the probability that the $c_t$-th component is actually active irrespective to the last active component $c_{t-1}$, which is the solution of the classification problem. For these weights it holds

$$w_{c_t} = \sum_{c_{t-1}=1}^{n_c} w_{c_t|c_{t-1}} = f^d_{c_t;t} \sum_{c_{t-1}=1}^{n_c} \hat{\alpha}_{c_t|c_{t-1}}\, f^c_{c_{t-1};t-1} = f^d_{c_t;t} f^c_{c_t;t-1} \tag{9}$$

From the last term of the previous formula it can be seen that the probabilities of the active component are composed of two factors: the data prediction measuring a kind of proximity of the current data to individual components and the pointer prediction that “guesses” the active component from the older data. The way, how the pointer is predicted, can be seen from the last but one term of the previous expression or from (8). The actual system state is predicted from the last pointer estimate and the estimate of the transition table.

To be able to construct the weights (7) or (9), the parameters $\Theta$ and $\alpha$ must be currently estimated. For the posterior pdf of the pointer and for those of the parameters, it holds.

Pointer estimate can be obtained from (6) by summing over $c_{t-1}$ and integration over $\alpha$ an $\Theta$.

$$f(c_t|d(t)) \propto \sum_{c_{t-1}} w_{c_t|c_{t-1}}. \tag{10}$$

Estimate of $\alpha$ follows from (6) by summing over both $c_t$ and $c_{t-1}$ and integrating over $\Theta$

$$f(\alpha|d(t)) \propto \sum_{c_t} \sum_{c_{t-1}} w_{c_t|c_{t-1}}\, D\left(\nu^{[c_t,c_{t-1}]}_{t-1}\right). \tag{11}$$

Estimate of $\Theta$ can be computed again from (1) by summing over $c_t$ and $c_{t-1}$ and integrating over $\alpha$

$$f(\Theta|d(t)) \propto \sum_{c_t} G_\Theta\left(V^{[c_t]}_{t-1}, \kappa^{[c_t]}_{t-1}\right). \tag{12}$$

In the previous relations, the notation introduced previously has been used.

## 3. Test model on real data

Model of mixture of distributions is a set of models (components), usually of regression nature, and a random process, which can be referred to as “pointer”. It is a process, which is discreet in time and values and which can be either static or have a form of Markov chain. Its values point in individual instances to the active component. Therefore, we are considering a set of models and a pointer, which identifies the right model. The right model is the one, which best confirms to the measured data. The benchmark for the corresponding of the data and the model is the likelihood function. First, it is necessary that the model learns. That is achieved with the help of data collected on a large number of representative intersections. Once the model was learnt, its function is as follows: based on the incoming data, the model determines a component of weighted combination of several components, which best corresponds to the data. Subsequently, it calculates the optimal prediction of departure times based on the chosen components of combination of components. Should the situation on the intersection change (due to the time or location in which the model would be applied), new incoming data activate a different component or a group of components, which will best correspond to the data. This is how adaptability of the proposed model is achieved.

This theoretical approach has been tested on a set of data consisting of 1,219 departure vectors. Each departure vector is composed of three vehicles waiting in a queue for the green light. The departure vectors have been divided into three components (clusters), using the mixture distributions, hereby three important types of intersections have been found (Fig 1). The research further tried to establish, if it is possible to use the data of secondary quantities measured for each departure vector (for example the direction of departure of the vehicle, angle of the road etc.) to determine, in retrospect, to which cluster each departure vector belongs (the likelihood function above).

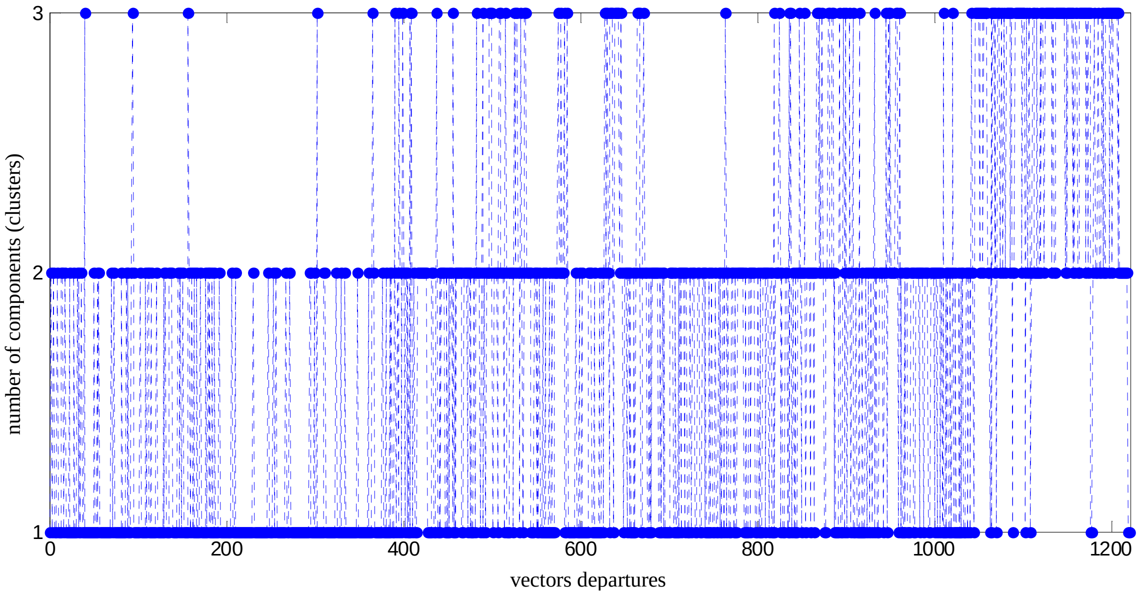


Fig 1. Assigning departure vectors into the particular cluster

For this would confirm that secondary quantities have significant impact on the departure of a vehicle. This part of the experiment was done using the logistic regression. The outcome has confirmed that secondary quantities carry information, which we can use to “show” the respective component (cluster) and thus use this component (a specific departure model) for departures of vehicles from a light-controlled intersection.

## 4. Conclusion

Application of mathematical apparatus of mixture of distributions on departure of vehicles from an intersection turned out to be the right and promising in finding the more accurate departure model. This methodology allows to determine more accurately departure times of vehicles in a queue in the relationship to their position and parameters of the intersection and therefore has a potential to be universal as opposed to local. This new approach will be further developed and made more accurate with the aim of its application for management of a light-controlled intersection, with the ultimate goal to positively influence traffic capacity of an intersection.

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# Old Age and Biometric Verification

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**Abstract**

The paper discusses the identification of seniors using biometric identifiers. It compares the possibilities of using biometric methods most commonly used for this age group. Specifically, it focuses on biometric user identification method by structure of veins on the wrist and the negative effect of medications on vascular disease on the quality of the scanned samples.

**Keywords:** seniors, biometrics, vein structure, wrist, medicaments, verification

## 1. INTRODUCTION

Unique identification of an individual is today, thanks to increased security risks around the world, a very timely topic. Therefore, to the fore increasingly getting biometrics. Biometric features are unique to each individual, non-transferable, inalienable, and we are all still together. Boom cognitive biometric methods is due to the high security risks, both the development of the necessary technologies and their affordability. Biometric characteristics of today just do not use private companies to identify their employees and the protection of property, but increasingly also national administrations (for example the introduction of biometric passports). In the future, biometric identification by replacing the existing character any proof of identity.

Generally, the most widely used biometric methods are: fingerprint, hand geometry, facial geometry, structure of blood vessels in the retina, the structure of the bloodstream palm or back of the hand or finger. I'm in my research devoted to identifying individuals with lived structures on the wrist, and I specialize in people over 65 years old.

## 2. Defining the target group

Number of seniors, people over sixty-five years, is increasing. With the availability of medical care, health care rising standard of living and other factors, people still live to old age. Seniors remain active longer both professionally and socially. They arrange their affairs themselves in offices, go by public transport, travel abroad, etc. The pressure on the independence from the company is very high. However, with old age comes sooner or later not only health complications but the everyday problems associated with just the signs of aging (slow pace of life, forgetting the problems make sense of the flood of information or changes to the reception).

The introduction of unique identification using biometrics, or using a particular biometric character, would this particular age group of the population (but not her) simplify everyday life. Seniors (and others) would in itself did not have any documents, credit cards, keys. There would be no worries about them forgotten, lost things or passwords and any costs associated with the processing of new documents and acquiring new things.

## 3. Comparison of the possibility of using the most widely used biometric methods in terms of seniors

The introduction stated that at present, the most commonly used methods for biometric identification and verification of individuals are: fingerprint, hand geometry, geometry faces, the structure of blood vessels in the retina, the structure of the bloodstream palm or back of the hand or finger.

### *3.1. Fingerprint*

The advantage of identifying individuals using fingerprint is easy to obtain a comparative sample, a large number of possible sources of the sample (we have 10 fingers), and also that this method can be used for the vast majority of the population. When used to obtain the fingerprint touch the sensor, then in terms of the elderly can be a problem with hand shaking, then the finger when shooting not turn and the user must press a finger on the sensor optimal force - neither too lightly nor too and push the sensor damage. When the reference sample gained patterning (swipe your finger across the silicon sensor), would have the user learn the correct procedure. This scanning method is not intuitive and generally speaking, the older a person is, the harder and longer to learn new things. The contactless sensor, which can be optical or ultrasound must be scanned finger also at rest in one position.

### *3.2. Geometry of the face*

Biometric method based on the geometry of the face investigates face shape and position of the optically important places on the face, such as those eyebrows, eyes, nose, mouth. In the database then put distance between the eyes, the distance from the nose and lips more. It is a method for the elderly user acceptable.

### *3.3. Geometry of the hand*

Hand geometry biometrics is not entirely clear property is used ie for medium security. In older people may change reference sample because of edema fingers, arthritis (joint deformation, distortion fingers) or changes in the thickness of the fingers. When placing the hand into the correct position can sensing process prevent shaking hands.

### *3.4. Retina of the eye*

When identifying individuals by the retina of the eye is kept on vascular structure in the background of the human eye around blind spots. This method requires the user to look exactly designated area while shooting. If a user wears glasses (which carries most elderly), must be removed and can be very difficult for him to look for the destination to be watch. They may have difficulty in focusing and fixation targets people with strong astigmatism.

### *3.5. Structure of bloodstream*

The use of structures such as blood vessels biometric identifier is relatively new and has been made possible through the development and greater availability of the necessary technology. The most frequently used to identify any individual structure bloodstream palm and back of hand. In recent years, the use began in the private sphere structure bloodstream finger. From the perspective of the user (regardless of age) is a user-friendly method that also guarantees a high level of security. In this group biometric methods include an user identification by structure of veins on the wrist, which will be described in more detail below. Elderly could capture reference sample or subsequent identification or changes complicate diseases of the venous system, or action of medicaments that are used to those conditions (more will be broken down in the chapter number 4).

It follows that in terms of seniors is not mentioned method without any complications. Aging is the least affected by the geometry of the face. This, however, does not belong to biometric methods with the highest level of security (for example, the face can be changed through plastic surgery). Geometry sensing face can also be negatively affected by improper lighting.

## 4. User identification by structure lived on the wrist with a focus on seniors

### *4.1. Description of the method*

Biometric scanning method based on the blood vessels (veins structure) on the wrist is very safe. The veins are not found on the body surface, so their structure can not be fake. In addition, acceptable sample can be scanned only from the living individual. It is comfortable for the user, when shooting one does not need to touch the device. The method is non-invasive and hygienic. Furthermore, there is a method completely unambiguous. Every man, even twins, has a structure of veins unique on the wrist, which guarantees unambiguous identification of an individual. Even vary the structure of veins on the right and the left wrist of one man. At the same time, this method can be considered as relatively new and less extended (the first commercial systems were implemented in 2000). Structure lived on the wrist is easily accessible biometric character with a wider and more comfortable for users possibility to use in practice.

### *4.2. Scanning method*

Scanning the structure of veins on your wrist can take place using a special camera operating in the infrared. The result is a black and white image of veins branching structures, in where we find a distinct pattern. Source of infrared light shines through the hand and due to different absorption (reflection) radiation blood vessels and surrounding tissue creates an image. Thanks infrared light to emphasize the contrasts between the bloodstream and surrounding tissues. Blood carries oxygen around the body. It binds to hemoglobin and oxyhemoglobin forms, which penetrates the surface and oxygenates the blood vessels surrounding tissue - which allows image rendering structures bloodstream. This is clearly given, that this method allows imaging only living individuals.

### *4.3. Use the device*

In my research I use to capture the structure of veins on the wrist PalmSecure device from Fujitsu, which includes LED emitting infrared light. thereby illuminates the shooting area and also removed near-infrared image. As a second device is used Nikon camera (SLR type) and infrared illuminator. Nikon camera with such equipment is better than the output device PalmSecure - the resulting image has a higher resolution output. As an illustrative example I present Figure 1 and Figure 2. Figure 1 is a snapshot of the structure of veins on the wrist shot PalmSecure device. In Figure 2, the structure of veins on the wrist snap a modified Nikon camera.The acquired images are vectorized, thus obtaining images that could be better processed (make algorithms) and they are also less demanding in terms of volume.

Fig. 1: PalmSecure

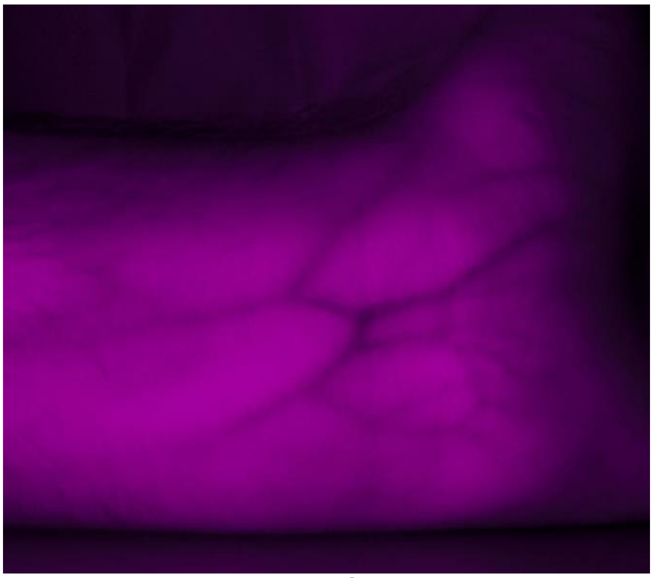
Fig 2: Nikon

### *4.4. Seniors*

For seniors aging occurs due to degenerative changes of the venous system, such as: arteriosclerosis, phlebitis, blockage and clogging of blood vessels, making blood clots. All the mentioned diseases are caused by the aging process, and today it is possible to treat these problems or mitigate with medicaments. However, their use may negatively affect the quality of the scanned sample as well as degenerative changes itself. As shown in Figure 3. The Figure 3 shows the structure of the veins on the wrist a man who's 83 years old. Man uses every day Godasal 100 (the active ingredients are Acidum acetylsalicylicum 100mg and Glycinum 50 mg per tablet), medicament that thins the blood and thus fights against blood clots. Another medicaments that is used every day man, it is Torvacard 20 (the active ingredient is Atorvastatinum in the form of Atorvastatinum calcium 20 mg per tablet), which is to lower blood cholesterol levels. In Figure 3 are clearly visible degenerative changes of the venous system and the negative impact of medications on the image quality. Changing the density of blood (its dilution) makes the contrast between veins and surrounding tissue oxygenation is very small and therefore it is very difficult to recognize the structure of veins on the wrist. For comparison even mention Figure 4, in which the structure of veins is captured woman, who is 35 years old. This woman does not take any medications and does not suffer from any disease of the vascular system.


Fig. 3: The structure of the veins on the wrist (a man, 83 years)

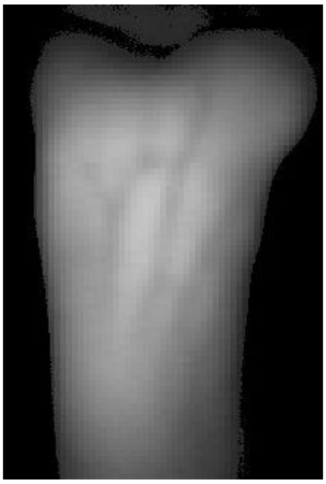

Fig. 4: The structure of the veins on the wrist ( a woman, 35 years)

### *4.5. Collected data*

The actual sampling has several phases. In the first stage, I measured the reference samples. For each, I noted the following parameters: age individuals (all persons older than 65 were years), medicaments that used the individual (especially medicines for diseases of the vascular system) and other information related to his medical condition (for example, whether a smoker or nonsmoker).

Each individual was then removed in the course of a few samples and each sample was noted, whether an individual is using or not using medicaments for cardiovascular disease and whether it took place or has taken place verification. The collected data showed that if an individual was taking medication for cardiovascular disease, significantly decreased its success verification.

## 5. Conclusion

Today, for a given age group, thus the elderly, treatment of illness or problems related to the venous system quite common. That it can be examined biometric identifier used without problems in the broader practice and in the continuation of my research will focus on finding a suitable algorithm that could compensate negative impact of medicaments on the verification process in the elderly.

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# Sensitivity Matrices in Public Transport Complex Safety and Anti-Collision System Description

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**Abstract**

From the system analysis point of view, the transport system behavior during destructive impacts has to be analyzed simultaneously through structural and functional sensitivity analysis. This approach is giving possibility to find key influenced places and components in the system having the significant role in the safety and security of the transport system.

**Keywords:** Transport, safety, security, sensitivity analysis, sensitivity matrices

## 1. Introduction

As we can see in documents of US Transport Security Administration (TSA) a transportation system can be viewed as a set of interdependent links and nodes in which no element is secure if it can be influenced by weak influences. Because transportation security is interdependent in nature, safety strategy must be built on a systems point of view. It is why transportation system can be thought of as a very complex system of interacting elements, which is adapting to each other over time. The concept of a Complex Adaptive System (CAS) can be described from the point of view of „complexity theory", which offers following conclusions:

- The system usually behaves non-linearly-which means that small perturbations in the system can sometimes lead to large effects
- The system displays „emergent properties" – which means that complex patterns can be based on specifically random interactions among all elements of the system.

These conclusions are the key to understand why TSA´s mission is to enhance transportation security. Terrorists seek to inflict damage that is out of proportion to their efforts by attacking parts of the system that will lead to non-linear consequences. TSA must guard against that risk. In seeking to minimize the impact of security measures, TSA seeks to ensure that the emergent patterns of commerce in our economy are not disrupted.

The public transport, especially urban public transport, has to be described as an open system in three hierarchical levels:

- public transport infrastructure
- transport processes
- information system , see Fig. 1

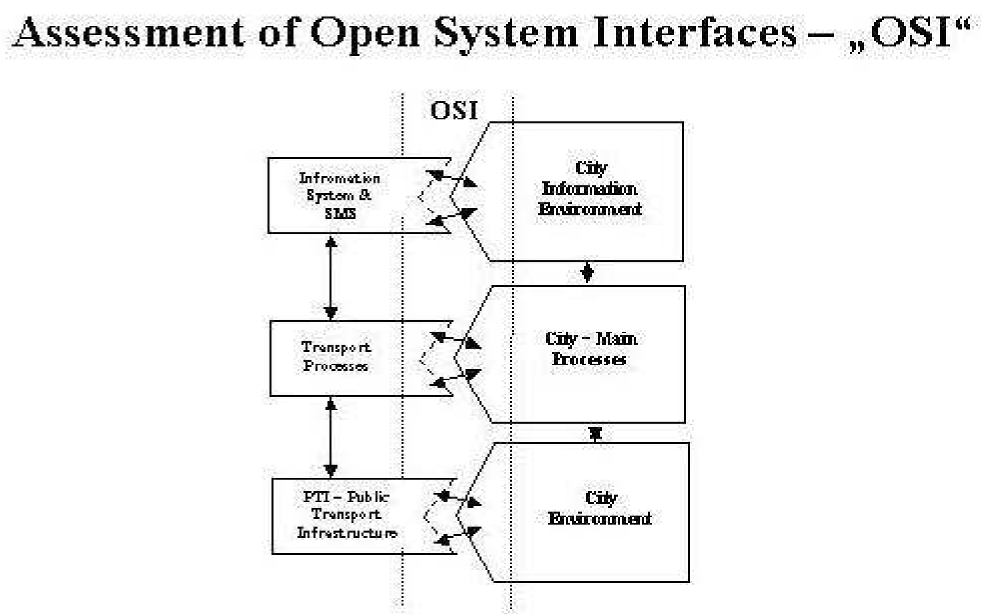


Fig. 1 Public transport system levels - open system

From the system analysis point of view, the system behavior during destructive impacts can be expressed simultaneously by structural and sensitivity analysis, where function F represents multi-parametrical general function describing the fluent and safety transport flow.

## 2. Sensitivity analysis – conditions for safety and security management system design

The incremental changes of resulting general system function F can be generally expressed as $dF(dF_1, dF_2, \ldots dF_n)$, where the set of input effecting factors is represented by vector of state variables: $dI(dI_1, dI_2, \ldots dI_n)$.

To have possibility for modeling of resulting function to the matrix equation has to be introduced the matrix of sensitivities $S[s_{ij}]$ , where elements $s_{ij}$ corresponds to individual sensitivities of the process in the public transport. The output function of matrix equation of the faze x represents the input function of the phase x+1. The complex sensitivity matrix in the equation (1) is a good format for the comparison of the main sensitivities to find the dominant one. The structural concept of system sensitivity analysis is based on the graph theory, especially on the sensitivity of transfer function of the graph on the individual branches in the graph structure and the dominant sensitivity place in the graph (critical place in the structure) can be finded.

$$\begin{bmatrix} dF_1 \\ dF_2 \\ dF_3 \\ \cdot \\ \cdot \\ \cdot \\ dF_n \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} & \cdot & \cdot & \cdot & \cdot & s_{1m} \\ s_{21} & s_{22} & \cdot & \cdot & \cdot & \cdot & s_{2n} \\ \cdot & & \cdot & & & & \cdot \\ \cdot & & & \cdot & & & \cdot \\ \cdot & & & & \cdot & & \cdot \\ \cdot & & & & & \cdot & \cdot \\ s_{n1} & s_{n2} & \cdot & \cdot & \cdot & & s_{nm} \end{bmatrix} \cdot \begin{bmatrix} dI_1 \\ dI_2 \\ dI_3 \\ \cdot \\ \cdot \\ \cdot \\ dI_n \end{bmatrix} \tag{1}$$

or in the simplified form:

$$[F] = [S] \cdot [I] \tag{2}$$

If the sensitivity is expressed by relative scale, than the parameters are also relative values:

$$x_{ir} = \frac{x_1}{x_{\max}} \quad (3)$$

where $x_{max}$ is the maximal value of the measure.

Relative Stress Sensitivity Matrix is defined through the equation:

$$F_{i,rel} = Sr_{ij} \frac{dx_j}{x_{j,\max}} \quad (4)$$

where

$$Sr_{ij} = \frac{dF_i}{dx_j} \cdot \frac{x_{j,\max}}{F_{io}} \quad (5)$$

and where $F_i$ is the relative change of influence of the parameter in component i a $dx_j$ is deviation of value $x_j$. Coefficients of relative sensitivities can be replaced by fuzzy parameters, or in final form by fuzzy matrices.

$$S_{ij} \in \{1, 2 \ldots 5\} \quad (6)$$

The stages could be determined by expert evaluation.

The measures of fuzzy description - $Sr_{ij}$

| $x_j$ | Measure of influence | $Sr_{ij}$ |
|---|---|---|
| 1 | No influence | 0 |
| 2 | Small influence | 0,25 |
| 3 | Middle influence | 0,5 |
| 4 | Remarcable influence | 0,75 |
| 5 | Dominant influence | 1 |

Having use so called „integral measure“ of the parameter influence the time factor will be taken in the account. The matrix equation will have than form:

$$FM_{Vi}(T) = \frac{1}{T} \cdot \int_{t_2}^{t_1} \sum_{j=1}^{k} (Sr_{x_j}^{C_i} \cdot W(t) \cdot x_j(t))d \quad (7)$$

Where $T = t_1 - t_2$ is the time duration of the monitoring of system parameters in the vector $V_i$

And the vector
$M_C(T) = [M_{C1}(T), M_{C2}(T), \ldots M_{Cn}(T)]$
is called the integral measure of influences of the set input state variables. Having the evaluation of sensitivity matrix parameters the weakest system component.

**3. Anti-collision system in public transport**

For all terrestrial transportation systems on roads, railroads, water and also in the air, the danger of collisions significantly increases. This is the natural price, which we all have to pay for increasing traffic density and speed. Many serious accidents of transportation vehicles occur daily in the all countries around the world. The losses, both economic and on lives and health are tremendous and consume still higher part of each world country economy budget.

This fact has already before many years motivated many people for investigation of the reasons of such collisions and for development of various anti-collision systems, the main aim of which is to be seen in:

1. warning against the possibility of transportation vehicles collisions,
2. their prevention, if possible, and eventually
3. minimizing their consequences.

At first, the complexity of respective Systems alliances with which one has to deal in space transportation is already now so high, that the configuration of partial cooperating systems must be carefully controlled and coordinated. This concerns also the cooperation of the whole systems alliance, controlling the movements of space vehicles in respective part of cosmic space.

The system concept of safety and reliability in cosmic space will be therefore based on "layered" model, including system description of related objects interaction in the layer:

- object – outer space,
- object – object,
- object – internal space vehicle world (including the interaction with crew and internal vehicle interfaces).

This concept involves not only the identification elements of multi-dimensional matrices of related sources (agencies), impacts, but also the multi-dimensional matrices of agencies transmissions and multidimensional matrices of impacts to the object construction and crew activity. These matrices will be investigated also from the respect of transmissions sensitivities.

## 4. Conclusion

The successful ACS must be developed as a complex, complicated and will need to operate with very high functional safety and reliability.

The problem of research and development is of high inter-disciplinarily.

For its successful solution it is necessary to use all the disposable knowledge from

- System and Systems Alliances theory and analysis,
- Telematics,
- Control engineering,
- Reliability and safety theory,
- Theory and analysis of complicated signals,
- Prediction diagnostic of multi-dimensional systems,
- Reliability of interactions of human subjects with artificial Systems and Alliances,

Czech technical university in Prague has concentrated capacities and competencies for such research program.

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# Artificial Neural Networks for Models of Driver´s Brain Functions

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**Abstract**

Neural networks are used in various applications such as signal modelling, prediction or pattern recognition, however, they are still rarely used for the purposes which stood beside the original motivation of the concept of their development; the inspiration for the design of the artificial neural networks was an attempts to imitate the functions of the biological neuron. The growth of computational power in connection with the increasing knowledge of the biological neural cell makes viable the original idea of using the neural networks for fast decision making and recognition of situations in similar way to the humans. Several research centres throughout the whole world are now carrying out the task of accurate brain simulation. Despite the complexity of this assignment and the unprobability of meeting it during the next years, the work on such simulations can improve the knowledge of brain functions which can lead to many practical applications that can improve the transport safety and effectivity by helping the human operator. The improvement proposed in this article can increase the quality of modelling and simulation.

**Keywords:** neural networks, modelling, prediction, road safety, brain functions, human machine interface

## 1. INTRODUCTION

The state of art of the brain function simulation is briefly described on three projects (Blue Brain, Blue Brain and China Brain). In the second part, the author´s work on the simulation by neural networks is described.

All the simulations that are realized by the neural networks have in common the basic inspiration by the biological neuron. This cell, with high complexity, carry out its functions by seemingly simple function. The observation of the biological neuron led to several models; the most commonly known is the McCulloch Pitts model. In this model, the neuron is simplified as a unit with several (theoretically unlimited) number of inputs and one output. Every input has its weight which multiplies the signal that is coming into the input. The weighted inputs are summed and subsequently the transfer function of this sum is calculated. Typically, the Sigmoid or Radial Basis Functions are used as the transfer functions. Mathematically, the output is

$$y = f(\bar{x} \cdot \bar{w}) \quad (1)$$

$$f_s = 2/(1 + e^\wedge(-s)\,) - 1 \quad (2)$$

$$f_{RBF} = e^{-s^2} \quad (3)$$

where $\bar{x}$ is the input vector and $\bar{w}$ is the weight vector. Examples of sigmoid and radial basis function are in eq. (2) and (3) respectively. This is an example of mathematical model (and is the most commonly used mathematical model). There is a high variety of both mathematical and physical models. The first physical model was Louis Lapicque model (1907) called also ´Integrate and Fire model´ that suposses that the neuron fires a constant signal when the sum on the inputs exceeds some level. Hodkig-Huxley model (1952) describes the biophysical function on more detailed level and uses the analogy to the electric circuit. FitzHugh-Nagumo model (1961) is good for the description of the situation in the short time period when the electric signal is fired. Morris-Lecar model (1973) is focused on the oscillations caused by the $Ca^{++}$ and $K^{++}$ ions. There are many other physical models of neuron that are mostly useful for medical research and can also be used for the simulation purposes.

Apart from the aforementioned McCulloch-Pitts model, there are many other mathematical models of neuron and neural networks. The ADALINE (ADAptive LInear NEuron) and MADALINE (many Adalines) are structures based on McCulloch-Pitts neuron with different learning processes. Both of these paradigms belong group of so called supervised learning algorithms, which means that there are two phases in the use of the network. The first one is the learning phase when the network is trained on data for which the result is known. Then the parameters are fixed and the network is used for patterns that haven´t been presented before but that are similar to the training data. The second group is the unsupervised learning, where the problem is to find a hidden structure in unlabeled data.The Self-Organizing map (SOM) and Adaptive Resonance Theory (ART) are commonly used unsupervised learning algorithms. In continuation, 3 significant models of brain functions are described.

### *1.1. SyNAPSE*

SyNAPSE (System of Neuromorphic Adaptice Plastic Scalable Electronics) is a DAPRA program that aims to develop an electronic device that scales to level of biological neurons. The required cognitive computer is supposed to have similar form and architecture as the mammalian brains (for mammalian brains the layered structure is typical). The artificial brain should have similar total number of neurons, synapses and connectivity as a mammalian brain. In this project participate several universities and IBM research centre.

The basic motivation for this project is the expected insufficiency of the current principles of Von Neuman´s architecture, which doesn´t provide enough computational power for distributed algorithms. The way how the information is treated in Von Neuman´s based computers and in biological network is completely different. The biological network doesn´t distinguish between computation and memory. In the brain, there is no specific section for memory, rather the memory is distributed throughout the whole brain. Thanks to this fact, the computation (even though much simpler than in case of processor) is running at much higher speed. By contrast, in case of computer the speed of the access by bus to the information stored in the memory is the main limit of the computation and will prevent the continuation of the growth of speed, even if Moore´s law continues valid. The simulation of the brain function is not the main task of SyNAPSE, even though the results are often presented by comparison to the part of mammalian brain that was simulated (the press releases usually speak about the simulation of rat cortex, cat cortex, etc., however, it is more an understandable presentation than a real research). The main task of SyNAPSE is the design of new architecture of computers. Until now, the greatest simulation has $10^9$ neurons and $10^{12}$ synapses and is running of BlueGene/P supercomputer, where it is about 100 times slower than in the reality.

### *1.2. Blue Brain*

Blue Brain is a European project that is coordinated by the Polytechnic University of Lausanne in cooperation to IBM research centre. The target of this project is different from the target of SyNAPSE. The SyNAPSE is focused on the simulation of a huge number of simple neurons, meanwhile the BlueBrain is focused on exact simulation of small number of neurons. The research was started to model a small part of cortex with the highest accuracy possible. The network consists of relatively small number of neurons that are true copies of biological neurons. The project is divided into several stages; in the first part, the software model of neuron was designed. Later, these neurons were composed into a model of column of rat, which contains $10^4$ neurons and $10^8$ synapses. The column is a structure that is often repeated in the brain, therefore this model is applicable to wider simulations. The project BlueBrain is toughly related to Human Brain project which unites 12 research institutions for the sharing of knowledge about biological neurons. One interesting issue of this project is the relation between the real word and the model. In case of biological neuron, the existence of the neural network depends on its function (incorrect function of the neural network can cause the death of the organism), in case of the model, the neurons are virtual and no deviation to the correct function endanger its existence.

### *1.3. China Brain*

China Brain is project of Wuhum University started in 2008 aimed to the design of the ´artificial brain´. This project works with the principle of neural modules, which means groups of 12-20 completely connected neurons. According to the theory, the intelligence should emerge from these modules. The modules itself are not intelligent, but in connection should perform intelligent behaviour. The first goal of this project is an independent robot whose motorics is based on 50 000 neural modules. The relative lack of information related to this project thwarts the usability for another research. In all the cases of these simulations, the energy needs of the artificial systems by far exceeds the natural ones.

## 2. Neural networks for models of human operator

Within the purview of the project that is taking place on the Department of Applied Informatics, the new type of learning of neural network has been proposed. The idea is to simulate some of the brain functions (the simulation of the whole brain is far beyond the possibilities of nowadays science). However, as the simulation of the brain as a whole is not achievable with current facilities, it is worth to try to simulate some particular functions that can improve the quality of life by enhancing the safety and effect of activities performed by human operator. Especially, in transport one can find many applications where the human operators are the key factors for the fulfilment of the task. For instance, the driver on the highway is doing relatively simple task of maintaining the distance from the previous vehicle and the position on the lane. This relatively monotonous work is in fact in contrast to the majority of the activities of our brain, therefore a possible thread caused by the loss of attention is a problem that can be hardly avoided. Another possible threads are situations when the driver is in another state of mind (aggresivity, micro sleep, inattention). These states are difficult to detect or even predict. The better we understand the way how the brain interacts, the higher is the probability to find out when the possibility of an error is higher.

The proposed neural network is called ´homeostatic´ neuron because the name describes its main principle–the use of the idea of homeostasis in the field of artificial neural networks. The homeostasis (or the ability to maintain favourable internal conditions in environment that is under changes) is a principle often used in many fields as biology, chemistry or sociology, but rarely in connection to neural networks. One of few exceptions is the work about the hardware realization of neural nets with special interest on homeostasis that is presented in [1]. The principal question of spatial memory is discussed on the background of neural cell in [2], where the homeostasis is playing an important role. There are many other applications that can be improved in connection with the principle of homeostasis, from which the vast majority focus on the transmission of electric signal [3,4].

The proposed neuron is based on McCulloch Pitts model, where the sigmoid function is used as transfer function (2). The similarity in the main characteristics to biological neuron was required; for this reason the typical back propagation learning is not a suitable; the back propagation implies that a higher structure (or teacher) exists and trains the neuron. Instead, the homeostatic neuron makes use of its proper forward connection to improve its functionality. Here, the idea is not that the neuron is ´learning´ some function, but it is increasing its importance to other neurons. The ´axon´ in this wiev has two functions–first (as in the other models) is the transmission of the output signal, the second is the training of the neuron.

The principle is that the neuron wants to improve its importance in the network, which means it is trying to maximize the part of its output signal that is accepted by other neurons. That is not in contradiction with the physics of the real neuron, as the signal transmitted by the axon has also the energy form and in fact is inseparable from the energy.

The process of learning can be described by this procedure: first, the neuron computes its output with its initial random weight according to (1) and (2). The neuron in the higher layer set their weights according to their level of contentment with the reference neuron. In the next step, the neuron changes its weights according to some algorithm (may be differential or random). Several possibilities of this algorithm are described later in this paper, however, the important point is that the neuron is comparing its function with the previous states, which implies that it must have memory.

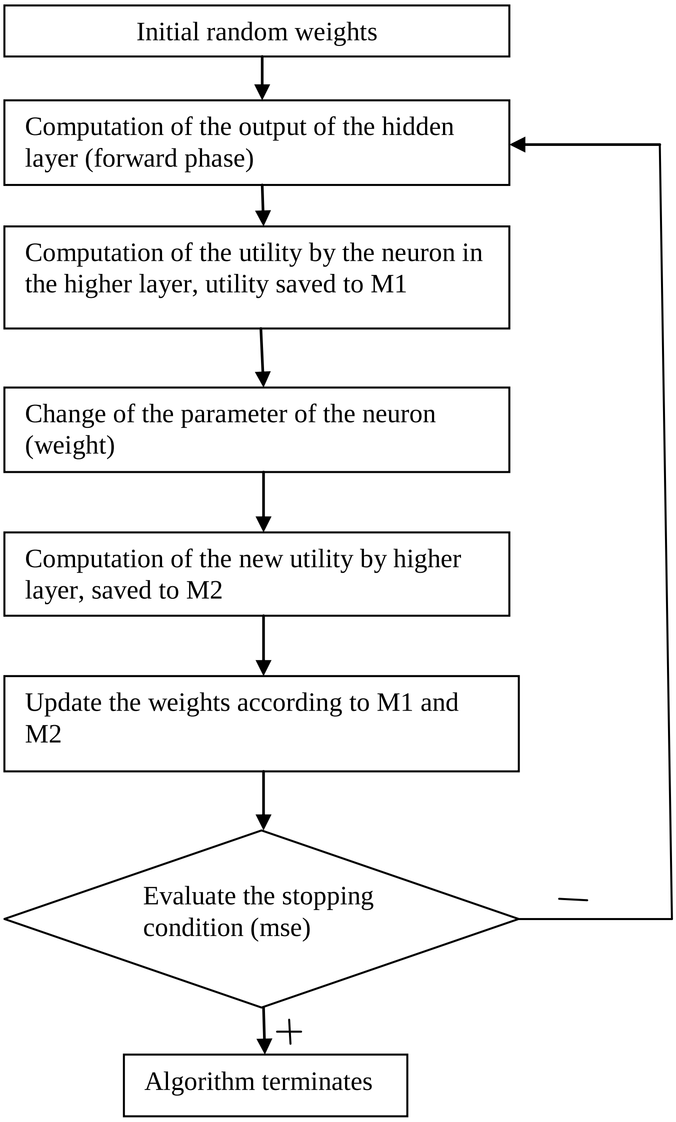


Fig. 1. Learning of the neuron in algorithm

Several methods can be used to calculate the importance of the neuron. The basic difference among these methods is the number of the output neurons for which the reference neuron is ´working´. The first extreme is a neuron that is working for all output neurons. This neuron is improving all the output weights without taking any particular output neuron into consideration. The other extreme is a neuron that works only for one neuron in the higher layer, or that is optimizing its function in order to improve its utility for only one neuron. There are many compromise solutions between these cases.

*2.1. Learning based on the sum of the output weights*

This idea corresponds to the first case (neuron is trying to be useful for all neurons and therefore is maximizing all the output weights). In other words the neuron is finding such a weight vector $\Lambda=\{w_1, w_2, ... w_n\}$ for which the sum of the absolute values of the output weights is maximal. This idea corresponds firmly to the biological model because there is only one axon and therefore the neuron can only be aware of the total amount of the signal that is accepted by others, not of the particular weights. In the artificial neuron we also count with negative weights; because of that, the neuron sums the absolute or square values. The utility q is:

$$q = \sum_{j=1}^{n} \left| w_j^o \right| \quad (4)$$

respectively

$$q = \sum_{i=1}^{n} (w_i^o)^2 \tag{5}$$

Eq. (5) puts stress on great values and reduces the importance of the small ones. This can be advantage for the learning but does nor correspond to the reality of biological neuron.

*2.2. Learning based on maximumal weight of one neuron*

The other type of training is based on the presumption that the neuron is increasing its importance to only one neuron in the higher layer, therefore it maximizes the function:

$$q = max|w_i^o|; i \in \{1,2, \dots n\} \tag{6}$$

If max $|w_o|$=1, no further improvement is possible, and the training stops. In real situation we expect a networks with many neurons, so that the learning will stop soon. This is not a desired behaviour, therefore in that case there should be an additional condition that ensures the continuation of the training. The solution of this problem is to use some compromise solution that takes into consideration more than one output neuron but not all of them. This can be done by optimization of some given number of maximal output weights:

$$u - max|\overline{w}| + \max(\overline{w} - \max|\overline{w}|) + \dots \tag{7}$$

Every of these methods has its strong and weak parts. The practical simulation is the best way to reveal which proceeding is the most suitable for the concrete task.

*2.3. Future work*

The tests of homeostatic neuron [5, 6] has proven its usability for signal modelling and prediction. In comparison to back propagation the learning process is significantly slower, however, this is not a reason for refusing this theory, because other characteristics are favourable for this method. The basic difficulty in the practical realization of the network is not the homeostat neuron itself (which is exactly defined and can be easily programmed), but the ´standard´ neuron in the higher layer (or, more precisely, the interaction between the layers). As the number of layers increases (and it must increase if we want to use it for the simulation of brain function–one reason is that the brain has layered structure and also because multilayered networks model better the functions). There are several ways how to solve out the problem of the delay. It can be done by adding some more ´intelligent´ memory or by changing the dynamics of the system to sufficiently high level where the neurons will be slower that the environment.

Regardless on the actual level of exactness of the achieved results, the models made by neural networks are having an increasing importance in the field of simulation and modelling. The models based on the biological neurons may open new opportunities for a variety of human activities; the transport engineering is in one of the front places.

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# Service Quality Management for the ITS Mobile Wireless Multipath Telecommunications Subsystems

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**Abstract**

Guaranteed quality of telecommunication service and wide area coverage are typical requirements of the ITS (Intelligent Transport Systems) applications. Extensive range of wireless data services with reasonable coverage is offered by public wireless data services providers, however, mostly no guaranteed relevant range of quality and security has been available. As ITS services require cost-effectively solution, as well, requirements can be resolved by seamless switched combination of public and private services selected in accordance to agreed criteria realized by implemented decision processes. Specific situation is identified in case of the C2I (Car to Infrastructure) and C2C (Car to Car) communication namely if the vehicle on board unit is interconnected with the vehicle CAN (Controlled Area Network) based network. Such dynamically developing telecommunications solution touching public networks significantly increase potential of dangerous intruders´ attacks. That is also the main reason why relevant telecommunications security support is understood as one of the crucial part of the ITS telecommunications solution. System security is discusses in detail in this paper and security performance indicators are defined in context of already adopted telematics and telecommunications performance indicators.

**Keywords:** Intelligent Transport System, Telematics, system performance, moving object identification, data security

## 1. Introduction

ITS system can be described as a final automaton defined by mapping the system inputs with respect to the internal state plus mapping the inputs and internal state with respect to the system outputs. System can be split in several subsystems. A subsystem must be describable through an identical methodology like a system; in its substance the subsystem is a system to be described at a more detailed distinguishing level.

An identification process reflects the chained events within a system. An event may mean a change of a system state brought about either by an initiation on inputs (transfer of input values), initiation of the internal system state or the “only” in the course of the time. A set of all activated processes at possible environmental conditions defines the system behavior.

ITS solutions have been associated with serious expectations and getting ITS applications in the real practice is understood as the essential potential to significantly faster resolve many transport challenges. The main afford of the ITS research is to prepare actual conditions to integrate ITS architectures in the real practice with aim to support different transport optimization tasks.

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This paper is concentrated on the telecommunications issues of the ITS architectures, and, the same principles adopted in the ITS applications are applied in the telecommunication solution design. Such decomposition simplifies both analysis as well as synthesis of the systems including security parameters being accepted as the critical ones.

**2. Telematics Sub-System Requirements**

The methodology for the definition and measurement of following individual system parameters has been developed in frame of the ITS architecture and it is described in [1] - [5]. Individual system parameters – performance indicators - were accepted and de facto standardized in frame of the ITS architecture to enable to simply compare different subsystems parameters and their behavior to enable efficient and secure synthesis of the whole system:

- Reliability - the ability to perform required function under given conditions for a given time interval.
- Availability - the ability to perform required function at the initialization of the intended operation.
- Integrity - the ability to provide timely and valid alerts to the user when a system must not be used for the intended operation.
- Continuity - the ability to perform required function without non-scheduled interruption during the intended operation.
- Accuracy - the degree of conformance between a platform's true parameter and its estimated value, etc.
- Safety - risk analysis, risk classification, risk tolerability matrix, etc.

Decomposition of system parameters enables application of the follow-up analysis of the telematics chains in accordance to the various criteria (optimization of the information transfer between a mobile unit and processing center, maximum use of the existing information and telecommunication infrastructure, etc.). It is obvious that quantification of the requirements on the relevant telecommunication solutions within telematics chains plays one of key roles in this process.

Mobility of the communication solution represents one of the crucial system properties namely in context of specific demand on availability as well as security of the solution.

Following communications performance indicators quantify communications service quality (see e.g. [6]):

- Availability – (Service Activation Time, Mean Time to Restore (MTTR), Mean Time Between Failure (MTBF) and VC availability),
- Delay is an accumulative parameter and it is effected by either interfaces rates, frame size or load/congestion of all in line active nodes (switches),
- Packet/Frames Loss (as a tool which not direct mean network failure),
- Security.

Performance indicators applied for such communications applications must be transformable into telematics performance indicators structure and vice versa. Indicators transformability simplifies system synthesis. Additive impact of the telecommunications performance indicators vector $\overrightarrow{tci}$ on the vector of telematics performance indicators $\overrightarrow{\Delta tmi}$ can be expressed as

$$\overrightarrow{\Delta tmi} = TM \cdot \overrightarrow{tci} \qquad (1)$$

where TM represents transformation matrix. It is valid, however, only under condition that probability levels of all studied phenomena are on the same level and all performance indicators are expressed exclusively by parameters with the same physical dimension – typically in time or in time convertible variable (see e.g. [7]). Transformation matrix construction is dependent on the detailed communication solution and its integration into telematics system. Probability of each phenomena appearance in context of other processes is not deeply evaluated in the introductory period, when specific structure of transformation matrix is identified. In [8] are presented details of proposed iterative method.

**3. Telecommunications Solution**

Range of mobile data services with wide area coverage is available for ITS. These are namely GPRS, EDGE, UMTS and coming LTE, but also namely locally applicable WiFi, WiMax. Specific role play DSRC 5.8 and coming DSRC 5.9.

Most of services dedicated for public market do not guarantee quality, i.e. defined range of theirs performance indicators. To improve conditions for ITS implementations and service provisioning combination of different services with automatic seamless switching (second generation of handover) was introduced.

Principles of procedures supporting selection of the best possible communications solution quantified both by performance indicators and some other parameters e.g. like service cost, company policy as well. ISO TC204, WG16.1 “Communications Air interface for Long and Medium range” (CALM) group presented their complex approach to resolve described procedures – see. [11] - [13]. A basic tool – the second generation of the handover principles are defined by CALM standards. Complexity of the ISO approach offers solution with transparent RM OSI compatible architecture, however, such approach also represents highly demanding implementation phase requiring most probably some additional years to introduce on the market products with reasonable pricing.

The IEEE 802.21 standard presents handover in heterogeneous networks standard known as Media-Independent Handovers (MIH) – see [14]. The standard is designed to enable mobile users to use full advantage of overlapping and diverse of access networks. IEEE 802.21-2008 provides properties that meet the requirements of effective heterogeneous handovers. It allows transparent service continuity during handovers by specifying mechanisms to gather and distribute information from various link types. The collected information comprises timely and consistent notifications about changes in link conditions and available access networks. Scope of IEEE 802.21-2008 is restricted to access technology independent handovers and additional activities in this area are on the way. Handover decision and target assessment constitute a multiphase process where the assistance of IEEE 802.21 is essential. However, the actual handover execution is outside the scope of the IEEE 802.21 standard.

Authors of this paper introduced recently easily implementable alternative solution applicable namely for compact solutions like On Boar Units (OBU) where all telecommunications technologies units are integrated into one compact system with smart decision adaptive processes process replacing commonly used PBM (see [15] – [17]). This alternative is adoptable in much shorter time horizon if compared with system based on complex ISO CALM approach or IEEE 802.21 standard. Authors applied L3 “intelligent” routing which allows fast implementation namely in compact units like vehicle OBUs. It is based exclusively on the SW package system integration with minimal or no additional requirements on HW specific support. Results of the research are step by step described in [18] - [32].

**4. Data Security**

Security performance indicator describes ability of the system to ensure that no material damage or loss of human life will occur in cases of any non-standard events like e.g. fake transaction. It means that system detects the forgery on a defined level of probability.

$$P\left(\left|W_i - W_{m,i}\right| \leq \varepsilon\right) \geq \gamma \qquad (2)$$

This equation describes that the absolute value of difference between desired risk situation $W_i$ and real situations of risk $W_{m,i}$ does not exceed ε on the probability level γ.

“Car to Infrastructure” (C2I) and “Car to Car” (C2C) communication as well as vehicles on board data communication via Controlled Area Network (CAN) bus are areas with progressive growth of transferred data volumes. If private on board network solution is not connected to any communication cannel than such system can remain reasonably secure and no additional security treatment is typically needed and implemented. However, vehicle private data network security and integrity can be violated in a moment when this network is connected to any other device or network. It is absolutely necessary to take in account that most of vehicles with the CAN based network architecture are minimally equipped with interface for diagnostics purposes, nevertheless, above that interconnection of the CAN bus to the C2C or C2I communications structures becomes “trendy”. Data available on the CAN interface are applicable for remote wireless identification of the car or its parts identity or car elements functionality and history of each part status. However, in such applications data security represents sensitive issue to be carefully studied and treated and e.g. basic authentication of two actors for mutual communication based on identifier like VIN code or OBU-ID, however, is not acceptable as sufficient tool and extended approach is strongly required.

Second security aspect which follows authentication is data privacy and actors authorization to provide relevant data. Authors´ approach is based on selective data transmission according to the actor role/category. Proposed security approach is based on two steps – reliable and secure authentication and the only relevant to actor’s rights data exchange (data which can be provide to the actor). These tools must be combined with other available security tools.

The third aspect of security is to use the approach to prevent the legalization of stolen cars, which are dismantled after the theft to the individual parts as well as parts from stolen vehicles. VIN code and the other identifiers can be included in the new vehicle documents, however, by implementation of the electronic authentication of key parts of each vehicles via CAN bus by in vehicle integrated OBU such crime activities can be substantially limited.

*4.1. Unique Identifier*

Presented approach is based on usage of Universal Identifier of Vehicle (UIV) is generated as set of all important partial vehicle identifiers where each of them describes non-changeable part of the car detailed identification.

Choice of important identifiers and characteristics of the vehicle must be based on an analysis of the vehicle as a system, which is a purposefully defined as a set of parts or elements and set of links of certain attributes which determine the characteristics, behavior and function of the system as a whole. The vehicle as a system decomposition is performed in order to find basic elements of the vehicle and links between them, as shown in Fig. 1.

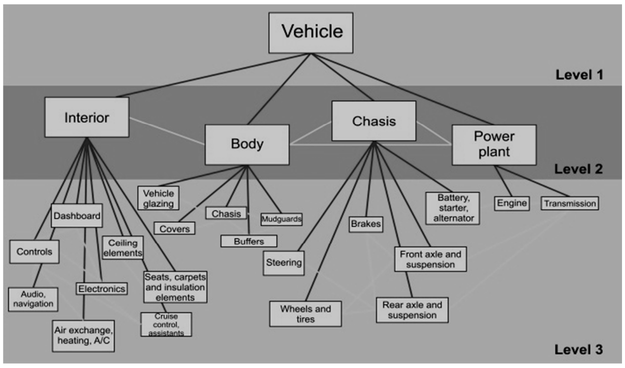


Fig. 1 Vehicle decomposition

Based on vehicle decomposition there are examples of partial identifiers and vehicle properties which describes vehicle as a whole:

- VIN (Vehicle Identification Number),
- No. of axles,
- Emission class,
- Vehicle weight,
- Year of its manufacture,
- Optional list of key identifiers and characteristics of the vehicle like:
- Chassis Ident. No.
- Engine type and Ident. Number, No.,
- Transmission type and Ident. No.,
- Front axes and suspension,
- Rear axle/-s and suspension,
- Wheels and tires.

The UIV represents set of partial identifiers extended by unique non-public part generated from agreed data by standard cryptography algorithm (e.g. AES or SHA-2) to prevent possibility of UIV algorithm identification in case set of identifiers is for any reason known to the hacker. Check part at the end of identifier is connected for fast check of identifier validity (like validity check of credit card number). The example of UIV is on the Fig. 2.


Fig. 2 Example of unique identifier

It is not necessary to take care of UIV uniqueness because this functionality is ensured by unique VIN code. Advantage of such approach is in fact that complex information about vehicle integrated in the UIV can be used for different telematics applications. Threat of sensitive data abuse is prevented by the data selection availability to the user in dependence on the service class assignment to each one. System allows to use the only that parts of identifier which is dedicated to identified service class – like emergency, public and commercial services.

*4.2. Communication and Secure Identification*

As we described above due to high sensitivity on data privacy exchanged between vehicle and service infrastructure UID must be reasonably protected against potential hackers´ attacks. Three categories of telematics system security in ITS are provided:

- Identifier and data security in vehicle (vehicle environment),
- Identifier and data security for data transmission (wireless environment),
- Identifier and data security in receiver part (server area).

In this paper the only intermediate part - wireless environment - will be discussed.

The communication channel can be secured e.g. by application of a VPN (Virtual Private Network) or a cryptographic SSL (Secure Sockets Layer). If the attack is successful than misuse transferred data can be misused by hacker. Proposed approach to the data security yields lies in the dynamical component extension (time and position dependency) and symmetric or asymmetric encryption, which is chosen depending on the application.

For Point to Point (P2P) communication symmetric encryption can be effectively applied. In such case e.g. the Diffie-Hellman (D-H) key exchange or any other newer algorithms based on the D-H principles can be used, i.e. a cryptographic protocol that allows to establish the encrypted connection over an unsecured channel between two communicating parties, without the first explicit agreement of both parties on the encryption key. Result of this process allows generation of the unique symmetric encryption key which can then be used to encrypt further mutual communication. The key advantage of such approach lies in the fact that such symmetric encryption key cannot be identified based on the exclusively “listening”. All keys are constructed by participants case by case and communication is never processed in an open form.

The main disadvantage of this protocol is an attack via “man in the middle”. Solution on described principles cannot be applied without combination with other methods whenever the attacker can actively interfere with communication channels.

In case of Point to Multipoint (P2M) communications namely if large number of active terminals are served, asymmetric cryptography can be efficiently used, as well.

In this solution the identifier is concatenated by actual time, current GNSS coordinates (i.e. exclusively in direction from by GNSS equipped vehicle to infrastructure) and finally by the user ID. Identifier is than encrypted by either asymmetric or symmetric cryptographic algorithm. Encryption of the UIV is described as follows:

$$M1 = EK(UIV \parallel Ti \parallel Pi) \tag{3}$$

where UIV means Universal Identifier of the Vehicle, EK - asymmetric encryption with public key K, Ti - clock state in time of message generation, Pi - position in time of message generation, UIV II Ti II Pi - identifier with link to current time and position

After receiving the request by the central system, the message M1 is decrypted and UIV is read in „static form“ - received time Ti and Pi are checked for validity.

It means, that the message is not older than n seconds and the message has been sent from area with maximum of m meters tolerated difference. Data message with identifier in dynamic format is not impacted by this process and this approach doesn’t influence usage of the other security tools.

The goal of this approach is to highly secure data against attacks mainly like eavesdropping and usage of the data for forgery.

Identifier extended by the transaction time and location in a dynamic form is usable for transaction validation. It is possible to apply this information also in the other telematics applications like traffic management.

*4.3. Service Categories*

Proposed approach covers categorization of the telematics services. Each category has defined set of data allowed to user application. Because the unique identifier includes complex information about the vehicle there must be special tool implemented on both sides (sender and receiver) which process incoming identifier and transfers and publish the only relevant data to user. Such component can also cover “dynamisation” of the message content as it was already described above.

Three service categories may be for example defined:

- Security services – e.g. emergency, fire dept., police,
- Public services (public authorities) – e.g. customs,
- Commercial services.

Set of available data is identified by the unique identifier. Vehicle unit processes the request and provides defined selection of ITS data dedicated to the service category of the customer.

**5. Authentication Performance Indicators**

The authentication system is an integral part of any information system. Different information systems have different requirements on functionality of applied authentication and determination of the metrics enables easier different authentication systems comparison and specifies the required parameters for authentication system. Following authentication performance indicators quantify authentication service quality.

Transformation between telecommunications and telematics system of performance indicators was summarized in chapter 2. Equation (1) is applicable, however, only under condition that probability levels of all studied phenomena are on the same level and all performance indicators are expressed exclusively by parameters with the same physical dimension – typically in time or in time convertible variable. We therefore primarily define performance indicator Duration of authentication effectively applicable with other communications performance indicators. Than other even more representative indicators are introduced, as well.

*5.1. Duration of Authentication Process*

Duration of authentication, i.e. time interval between the client request to the authentication and information on successful/unsuccessful authentication from authenticator is influenced by the complexity of the calculations, both the client and the authenticator side, but also the volume of data exchanged between the parties and mainly used telecommunication connection between the client and the authentication server.

The total duration of authentication can generally be divided into sub-periods

- the processing on the client side ($duration\_Z_K$),
- the processing time for the authenticator ($duration\_Z_A$),
- the communication time between the client and the authenticator ($duration\_K_{KA}$).

$$duration\_of\_authentication = duration\_Z_K + duration\_K_{KA} + duration\_Z_A \quad (4)$$

All three times are sums of partial times and it is therefore possible to write

$$duration\_of\_authentication = \sum_{i=0}^{j} dzK_i + \sum_{i=0}^{k} dkKA_i + \sum_{i=0}^{l} dzA_i \quad (5)$$

where

$dzK_i$ is duration of the i-th processing on the client side,

$dkKA_i$ is duration of the i-th communication between the client and the authenticator,

$dzA_i$ is duration of the i-th side processing on the authenticator side

For those protocols that must be repeated several times (generally $t$-times), to reduce the probability that an attacker has successfully authenticates fraud, the

$$duration\_of\_authentication = t \cdot \left( \sum_{i=0}^{j} dzK_i + \sum_{i=0}^{k} dkKA_i + \sum_{i=0}^{l} dzA_i \right) \quad (6)$$

For those authentication protocols that must be repeated n times in order to reduce the likelihood that an attacker fraud an authenticating, their drawback is being longer duration authentication (theoretically n-times). The total time of authentication is to be viewed in the context of the overall time of the transaction. If the user took every request in the order of seconds, it is acceptable if the authentication will take as a few tenths of a second. It is therefore an important aspect

$$\frac{duration\_of\_authentication}{duration\_of\_transaction} \tag{7}$$

If the authentication protocol is still based on trusted authority, the total time authentication is affected by the processing time on the trusted authority ( $duration\_Z_{DA}$ ) and time communication with the authenticator ( $duration\_K_{DAA}$) or client ( $duration\_ZK_{DAK}$ ).

$$\begin{aligned} duration\_of\_authentication = duration\_Z_{K} \\ + duration\_K_{KA} + duration\_Z_{A} + duration\_Z_{DA} \\ + duration\_K_{DAA} + duration\_K_{DAK} \end{aligned} \tag{8}$$

The duration as performance indicator may be approached from the perspective of two requirements. The first request is static - it is determined the maximum required duration limit authentication regardless of the load current authentication system. Using this requirement the duration is the ability of authentication system to serve request for authentication to a certain specified maximum duration regardless of the load that can be defined as the probability

$$P\left(\left(t_{R,i} - T_{R}\right) \leq \varepsilon_{DAP}\right) \geq \gamma_{DAP} \tag{9}$$

that the difference between the measured duration of $i$ -th authentication process $t_{R,i}$ and the specified maximum duration $T_R$ will not exceed the value $\varepsilon_{DAP}$ on the probability level $\gamma_{DAP}$.

The second requirement is dynamical that takes into account the current authentication system load (number of authentication requests per time unit). For this requirement the duration as performance indicator is the ability of authentication system to serve the authentication request to a specified maximum duration for the current load that can be defined as the probability

$$P\left(\left(t_{R,i} - T_{R,(m,n]}\right) \leq \varepsilon_{DAP,(m,n]}\right) \geq \gamma_{DAP,(m,n]} \tag{10}$$

where

$m < n$,

$m, n$ are positive integers,

that the difference between the measured duration of $i$ -th authentication $t_{R,i}$ and the specified maximum duration $T_{R,(m,n]}$ for a given load (expressed in an interval $(m,n]$ of the number of requests per time unit) will not exceed the value $\varepsilon_{DAP,(m,n]}$ on probability level $\gamma_{DAP,(m,n]}$. So for different load ranges $(m,n]$ can be defined different threshold values $\varepsilon_{DAP,(m,n]}$ for the relevant probability level $\gamma_{DAP,(m,n]}$, the union would be appropriate probability level $\gamma_{DAP}$ and threshold value $\varepsilon_{DAP}$. Expression should therefore changed

$$P\left(\left(t_{R,i} - T_{R,(m,n]}\right) \leq \varepsilon_{DAP}\right) \geq \gamma_{DAP} \tag{11}$$

Performance indicator the duration may be determined from the viewpoint of the client, but also of the server. For real use is preferable to determine this from the viewpoint of the client.

For example when client and server were in the same network (LAN) and it was used Fast Ethernet (100Mb/s) as telecommunications access solution and Fiat-Shamir protocol was repeated 4 times, the average duration of authentication process was 567 milliseconds and standard deviation was 60 milliseconds. When we want to use performance indicator "Duration" then for $\varepsilon_{DAP}$ equal zero and probability level $\gamma_{DAP}$ equal 99% the maximum duration $T_R$ must not be greater than 687 milliseconds (see graph on Fig. 3).

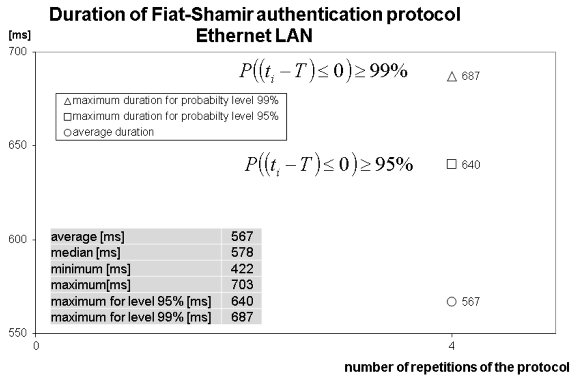


Fig. 3 Graph of measured duration of authentication with specified maximum duration

### *5.2. Stability of Serviceability*

Stability of serviceability is the ability of authentication system to process the authenticate requests without loss up to the allowable limit that can be defined as the probability

$$P\left(\left(\frac{r_{t,s}}{r_t}\right) \ge \varepsilon_{SoS}\right) \ge \gamma_{SoS} \qquad t \in \langle 0,T \rangle \qquad \varepsilon_{SoS} \in \langle 0,1 \rangle \tag{12}$$

that the percentage of served requests $r_{t,s}$ and the total number of requests $r_t$ is greater or equal to $\varepsilon_{SoS}$ on the probability level $\gamma_{SoS}$ for each time $t$ interval from $\langle 0,T \rangle$.

Thus in terms of the stability of serviceability ignores the current workload of authentication system and therefore for different intervals of workload $(m,n]$ can be expressed by the formula

$$P\left(\left(\frac{r_{t,s}}{r_t}\right) \ge \varepsilon_{SoS,(m,n]}\right) \ge \gamma_{SoS} \qquad t \in \langle 0,T \rangle \tag{13}$$

for unified probability level $\gamma_{SoS}$.

### *5.3. Loss Rates*

Loss rates reflects the ability of an authentication system to don't serve only part of the authenticate requests to a maximum allowable limit that can be defined as the probability

$$P\left(\left(r_{o,\langle 0,T \rangle} - R_{\langle 0,T \rangle}\right) \le \varepsilon_{LR}\right) \ge \gamma_{LR} \tag{14}$$

that the difference between the number of really outstanding requests $r_{o,\langle 0,T\rangle}$ and tolerated the maximum number of outstanding requests $R_{\langle 0,T\rangle}$ will not exceed the value $\varepsilon_{LR}$ on the probability level $\gamma_{LR}$ during a time interval $\langle 0,T\rangle$.

*5.4. Rate of Erroneously Accepted Authentications*

The rate of erroneously accepted authentications reflects the property authentication system erroneously authenticate to a certain extent that can be defined as the probability

$$P\left(\left(\frac{r_f - R_f}{r_t}\right) \le \varepsilon_{REAA}\right) \ge \gamma_{REAA} \qquad (15)$$

that the percentage of difference between the number of erroneously accepted authentications $r_f$ and the number of tolerated erroneously accepted authentications $R_f$ and the total number of authentication requests $r_t$ will not exceed the value $\varepsilon_{REAA}$ on the probability level $\gamma_{REAA}$ .

*5.5. Rate of Erroneously Rejected Authentications*

The rate of erroneously rejected authentications reflects property of authentication system reject authentication an authorized person to a certain extent that can be defined as the probability

$$P\left(\left(\frac{r_d - R_d}{r_t}\right) \le \varepsilon_{RERA}\right) \ge \gamma_{RERA} \qquad (16)$$

that the percentage of difference between the number of erroneously rejected authentications $r_d$ and the number of tolerated erroneously rejected authentications $R_d$ and the total number of authentication requests $r_t$ will not exceed the value $\varepsilon_{RERA}$ on the probability level $\gamma_{RERA}$ .

## 6. Conclusion

“Car to Infrastructure” (C2I) and “Car to Car” (C2C) communication as well as vehicles on board data communication via Controlled Area Network (CAN) bus are areas with progressive growth of transferred data volumes. If private on board network solution is not connected to any communication cannel than it remains reasonably secure and no additional security treatment is typically needed and implemented. However, vehicle private data network security and integrity can be violated in a moment when this network is connected to any other device or network. CAN and OBU interconnect is coming namely due to on network representative data availability applicable for services like car identity or car units integrity or functionality remote identification. However, data security in such applications represents sensitive issue to be carefully studied and treated.

Reliable and secure identification of both partners for remote communication represents between others one of important security tools to prevent unauthorized data exchange. It must be, however, combined with other security tools. Authentication of two actors for mutual communication based on identifier like VIN code or OBU-ID is not acceptable as sufficient tool. Identification based on newly designed dynamical Unique Vehicle Identifier UIV is presented as relevant alternative.

The authentication system is an integral part of information systems. It allows access to data and functions of information system only to authorized persons. Poorly functioning authentication system affects the whole information system. Different information systems may be different requirements for the functioning of its authentication system.

Second security aspect which follows authentication is data privacy and actors authorization to receive relevant data content. Authors´ approach is based on selective data transmission and delivery in accordance to actor role/category. These described principles are combined with available security tools like in this case applied asymmetric data encryption. Such combination of presented tools leads to solution with relevant level of reached system security.

Possibility to quantify impact of authentication process on telematics solution performance relates with conditions of presented transformation between telecommunications and telematics set of performance indicators.

Such transformation is applicable only if probability levels of all studied phenomena are set on the same level and all performance indicators have the same physical dimension – typically time is applied. Therefore performance indicator “Duration of authentication” was firstly defined with aim to have effectively integrate-able in processes performance indicator. Than the other specific indicators where introduced, as well.

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# DEPARTMENT OF LANGUAGES AND HUMANITIES

# K615

The Department of Languages and Humanities aims to humanize technical education with the overall goal of broadening the future transport engineers' horizons by equipping them with the knowledge, understanding, skills and attitudes needed for their future careers. Special emphasis is put on knowledge of foreign languages.

The department offers:

- language courses in English, German, French, Spanish and Russian for different levels of language skill
- basic courses in the humanities (history, sociology, psychology, history of art, ...)
- specialized courses and seminars (History of Civil Aviation, History of Railways, History of Public Mass Transport, Psychology in Transportation, ...)

Other Projects and Activities:

- Life-long education: The University of the Third Age (history and language courses)
- Czech language courses for foreign students
- Psychologist's assistance
- FCE preparatory courses for the public

# DEPARTMENT OF VEHICLE TECHNOLOGY

# K616

The Department of Vehicle Technology is expertly aimed at vehicle construction and operation. Lectures taught by this department help bachelor degree students to become familiar with vehicle construction and dynamics theory. In frame of magister degree students take lectures in special properties of particular vehicle systems, testing, vehicle safety and biomechanics, vehicle dynamics and electronic systems, car body design, production technology, operation and control. These topics create content of ongoing projects where students draw on software for vehicle dynamics simulations.

In frame of doctoral study candidates are educated in following topics: vehicle dynamics, passive safety, vehicle testing and operation, special production technology of vehicles and railway cars.

Department of vehicle technology cultivates wide national and international cooperation both on the level of universities (or other institutions) and industrial enterprises. In case of vehicle producers and operators it concerns long term technical cooperation.

# Exact Calculations of Traction Energy Quantities

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**Abstract**

Today's computer technology offers an unprecedented approach to motion simulation of land transportation means, which allows for solving a great deal of complicated problems very efficiently. The result of the calculations is a comprehensive detailed description of a given drive, including not only acceleration, driving speed and energy consumption, but also, for example, combustion engine emissions or the warming of propulsion system components.

**Keywords:** energy consumption, Transport Energetics Laboratory, traction energy chasracteristics, energy efficiency, energy drive-simulator

## 1. INTRODUCTION

The scientific field devoted to the energy of land transportation means explores the phenomena, relationships and laws of energy conversions related to the tractive quantity of work of moving vehicles. Today's computer technology undoubtedly offers an unprecedented approach to this issue [4]. Experiments which are demanding in terms of time, finances and technology can be efficiently replaced by exact calculations. The comprehensive system currently under work at the Transport Energetics Laboratory (TEL) of the Department of Vehicles allows for solving general cases with the view of optimizing technical solutions in the areas of propulsion systems and transport-related technology processes. The system can also be used for simulation calculations.

## 2. TRACTION ENERGY CHARACTERISTICS OF VEHICLES

Traction energy characteristics describe a given traction vehicle in terms of its driving utility and energy usage. Traction energy characteristics are expressed as a set of characteristic functional relationships describing the tractive force on the driving wheels $F_t$ and the corresponding input on the energy threshold, i.e. on the energy entrance of the traction vehicle $P_{1t}$ on the running speed $V$. This is applicable for various levels of use of the power rating.

When expressed in a graph, both of the above-mentioned functional dependencies are shown as surfaces constrained by corresponding limiting curves. In practical runs, the working points of each drive are situated beyond these limiting curves, i.e. within the working surface of each of the characteristic functions. In order to be able to precisely identify these points, another parameter, the relative working mode parameter $\tau_x$, needs to be defined. This means that each working point is determined by speed $V$ and relative working mode parameter $\tau_x$. For the limiting curve, $\tau_x$ = 100% is applied. Because of practical reasons, virtual driving stages for $\tau_x$ < 100% are set at certain intervals, e.g. 10% intervals.

The functions are thus as follows:

$$F_t(V, \tau_x) \quad \text{and} \quad P_{1t}(V, \tau_x) \qquad (1) \text{ and } (2).$$

Relationship (1) is called tractive force – speed diagram, relationship (2) is called traction input – speed diagram. In order to assess or compare the energy efficiency of various traction vehicles, efficiency speed diagram are going to be used,

$$\eta_{TVE}(V, \tau_x) = \frac{P_t(V, \tau_x)}{P_{1t}(V, \tau_x)} \quad [1] \qquad (3)$$

where $P_t$ stands for traction output, i.e. output on the driving wheels.

Relationships (1) to (3) are called traction energy characteristics of a traction vehicle.

The knowledge of functional relationships (1) and (2) as portrayed here is the fundamental condition for an exact calculation and thus a faithful simulation of a vehicle running [1], i. e. for determining the relevant time-related functional dependencies of supporting physical quantities, which are the following:

- running speed $V(t)$,
- acceleration or deceleration $a(t)$ or $b(t)$,
- distance travelled or the vehicle's position $L(t)$,
- tractive force on the driving wheels $F_t(t)$,
- traction output $P_t(t)$
- traction input on the energy entrance into the propulsion system $P_{1t}(t)$,
- tractive quantity of work $A_t(t)$,
- energy consumption in relation to energy entrance $E_1(t)$,

The calculation of other quantities valid for a given research or study is also possible.

Based on this detailed description of driving, it is possible to determine the level of power usage and heat load of the propulsion and regulation systems of a traction vehicle. If required, it is also possible to determine the power load of fixed traction installations for vehicles supplied by a traction line. This data can also be used for calculating emission components for heat engine propulsion systems and other important functional dependencies (see part 4).

## 3. EXACT CALCULATION OF ENERGY CONSUMPTION

Determining energy consumption for tractive quantity of work is an integral part of the assessment of a vehicle's traction energy characteristics. This is the only way to carry out a comprehensive and reliable assessment of the energy characteristics of a given traction vehicle and its suitability for a given purpose. The assessment can be carried out by means of measurements or calculations. Measurements conducted in traffic are very costly, as it is necessary to carry out several measurements because of the difference between the boundary conditions of the experiment. These conditions cannot be influenced in any way, given the character of traffic. A reliable result can thus be obtained only by a mathematical and statistical analysis of the results of a series of numerous measurements.

Therefore, the development and usage of an exact calculation method is a very rational step, especially given the possibility of its usage for **variant study calculations**, which are described in [7]. Measurements can then be used only for a selective verification of these calculations results and for obtaining entry data for the calculations.

The method is also applicable for **simulation calculations** of specific drives, which can be used for research and teaching, and when complemented with certain supplements, they can be part of an energy drive-simulator illustrating the influence of certain operational and technological aspects on the energy consumption of tractive quantity of work.

When calculating energy consumption, the most precise results can be achieved by means of the integration method, the principle of which is described by the following mathematical relationships. The advantage of this method is the possibility of its application in online transport-related technology processes.

For instantaneous acceleration, the following relationship is applied:

$$\frac{dV}{dt} = \frac{f_t(V, \tau_x) - [r_v(V) + r_g + r_c]}{102 \,.\, \xi} \quad [\text{m/s}^2] \tag{4}$$

while specific tractive force on the driving wheels is calculated as follows:

$$f_t(V, \tau_x) = \frac{102\, F_t(V, \tau_x)}{M} \quad [\text{N/kN, kN, t}] \tag{5}$$

Under the assumption that in the time interval

$$\Delta t = t_2 - t_1 \quad [\text{s}] \tag{6}$$

it is possible to consider the selected value $\tau_x$ to be constant and to simplify the relationship (5) and consider it to be a function of driving speed

$$f_t(V, \tau_x) = f_t(V) \tag{7}$$

Time dependency of running speed for $t \in \langle t_1 , t_2 \rangle$ is thus

$$V(t) = \frac{3{,}53 \,.\, 10^{-2}}{\xi} \int_{t_1}^{t_2} \{ f_t(V) - [r_v(V) + r_g + r_c] \} dt \quad [\text{km/h}] \tag{8}$$

The symbols of quantities in square brackets in relationships (4) and (8) stand for specific resistances: vehicle resistance as a speed function, gravitation resistance and the resistance caused by driving in a track curve.

The corresponding time behavior of the input for tractive quantity of work as related to the energy entrance into the propulsion system is then

$$P_{1t}(t) = \frac{F_t\,[V(t)] \,.\, V(t)}{3{,}6\, \eta_{TVE} \; \{F_t\,[V(t)],\; V(t)\}} \quad [\text{kW, kN, km/h, 1}] \tag{9}$$

and the energy consumed in the given time interval according to (6) is

$$E_1(t) = \frac{1}{3600} \int_{t_1}^{t_2} P_{1t}(t) \,.\, dt \quad [\text{kWh}] \tag{10}$$

See part 2 for the explanation of the symbols and quantities used.

When making exact calculations by means of the above-described integration method, it is necessary to take into account the immediate correct values of the total efficiency of a traction vehicle $\eta_{TVE}$ – their variability can be seen when expressed graphically, i.e. as curves of constant values of the efficiency inserted into the system of coordinates of the tractive force – speed diagram, which is shown in Fig. 1.

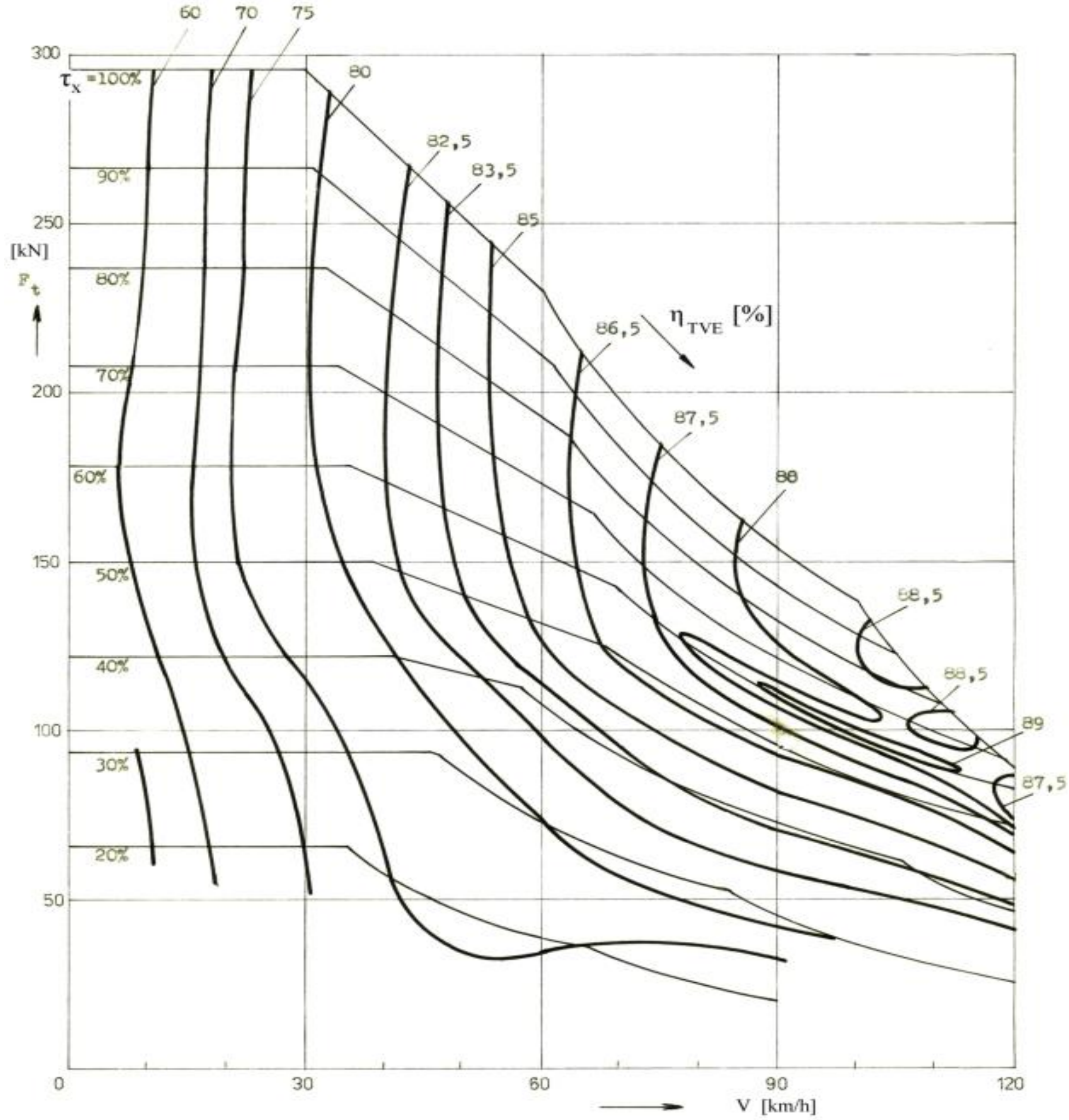


Fig. 1 An example of the curves of constant efficiency values for an electric traction vehicle supplied by traction lines

Source: The author, based on primary materials from the producer

It is clear that energy efficiency of a given traction vehicle is heavily dependent on both the tractive force on the driving wheels $F_t$ and on driving speed $V$ and that in general, it decreases with lower traction output. This is true for other propulsion systems as well. Failure to respect this fact makes it impossible to make exact calculations either for variant study calculations or for simulation calculations, such as calculations for energy-drive simulator.

The necessary functional relationships (1) and (2) can be obtained by:

- a calculation based on partial data obtained by measuring the given elements of a propulsion system (see Fig.1) or by
- global measurements on a specific traction vehicle [2] (see Fig. 2)

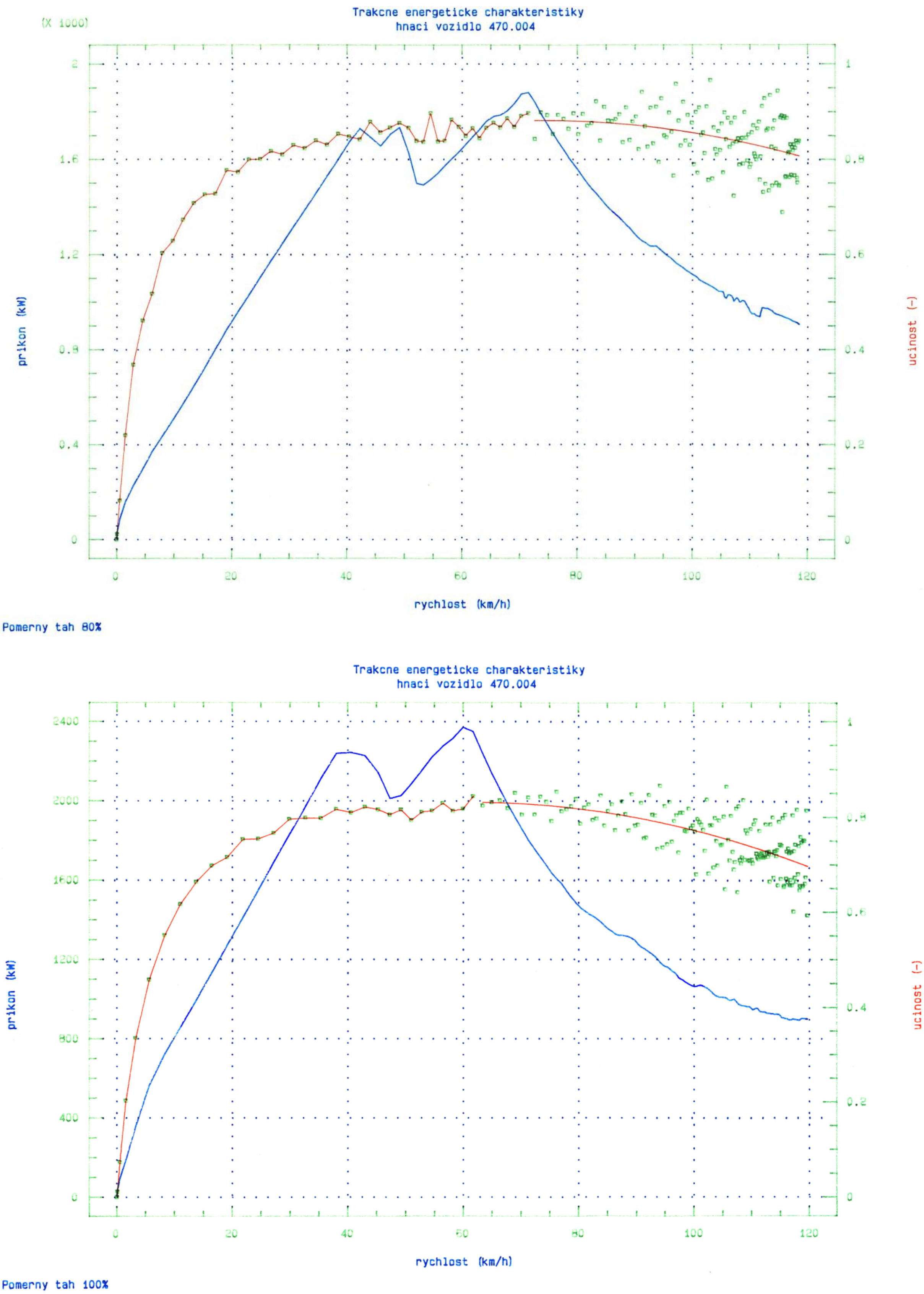


Fig. 2 An example of experimentally obtained traction input – speed diagram and efficiency – speed diagram for an electric vehicle supplied by a traction line. Above for $\tau_x$ = *80 %* , below for $\tau_x$ = *100 %.*
Source: Measurement by the author

## 4. THE STRUCTURE OF THE COMPREHENSIVE CALCULATION SYSTEM BY TEL

The basic requirement for the TEL's calculation system is its universality, which allows it to be complemented by specialized subprograms and used for solving standard as well as less standard tasks when analyzing a driving vehicle. The system will be applicable for both rail and road vehicles with various traction propulsion systems and energy sources. Besides the basic program level (see parts 2 and 3), the comprehensive calculation system will offer several supplementary levels:

- ECOSIM – for determining the environmental burden by means of ascertaining the amount of monitored emission components in relation to time and distance during driving,
- TERMOSIM – for determining the warming of the individual components of the propulsion and source system,
- ACCUSIM – for monitoring and analyzing the working regimes of vehicles with electrochemical accumulators or other mobile sources of electric energy,
- RECSIM – for monitoring energy flows during regenerative braking.

## 5. CONCLUSION

The outlined comprehensive calculation system by TEL has so far been implemented on the two basic levels, which are closely described in Mr. Večeřa's contribution. Mr. Jirků is working on the confirmation of the working hypothesis for the ECOSIM level. Mr. Kučera is working on the energy drive-simulator. The team is also working on the creation of a measurement system [2] for the experimental obtaining of entry data for exact traction energy calculations and for the selective verifications of their results.

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# Electro Vehicle car sharing system – simulation for cities

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**Abstract**

This paper considers a problem of introduction car sharing systems for electric vehicles into metropolises and deals with simulation of such systems which can bring benefits in the early stage of development. In contrast to standard simulation technics, this project deals with simulation through introduction of a virtual online system and using real consumer's opinions instead of Human Behavior Model. In addition, natural landscape characteristics of the city, like elevation profile and real weather forecast, are considered in Electric Vehicle Consumption model. Simulation software can be found on a web page http://elektromobilita.fd.cvut.cz/

**Keywords:** Car sharing, Electric Vehicle, Simulation, Web application, Data acquisition

## 1. INTRODUCTION

Simulation is a strong tool which allows researchers to test their hypothesis with different initial conditions, and at the same time, in case of project with big outlay it helps managin staff to understand a feasibility of proposed solution without risking of investment capital.

Electric Vehicle (EV) Car Sharing (CS) is exactly this case. For instance Paris Autolib project made more than 25% of drivers switch from their personal vehicles to EV CS service. But to gain such results they had a huge personal investments (€235 million) and legal support from the government. But even for a small project with 36 stations and 72 EV in operation more than 528.021.600 CZK investments are needed (about €26 million) so the question about popularity of the service and consequently a load (amount of users) for each station become crucial.

Simulation seems to be a proper approach to answer this question. Nevertheless, to predict and simulate Human Decision process and to understand amount of possible customers, we need a strong statistical background which, in case of Prague city, we don't have. So instead of dealing with the soft system problematic and try to simulate human behavior in offline simulation, we are letting them to make their own decision through "virtual" service, available on the Internet. This service should provide us with strong evident background for an analysis and serve as an input for further offline simulations. At the same time it should help Prague inhabitants to understand benefits of proposed service and familiarize them with EV technology and its specifics and reduce impact of range anxiety phenomena. The simulation of EV consumption takes into account not only special features of Prague city but also weather conditions.

There are some existed descriptions of Electric Vehicles (EV) consumption simulation software available on the internet but almost all of them deal only with ideal route characteristics, flat slope, no weather influence,

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standard driver behavior. There is an attempt to take into account an elevation profile of the route in [1] and driver behavior in [2] but weather conditions influence still missing in the calculation. Additionally all of them are dealing with simulation of only one EV. There are publications dealing with simulation of Car Sharing systems only. This articles aims to simulate symbiosis of two environmental friendly technology.

## 2. SIMULATION

Simulation software was created to analyze a consumer behavior and EV CS service popularity in selected region, with predefined price policy and predefined CS station distribution over the region. This information was obtained from a study performed in Czech Technical University [3] and serves as an input.

To obtain relevant data about consumer decision, simulation has to offer all available modes of transportation in selected region including Public Transport and Taxi service, and calculate time consumption and price for all of them.

### *2.1. Simulation input*

By summarizing the results published in [3] and by using the results form a public survey which was presented there, we can construct a list of “User needs” for an electric car sharing system in Prague:

- Service Network coverage represented in Figure 1 and cover areas :Prague 1 , Prague 2, Prague 3, Prague 7
- 36 car share stations should be built with approximately 5 minute walking distance between them (approximately 470 m.)
- 74 vehicles should be putted into operation
- The chosen vehicle is Smart for two electric drive
- Price of the service to get at least 60 % of perspective users should be in these limits
    - Registration fee shouldn’t be more than 250 CZK
    - Monthly payments shouldn’t be more than 200 CZK.
    - Hourly payment shouldn’t be more than 200 CZK


Fig. 1 Service network coverage [3]

The comparison of proposed price policy with companies which were described above can be found in Table 1

Table 1 Price policy compare

| | Purposed price model (CZK) | Autolib (CZK) | I-Go CZK | Zen-Car |
|---|---|---|---|---|
| Month fee (mean value) | 200 | 542 | 118 | 152 |
| Hours fee (mean value) | 200 | 323 | 159 | 297 |
| Registration fee | 250 | 0 | 1189 | 892 |

*2.2. EV consumption model*

The energy consumption models are developed from the first principles of mechanics and the vehicle parameters and calculated according to Equation 1.

$$E = O_{total} \cdot v \cdot t \quad (1)$$

v- Current vehicle speed [m/second]
t - Step of simulation [seconds]
E – Power [W per s]
$O_{total}$- is a power which we need to overcame the forces acting over the vehicle represented in Equation 2

$$O_{total} = \frac{O_F + O_V + O_S + O_Z}{\eta} + O_{aux} \quad (2)$$

This equation represents all losses during the driving, including losses for Aerodynamics, Drive-train, Tires and Ancillary systems.

Where Friction resistance

$$O_f = m \cdot g \cdot f_k \cdot cos\, \alpha \quad (3)$$

m – Mass of the vehicle
$f_k$ - Drag coefficient
g – Gravity acceleration
α– Angle of movement

Air resistance

$$O_v = \frac{1}{2}\, \rho \cdot c_x \cdot S_x \cdot (v - v_{wind})^2 \quad (4)$$

ρ - Air density,
$S_x$ - Vehicle frontal area,
v – Current velocity of the vehicle;
$v_{wind}$ – current speed of the wind (actin upon direction of movement )Information required for simulation

Acceleration resistance and power required to overcome road slope.

$$O_z = m \cdot a \cdot v \quad (5)$$

$$O_s = m \cdot g \cdot \sin \alpha \quad (6)$$

a – current acceleration of the vehicle.
α– slope angle in rad

Electrical loads

$$O_{aux} = O_{climat} + O_{batmngm} + O_{light} + O_{audio} \quad (7)$$

$O_{aux}$ - losses from ‘all other’ electrical loads in the vehicle from user-related systems. Such us climate control, external lights, and audio.

$O_{climat}$ – Consumption of power by climate control system (ACC and Heating)

$O_{batmngm}$ – Consumption of battery system management - systems necessary to regulate battery temperature, not all EV has this function.

$O_{light}$ – Consumption of lighting assumed that the maximum power consumption of internal & external lights is equal to 80 Watts. Due to the fact that LED lights are used in new vehicles and due to Czech legislation (lower beams should be turned on always) it’s not a temporal function.

$O_{audio}$ – Consumption of Audio, navigation system and communication system assumed to be 180 Watts.

Both $O_{climat}$ and $O_{batmangm}$ are functions of external temperature and can reduce EV range up to 34.7% when heating is turned on, and up 32.7% when ACC is turned [2]. Mean values of Climate Control system consumption is represented in Table 2

Table 2 Climate control Load Profile

| Mode | Peak Load (kW) | Average Transient load(kW) | Steady state load (kW) |
|---|---|---|---|
| A/C | 3.89 | 2.99 | 2.1 |
| Heater | 6 | 4 | 2 |

Based on this information $P_{aux}$ profile as a function of ambient temperature was constructed and can be found in Figure 2. To find a value of consumption at requested temperature linear interpolation (Equation 8) is used.

$$O_{climat} = O_0 + (O_1 - O_0) \cdot \frac{t - t_0}{t_1 - t_0} \qquad (8)$$

Where: $O_0$ and $O_1$ – value of consumption for temperature $t_0$ and correspondingly $t_1$ are known

Additionally, in case of precipitation 0.2 kW consumption is added to simulate energy loses on wipers and window ventilation.

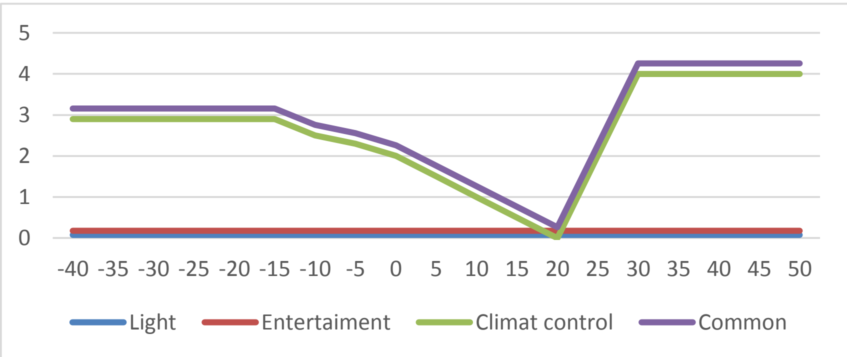



Fig. 2 Axillary consumption as a function of ambient weather

### *2.3. Required information*

From everything, which was mentioned above, we can construct a list of information which we need to obtain for suitable simulation:

1. Path characteristic
    a. Type of the route
    b. Length of the path
    c. Direction of movement (wind influence)
    d. Amount of crossings.
    e. Elevation Profile.
    f. Max velocity during the route
    g. Traffic condition on the route
2. Driver characteristic

    a. Driver Style
3. Weather condition
    a. Wind speed and direction
    b. Air density
    c. Temperature
4. Vehicle characteristics
    a. Mass
    b. Battery characteristics
    c. Acceleration deceleration characteristics

For a source of information about the route characteristics such as: route direction, elevation profile, direction for PT several candidates were considered: Google service, Mapy.cz or Open Street Maps. All of them are quite similar in their functionality and can be accessed from a client application. Google service was chosen due to the fact that it's capable to request a route for Public Transport and has additional functionality in driving route direction such as: influence of traffic density based on real-time data (business version only).

Today quite a lot of web services can provide a weather condition on a request either in XML (Extensible Markup Language) or JSON (Java Script Object Notation) format. Some of them are: openweathermap.org, Yahoo weather, worldweatheronline.com weathebug.com, wundergrround.com. Definitely the best and the most suitable choice would be the service which provides a forecast specifically and only for a chosen region, like metrocentrum.cz or pocasi.idnes.cz, but unfortunately they don't have such functionality. Finally, wundergrround.com was chosen due to quite a big amount of weather stations available in Prague. This service is capable to provide a detail forecast for 36 hours in advance in one response.

### *2.4. Simulation software description*

User through GUI (special web interface http://elektromobilita.fd.cvut.cz/) is capable to set desire location and destination address (if needed, waypoints can be added) after getting this information and based on external information such as weather traffic condition and etc. simulation software will calculate price and time for 3 possible solutions such us:

1. PT path and price
2. Taxi path and price
3. EV car sharing price/route/consumption.

After calculation is finished, customer have to choose one of them. When costumer made his decision, information about the route is sent and saved in MySQL database. It can be used later for offline simulation.

If a costumer chose EV car sharing solution, simulation of the movement will be displayed on the web interface. Additional questions can be asked during the simulation to obtain more data.

In case if costumer choses Public Transport, he or she is provided with detailed information about the route in textual form and in graphical form on the map. If he or she chose taxi, he or she simply redirected to a web page which provide him or her a possibility to order a taxi.

Use case diagram and rich picture of proposed simulation represented in figure 3.

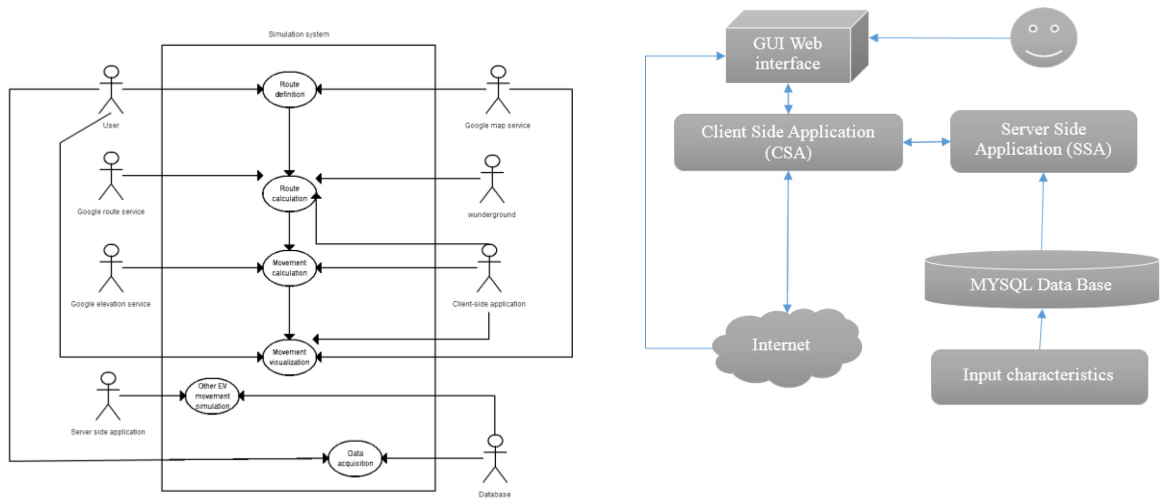



Fig. 3 (a) Use case Diagram (b) Rich picture

### *2.5. Elements and their functions*

#### *2.5.1. Server Side Application*

Special software which is written in PHP language that communicates with MySQL database. Main functions are:

- Calculate location and state of charge of all vehicles based on Client Side Application (CSA) request
- Provide a gateway between CSA and Database

#### *2.5.2. Client Side Application*

This application is written in JavaScript Language and is running on a client PC and consequently use its computational power. It communicates with a Database through Server Side Application, visualize output and capture inputs through WEB GUI. Main functions of CSA are:

- Page initialization and costumer input capturing
- Weather forecast update,
- Route request
- Calculate time and power consumption for 3 mode of transportation.
- Send gathered data to Database.
- Simulate movement of other vehicles currently in use
- Simulate movement of User vehicle
- Construct output tables

#### *2.5.2.1. Route request*

Based on the user input CSA will request Google Direction service to find the most suitable route. As a result CSA will receive JSON response with available information such as:

- Length of the route in meters.
- Polyline of the rote (Array of latitude and longitude coordinates).
- Time spend on the route.
- Routing Instruction.

To reduce amount of queries for Google direction service, route request for TAXI and EV is send in one query and Origin and Destination CSP is simply used as first and the last waypoint. Due to the fact that response from Google consist of one or more legs depending on whether any waypoints were specified, each of which contains information about a leg of the route, from two locations within the given route, hole response is used as a route for a taxi and legs from second till one before the end (route from origin CSP to Destination CSP) are used as a route for EV. Of course there is a drawbacks of such approach one and main of them is that route for Taxi has to lie through CSP and as a consequences we can have small inaccuracy in price estimation for the TAXI service.

#### *2.5.2.2. Velocity profile calculation*

Google direction service doesn't directly provide us with the amount of crossing and speed profile of the path, but it can be estimated approximately from "route steps" which gives us information about distance and travel time and consequently mean speed on a part of the route. Based on this information, we will create speed profile of the path (Modal Cycles involving periods in a constant speed). Output of the calculation for a path from Spiritka to Pámelníková represented in figure 4.

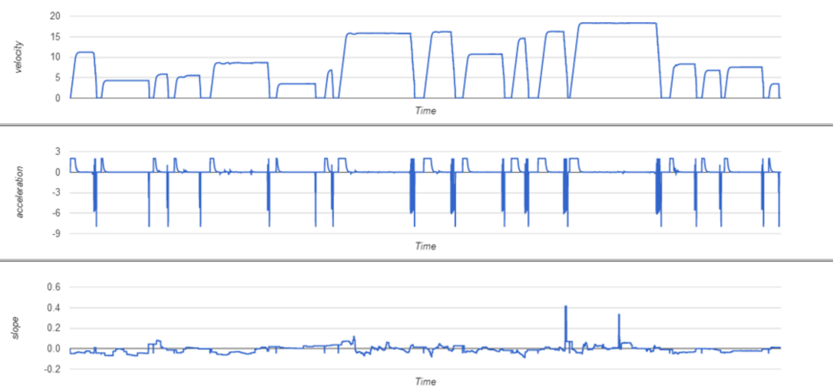



Fig. 4 Result of velocity profile calculation

### *2.5.3. Elevation along the path*

After CSA got the response from Google, Direction, polyline of the path should be used as an input for Google Elevation service. As a result, we got an array of elevation for points uniformly distributed along the path, Maximal amount of points is 512. The result of the query is represented in Figure 5

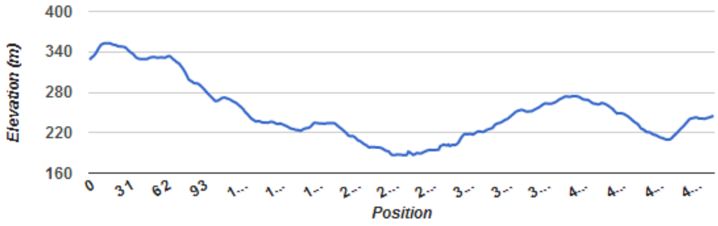



Fig. 5 Elevation profile of the Path

The slope of the route can be obtained from these data based on equation 9

$$Sl(i) = tan^{-1}\left(\frac{El(i) - El(i-1)}{\Delta Del}\right) \quad (9)$$

Where: *El(i) and El(i-2)* – Elevation at point i and (i-1) correspondingly,

$\Delta Del$ – Distance between two points of measurement.

One should understand accuracy problem of this method

- In each given request you may query the elevation of up to 512 locations, so for paths bigger than 5 km resolution become unreliable and additional measures have to be applied, such as breaking the path into smaller parts and query them separately.
- Source of the data from “Google elevation service” is unknown.
- In comparison with SRPM3 service whose response has resolution of 3 arc-seconds (about 90m), “Google elevation service” provides resolution information in Elevation responses for every query which varies from 50 to 150 m. Comparison of these sources can be found on figure 25
- Third problem, which we have to take into account, are tunnels and bridges, unfortunately both services have the same problem. They provide higher elevation of requested area.


Fig. 6 Comparison Google and SRTM3 elevation [4]

### *2.5.4. Database*

MYSQL database is used for storing all needed information for simulation and further analysis. Entity Relationship diagram of the database is represented in Figure 3 Database consists of 7 tables:

- Station table: Contains all needed information concerning Car Share Point it's spatial location coordinates, address, and it’s Charge Rate in kW per hour
- Customer table: Contains all information provided by customer through WEB interface. Such as his Name and Surname driver experience and familiarity with EV technology if customer doesn’t provide personal information empty row with unique ID value is created.
- Vehicles table: Contains vehicle characteristics and their current state such as Odome-ter value, state of charge, and current location either station ID or 0 – if vehicle status is on the route.

- Weather table: Is a backup table in case of online Weather forecast update failure, Contains latest available update from wunderberger API as a JSON data string.
- Paths table: Contains information about routes which consumers have queried through WEB interface. Also, includes data such as encoded polyline string, travel time, travel distance, origin and destination CSP and etc.  This table is a key element for the simulation.
- Questions table: Contains Questions, which can be pro-posed to answer for a user during the simulation.
- Answers table:  Contains Users' answers for questions from question table.

Additional Foreign Key relationships were established between tables to link them together, to improve computational speed and minimize errors during database update. They are marked as dash line in the figure 7

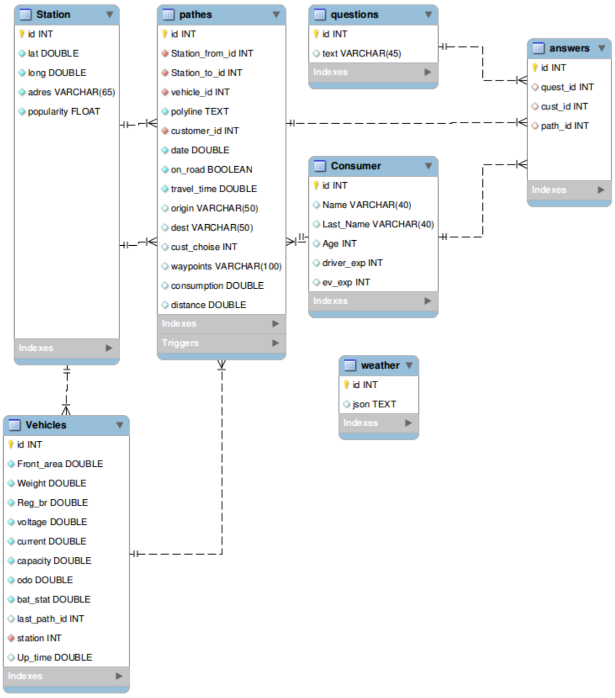



Fig. 7 Database ER Diagram

### *2.5.5. GUI Web interface*

GUI web interface is a dynamic web page written in HTML language and available on the internet. It was created as a gateway between user and simulation software, in order to provide user with a possibility to define inputs and to observe output of the system.

GUI provides different interface for several state of the simulation:

- Log-in page and Tem of use. (Figure 8 a)The user can provide the system with additional information about himself or herself or leave the fields blank, if he or she wants to stay anonymous. The user is obliged to accept the "Terms of Usage" to get access to the simulation application. In case of Disagreement, user can leave the page by closing it.
- User input acquisition (Figure 8 b). GUI Provides the user with a possibility to define origin, destination and waypoints for his trip, either through text input form, either directly by clicking on the map location. At the same time, it's a canvas for visualization of current state of the system (Station and vehicles location)). Additionally, weather forecast for the region is displayed in the right upper corner.  Power gauche battery gauche and speed gauche are preloaded for further simulation.
- Route results visualization (Figure 8 c) provides the user with a possibility to choose between available modes of transportation and visualize results of calculation. Result represented as tables
- Simulation visualization (Figure 8 d)Provides the user with a step by step on-line visualization of EV movement including position on the map, in cabin view, elevation profile, and basic instrumental indicators

- Details of calculation visualization (Figure 8 e)In order to provide the user with all results of calculation and make him or her more familiar with principals of EV consumption GUI can construct graphs of several variables such as Velocity and acceleration profile, slope of the route, and, of course, consumption.
- Virtual questioner (Figure 8 f)Provide a possibility for a user to answer questions and give us a feedback about the simulation software

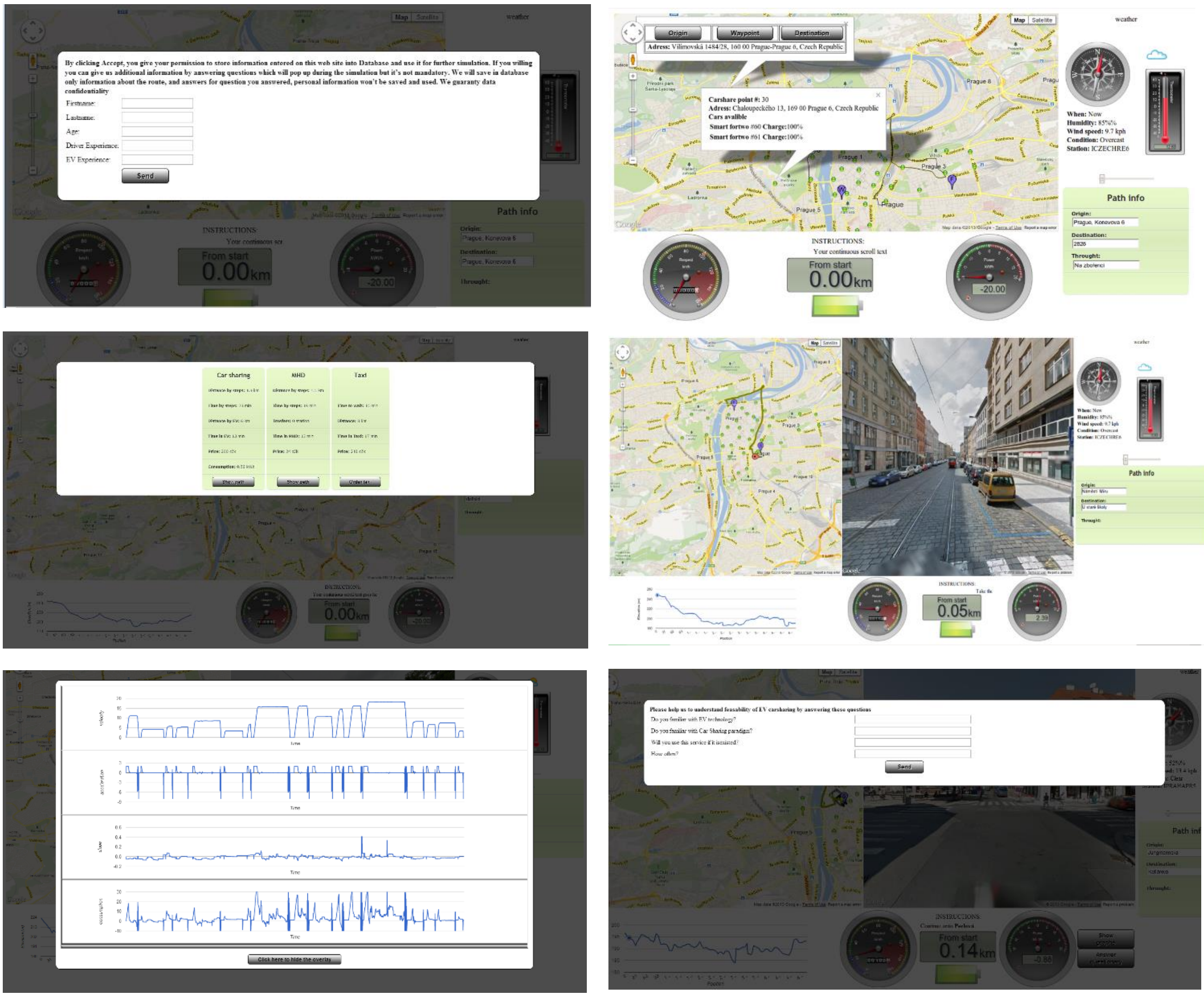



Fig. 8 (a) Log-in page (b) User input acquisition
(c) Route results visualization (d) Simulation of Movement
(e) Details of calculation (f) Virtual Questionnaire

## 3. Results

After simulation software was launched, several tests were performed to understand its functionality and to find out response of EV consumption model on different initial conditions such as different weather, Elevation profile influence and driver behavior influence.

### *3.1. Weather condition influence*

To understand influence of weather on consumption, a calculation of 2 rides on the same route with a different weather forecast was performed. Results are represented in table 16 and we can see 3% difference in consumption.

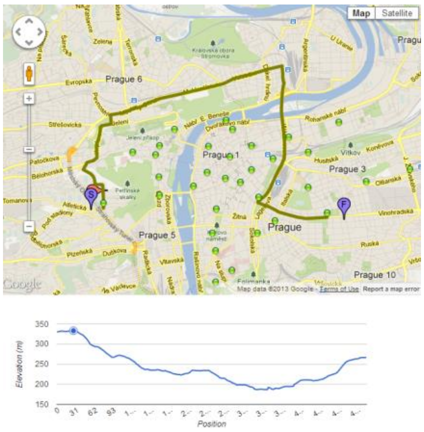
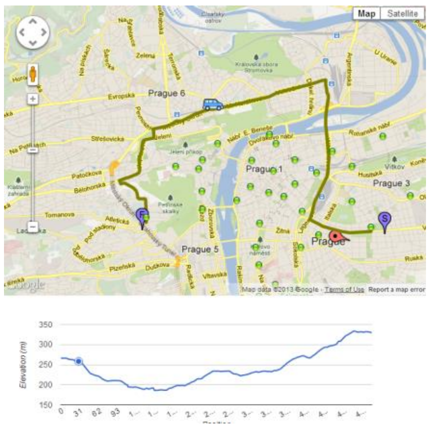
Table 3 Weather conditions influence

| Weather condition | | |
|---|---|---|
| Temperature [C] | 22.4 | 13.4 |
| Humidity [%] | 54 | 66 |
| Condition | Sunny | Partly Cloudily |
| Wind(direction) [km/h] | 12.9 (SW) | 6.4 (N) |
| Distance [km] | 6 | 6 |
| Consumption [kW] | 0.91 | 0.89 |

### *3.2. Elevation profile influence*

The influence of slope of the road on consumption of EV are represented in Table 4. As it can be seen, slope has much bigger influence then weather condition and for the path with the same distance and amount of crossings can reach almost 30 %

Table 4 Elevation profile influence

| | |
|---|---|
|  |  |
| Consumption: 0.9 kW | Consumption: 1.24 kW |

### *3.3. Path generation*

Google direction service provide “fastest” route as a response (route with minimal time consumption). Even if spatial location of origin/destination points are the same, sometimes response can provide two different routes directions in case of using Google for Business, this result will be influenced current traffic condition.

## 4. Conclusion

The simulation software was created with a main goal to understand a popularity of the service and familiarize prospective users with a proposed solution was created. The simulation is a virtual Car sharing service available on the internet, it was created using Google map functionality with respect of Google License policy. Simulation software provides a user with possibility to rent a Virtual vehicle from one of available stations for a route, defined by a user, and to observe vehicle movement and power consumption. Consumption is calculated with respect to spatial and weather condition of the route. The simulation is available for public access on the internet web page www.elektromobilita.fd.cvut.cz through Google Chrome web browser only. The results of the simulation on the early stage strongly depend on popularity of the web service and amount of participants. After, obtained information can be used as an input for an offline simulation.

We hope this work will provide a new perspective on simulation and data acquisition technics and will serve as an example or as a start point for our further colleagues. Hopefully, in collaboration with them we will make Electric vehicle car sharing work in Prague city and at least slightly decrease an impact of transportation on the environment.

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# Preconditions of Traction Energy Consumption Calculation with Exact Method using Computer

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**Abstract**

For full use of exact method of traction energy calculations (including complex traction and power consumption characteristics) is necessary to properly define needed inputs and their form, but also suitably formulate the algorithms and define the output data formats. Based on these well-described and set conditions is then possible (using the computer) to exploit fully the potential of exact method and all its benefits.

**Keywords:** traction characteristics, energy consumption calculation, exact method, isoeffectives

## 1. INTRODUCTORY CONTEXT

The basis of each traction energy calculation is the most accurate description of the various factors and variables that affect the final energy consumption. This description must be processed at any time during the entire ride in any mode (power ride, coasting, braking). The determination of required traction power and consumed energy is necessary based on the basic form of the motion equation, which provides the necessary traction on the wheel periphery based on the known driving resistance (both vehicle and track).

Specific traction force on the driving wheel periphery of traction vehicles $f_t$ shall at any time of ride fulfill the condition

$$f_t - r_v - r_{gred} - r_a = 0 \ \ [\mathrm{N/kN}] \qquad (1)$$

where $r_v$ is the specific vehicle resistance [N/kN],
$r_{gred}$ specific track resistance [N/kN,] and
$r_a$ specific inertial resistance [N/kN].

For such determined required specific traction force, which is further converted to the mass of the train (assuming a simplified physical model, where the calculation uses the mass point of zero dimensions and the weight of the train), is using traction characteristics and its fractional curves and using ***isoeffectives*** (curves of constant efficiency) determined the resulting instantaneous power input (in the given computational step). The aggregate value of individual instantaneous power inputs makes the resulting value of the traction power consumption.

## 2. BASIC PRINCIPLES OF THE EXACT METHOD COMPUTER CALCULATION

The program for calculations of traction energy consumption (ECalc) processes the input values and then work with them in discrete time intervals in which the value of individual variables (input and output) is considered constant. The change of the length of this time interval affects accuracy of the calculation (for a sufficiently accurate calculation is typically used interval of 100 ms).

For each calculation it is necessary to define and describe the traction vehicle (and its traction and power input characteristics), load and its parameters (relatively to surrounding conditions), relevant track section and its characteristics, as well as other parameters of the calculation (the ride mode at the speed reduction - the ratio of the coasting and power braking and other restrictions).

For well-defined inputs is then possible to perform calculation with an output as a graphical and tabular processing of the individual variables and the resulting energy consumption.

The basic concept of calculations is based on a modular approach. Program uses a few modules that are interconnected and carry out the various calculation phases. Individual modules share their outputs and results of partial calculations among themselves. The basic module, which performs calculations of ride characteristics and monitored values, and which contains a single computational algorithm for the ride is the module BASE. Its inputs and outputs are described below. Outputs are used as input for other additional modules and are also shown in the graph, respectively exported as tabular output.

ENERGY is additional module that as the output passes on power consumption of train ride based on the input from BASE module about course of the ride and given traction and power input characteristics. It is also considered with the possibility of future extension by module ECOLOGY dealing with the evaluation of ride in terms of the amount of emissions released into the environment while riding, module THERMIC watching thermal and energy losses while riding or module ACCUMULATION dealing with potential savings of energy shattered when braking and possible subsequent recovery. The entire procedure described above is illustrated in the following diagram.

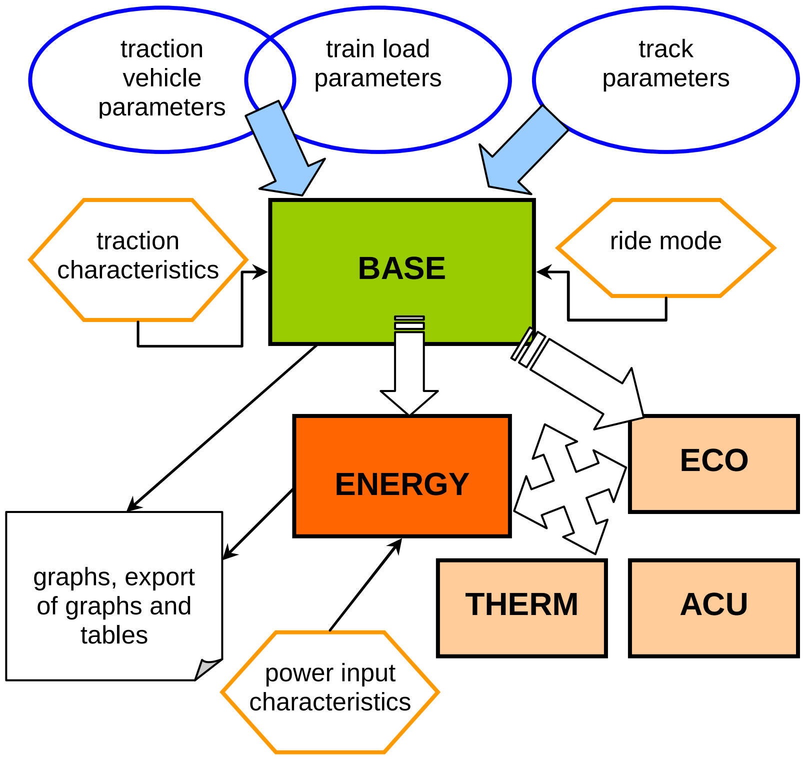


Fig.1. Block diagram of the program modules; source: Author

This procedure can generally be used (at a sufficiently precise description of the system) for almost any type of transport (rail, road, water). Detailed description in the next section, however, relates to railway electric vehicles.

## 3. INPUT VARIABLES AND THEIR FORMAT

Into the calculation within the module ENERGY and BASE using the exact method enter the following data in given formats.

### *3.1. Description of traction vehicle and train load*

Traction vehicle is described on the basis of its ***mass*** [t], ***resistance formulas*** for power ride and coasting (two sets of coefficients), the ***coefficient of vehicle rotating masses influence*** $\alpha$ [1] and ***traction and power input characteristics***. Resistance formulas are given by the coefficients of individual powers of the current speed in a resistance formula in the general shape

$$r = a + bV + cV^2 \qquad (2)$$

where $r$ is the specific vehicle resistance [N/kN],
$V$ is the instantaneous speed [$km.h^{-1}$],
$a$, $b$ and $c$ individual coefficients.

***Traction characteristics*** are given by the fractional curves which show the course of actual speed dependence on traction forces on the driving wheel periphery in the percentage of the relative thrust. Example of such traction and power input characteristics is shown below.

For the purpose of the exact calculations is needed to specify traction and power input characteristics using the equations describing each fractional curve. It is implemented using a polynomial suitable for continuous segments of individual curves. This is a cubic polynomial

$$y = a + bx + cx^2 + dx^3 \qquad (3)$$

that is described by individual coefficients. Additional parameter of traction characteristics is then $\delta$ [$kN.s^{-1}$] (value representing an increase of relevant engine traction force, which is necessary for the description of transition states).

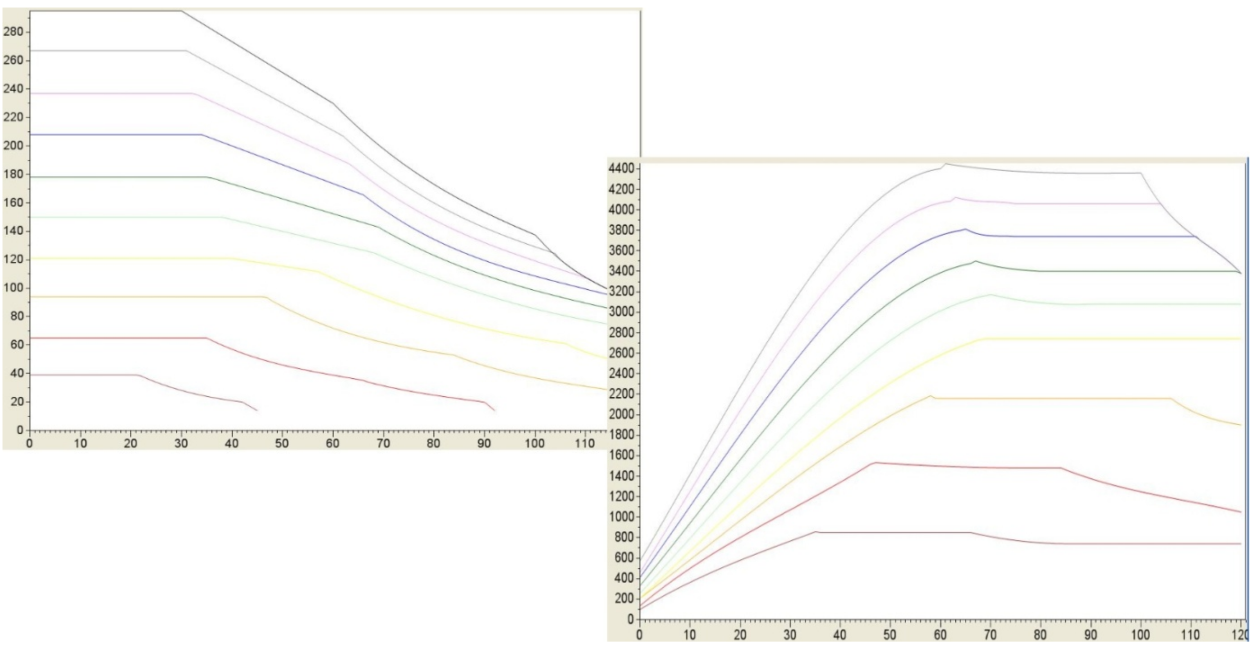


Fig.2. The sample of graphic representation of traction and power input characteristics; source: Author, [2]

In the way of working with traction characteristics, respectively efficiency is the most fundamental difference of exact method from methods commonly used. Normally the traction and energy calculations consider a simplified diagram of constant efficiency or efficiency by speed steps. However, the exact method works with specific and exact efficiency value for a given point of traction characteristics thanks to its interconnection with the graph of power input characteristics. Thus it is possible to more accurately evaluate the particular instantaneous power consumption.

The train load is similarly to traction vehicle described by its own mass [t], one resistance formula (set of coefficients as in the case of traction vehicle - see *(2)*) and coefficient of rotating masses influence [1] of the load, which due to different construction differs from analogical coefficient for traction vehicle.

*3.2. Description of track section*

Track section is ***described by partial (input) segments*** so that the individual sections are identical to the following parameters:

- the maximum track speed [km.h$^{-1}$],
- longitudinal gradient [‰],
- curve radius [m].

The above mentioned parameters of the track all influence the resultant reduced track resistance [N/kN] - see *(1)*, which is one of the key inputs of motion equation. Individual input segments (respectively their stationing) are thus derived from the changes of these parameters, ie. in each change of one of these parameters is started a new input segment (the line in the track description).

For each input segment is further possible to define whether a tunnel or whether the section, respectively stationing, where it is supposed to stop. Finally, for each of these segments can be define the ***deceleration ratio*** [%], which is described in more detail in the following paragraph.

*3.3. Calculation settings*

Important inputs are parameters of the calculation. Most important (affecting accuracy of the results) is the calculation ***interval*** [ms], which is mentioned in the introduction. It is also necessary for specific calculation to set relative thrust of engine (the percentage of the maximum possible thrust). This value is used for moving off. Additionally it is possible to limit the maximum speed (regardless of track limits) and increase in weight influenced for example by snow and ice or some other external factor. It is also necessary to specify whether a particular calculation considering riding after stationing direction or against its direction (relative to the input of track section).

Furthermore, the calculation setting defines the ***braking mode***. Specifically, it is possible to choose between three forms of expression of braking force:

- using constant braking deceleration [m.s$^{-2}$],
- using a constant braking force [kN],
- as changing braking force (depending on speed).

In the third case is breaking characteristics defined in the same manner as in the case of the traction characteristics (using cubic polynomials, respectively their coefficients - see *(2)*). The key parameter in terms of braking is ***deceleration (stopping) ratio*** [%]. The calculation of the deceleration ratio describes the formula

$$R = (V_{PB} - V_C)/(V_M - V_C) \qquad (4)$$

where $R$ is the deceleration (stopping) ratio [%],
$V_{PB}$ speed at the beginning of force braking [km.h$^{-1}$]
$V_C$ target speed (zero in the case of stop) [km.h$^{-1}$] and
$V_M$ the maximum speed in considered section [km.h$^{-1}$].

Deceleration ratio of 100% is thus equal to the maximum braking, 0% is analogous maximal coasting. More specifically is the use of this parameter described below. This ratio can be entered separately for ***stopping and***

***decelerating braking*** and at the same time it can be defined differently for each input segment in the track parameters. As an additional parameter, as in the case of the traction characteristics can be entered $\delta$ [kN.s$^{-1}$] (the value representing the increase of the braking force which is necessary to describe the transition states).

## 4. BASIC ALGORITHMS FOR VARIOUS RIDE MODES

The calculation procedure varies depending on the ride mode. There are three basic ride modes - ***acceleration***, ***power ride*** and ***braking***, respectively ***coasting***.

### *4.1. Acceleration*

Acceleration mode is defined as a part of the ride, when the speed increases from zero (or an initial) speed to the desired speed, which can be either the maximum track speed at a given section, or the maximum speed of a train set (the lower one), and the higher than the initial rate. Acceleration takes place using traction force depending on the input of relative thrust. From the curves of traction and power input characteristics are then for the current speed derived instantaneous power input. When approaching the target speed it is required a gradual reduction of forces in relation to the engine parameter $\delta$ down to the level that is needed for the next ride (which is usually power ride at constant speed).

### *4.2. Power ride (at constant speed)*

This mode is defined as ride at a constant speed, where is necessary traction force on the driving wheel periphery derived from the track, vehicle and inertial resistance. Depending on the required traction force and current speed is then set the desired relative thrust and derived current power input, which is further added into the overall consumption. Ideally, the desired speed is maintained constant during the entire ride in this mode. Its individual fluctuations may occur due to significant changes in track resistance and inability to respond to them immediately due to transition states expressed by the parameter $\delta$ no matter whether launching traction or braking force.

### *4.3. Power braking, respectively coasting*

This is ride mode where there is a reduction of ride speed on the maximum track speed limit reduction or stop request. When the calculation reaches the point where the speed reduction is required, it is started the ***reverse calculation***, that using a defined deceleration ratio simulates power ride acceleration from the target speed in the following section (stop point), when as traction force is considered the maximum braking force up to speed specified by deceleration (stopping) ratio. From this point, the reverse calculation runs as power ride when the traction force is considered in the amount of the instantaneous ride resistance at that point. This way reverse calculation continues up to the original (forward) speed in actual track section or until the end of segment with given speed limit. In case that there is no intersection of the original calculation speed and reverse calculation curves, the set deceleration ratio is ignored (it cannot be achieved under the given conditions) and is used coasting from the beginning of the section to the ***limit braking curve*** at given section (shows braking progress using maximal braking force so as to achieve the target speed for the following section or stop, therefore, as it is used stopping ratio of 100%).

Based on the results of reverse calculation is then determined the course of ride in examined deceleration (stopping) section and it is used as part of outputs.

## 5. OUTPUTS

Outputs of variant calculations implemented in BASE and ENERGY modules have ***graphic*** and detailed ***tabular*** form. The ***graphical output*** is best suited to illustrate the ride and its analysis in individual ride modes in relation to the stationing at specific time and demonstrates the behavior of monitored variables. In the graphical output it can be set to display any relevant variable and using pointer show the specific values in given stationing and time. It is also possible to resize the graph as needed so as to see the relevant details or all examined section. The final form can be exported as a file (see below).


Fig.3. The sample of graphical calculation output; source: Author

Calculated data (of all monitored values) can be after setting of the output time step completely list to the table and use for further work with them, searching for various specific values or exporting whole set of data to a format suitable for further processing (*. xls, *. csv, *.xml).

## 6. SUMMARY

Using the exact method for traction energy calculations can be achieved more accurate results when determining the energy consumption than using common methods. The derogation size of both calculations is dependent on both the accuracy and the complexity of inputs and the specific ride mode. The biggest increase of results accuracy provides the exact method compared to common within the calculation of power ride mode (either constant speed or acceleration), when is under it possible to accurately determine the required power input. Using ECalc is also possible on the basis of partial settings in variant calculations optimize the ride in terms of energy consumption in all ride modes with different requirements in different sections of the track. Concurrently it is possible to asses any potential for energy recovery and create a basis for further energy optimization by monitoring negative traction force (braking force in deceleration mode).

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# DEPARTMENT OF LOGISTICS AND MANAGEMENT OF TRANSPORT

# K617

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- In the domain of logistics the research deals with general principles including management of logistics systems and transportation logistics.

# Network-Bound Offer of Periodic Freight Train Paths

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**Abstract**

This paper is an extended abstract of the author's doctoral thesis Periodic Freight Train Paths in Network, which was already submitted for defense.

First of all, freight timetabling problems in the context of Integrated Periodic Timetable (IPT) of passenger trains, are analyzed. Because of character of freight railway, a conclusion is made that periodic train paths as an offer of capacity, rather than periodic timetables, make sense for freight trains.

This offer is understood as an analogue to IPT in passenger transport, which meets requirements of miscellaneous freight trains – the offer is regular, but flexible thanks to alternative connections in node stations into various directions. Elimination of useless stops of freight train is also stressed. On the basis of these requirements, a concept of freight IPT-node and a generic framework process for construction of network-bound periodic freight train paths (PFTPs) are formulated. The framework process is applicable by annual timetabling, as well as by strategic planning. The construction of train paths takes place in periodic, usually 1 hour wide, time window. This framework process is supplemented by proposal of suitable timetabling, technical and infrastructural measures for achievement of better results.

Afterwards, the framework process is verified on two valid timetables of passenger trains (idealised as purely periodic) in Prague node area. Freight node station Praha-Malešice is chosen as freight IPT-node. In the first study, by using of PFTPs constructed according to the proposed framework process, 104 stops of freight trains were avoided, which represents 34% of scheduled stops from corresponding real timetable. In the second study, 187 stops of freight trains were avoided, which represents 53% of scheduled stops from corresponding real timetable.

The results confirm suitability of proposed framework process.

**Keywords:** Integrated Periodic Timetable (IPT), periodic freight train paths, capacity utilisation, bottlenecks, speed bundling

## 1. INTRODUCTION

In European railway network, periodic timetables of passenger trains, in some cases even *Integrated Periodic Timetable (IPT)*, become more and more common – welcome by passengers, as well as by public transport planners. Such concepts, however, do not take needs of freight railway into consideration and in some cases lower quality of freight train paths (freight trains have to stop more frequently to be overtaken by faster trains). Since the contribution of IPT for public passenger transport is indisputable, it is necessary to look for solution in the context of IPT.

Freight train paths remain mostly individual, with few exceptions described below, where infrastructure managers implemented periodic freight train paths (PFTPs). Yet, systematic approach for reduction of often stopping of freight trains on lines with dense mixed traffic, as well as for direct connection of freight train paths in nodes (if needed, among more than two lines) to avoid stopping, is still missing.

European Commission declares support of sustainable means of transport, including freight railway and intermodal transport. Recent White Paper on European transport policy [1] states "Rail, especially for freight, is sometimes seen as an unattractive mode. But examples in some Member States prove that it can offer quality service. The challenge is to ensure structural change to enable rail to compete effectively and take a significantly greater proportion of medium and long distance freight...".

The author considers any ground-breaking solution of mentioned problems, e.g. construction of network of dedicated freight railway lines, very unlikely. High-speed railway lines in Europe have great potential to relieve main lines with mixed traffic of the fastest trains, but they are not designed everywhere. Thus, a solution, which is applicable now and there, as well as in conceptual planning, is further proposed.

The author of this thesis considers the idea of IPT last significant achievement in qualitative research (i.e. non-quantitative research) of railway networks.

On the other hand, freight timetables (and train paths) are by vast majority of researchers and experts considered as irregular (with the only exception – when there is a time window between periodic passenger trains only for one freight train per period). This perception reflects in proposed algorithms and developed software tools.

Except for bypasses of bottlenecks and dedicated freight lines, *there are not formulated infrastructure requirements of freight railway, derived from prospective timetable*. Because of irregular timetabling it is impossible to predict stations for regular overtaking or crossing, which makes the infrastructure projects more expensive, even if requirements of passenger transport are exactly determined from IPT-based operational concept.

### *1.1. Principle of Integrated Periodic Timetable*

All services included in IPT operate in public transport lines (PuT lines). The IPT is described by following rules:

- *Unified period (interval) of all PuT lines* – one hour as a rule
- *Unified symmetry time for all PuT lines* (the time when services of the same PuT line, but opposite directions meet each other) – zero minute as a rule
- *IPT–nodes* (the stations where all services arrive before symmetry time and depart after symmetry time)
- *Arc equation* – travel time between each two IPT-nodes must be equal to integer multiple of half period
- *Cycle equation* – all round trips from one IPT-node to the same IPT-node (through at least two other IPT-nodes) must be equal to multiple period

## 2. Aims of the Thesis

The aim of this thesis is to contribute to qualitative (in the sense of "non-quantitative") research in the field of railway capacity management, especially basic principles of timetabling of freight trains (or capacity allocation for them) in the context of IPT. A framework process for construction of network-bound periodic freight train paths (PFTPs) on the level of operational concept will be designed. Such framework process should neither affect IPT, nor restrict network capacity. Only small adaptations of present IPT or other penalising measures for passenger transport are allowed, assumed that achieved effect for freight transport is significantly larger. The thesis focuses mainly on railway lines and nodes with *mixed traffic*.

The framework process, proposed in this thesis, should be understood as a guideline for railway infrastructure manager, which should be applied adequately to specific local conditions, rather than proposal of strict regulation.

The thesis should affirm or disprove following hypothesis:

*PFTPs in network in the context of IPT (constructed according to proposed framework process) lead to lower number of overtakings of freight trains by passenger trains.*

## 3. Methodology

This thesis is elaborated at level of detail, which corresponds to *operational concept*. This is the level where orderers of public service[*] usually outline PuT lines, IPT nodes etc. Then, final timetable is negotiated and finally constructed by IM, together with public service orderers, passenger railway undertakings charged by the order, and railway undertakings (RUs). Exact timetable construction is, to the author's opinion, already being researched thoroughly by quantitative research.

Chosen level enables the author to focus on such phenomena and processes, which are common for all European railway networks with IPT, and influence railway capacity utilisation and quality of freight train paths – especially number of stops. This level is more general than the process of timetabling.

The three crucial objects of qualitative research of railway capacity in this thesis are

- *periodicity* of freight train paths (periodicity of passenger train paths is assumed)
- mutual *heterogeneity* within a period
- *symmetry* of freight train paths in both directions.

[*] In the Czech Republic, Ministry of Transport orders fast and some express trains, and regional authorities or charged subjects order regional trains. Due to its nature (see sub-chapter 2.1), IPT is usually not suitable to be operated commercially.

Periodicity is assumed as a basic point of view.

Theory of periodic timetabling was mathematically formulated using *PESP (Periodic Event Scheduling Problem)*. For railway timetables, formulation of PESP was adapted by Nachtigall [2]. With aid of graph theory, *events* (i.e. time moments – e.g. arrival, departure) were represented by *vertices* and *activities* (e.g. running between stations or dwell time) as *edges*.

Periodic sequence of events was defined (for instance, sequence of minutes 0, 20, 35, 50, 75 changes by period of 60 min to 0, 15, 20, 35, 50 min, because 75 mod 60 = 15).

*In this thesis, there is stressed only the above outlined understanding of periodic timetable (or IPT) in network.*

For presented aims of the thesis, macroscopic level (number of trains of particular category per time unit) is too gross. On the other hand, microscopic level (blocking time theory - see UIC 406 [3]) is too detailed, as quantitative research is not purpose of this thesis.

The chosen level of detail distinguishes

- parallel or heterogeneous train paths
- sequence of trains (double- and more-track lines), or order of trains (single-track lines), i.e. every single case of overtaking or crossing
- (partial) "bending" of train path, i.e. slower planned running than technically possible due to restricted capacity
- number of tracks on every section of railway line – in a station, only tracks for overtaking or turn-around are considered
- compliance of passenger or freight train paths with unified (zero) symmetry, which is one of basic elements of IPT

The research is done in periodic time window for two reasons:

1. to adopt periodic view on capacity
2. to decrease complexity of the solved problem

On network level, bottleneck areas are distinguished. The framework process, developed in this thesis, uses the idea of division of railway network, presented by Caimi et al. [4], into condensation zones (bottleneck areas, where as little time reserves as possible are required, because of better capacity utilisation) and compensation zones (where higher time reserves are required to compensate small delays from condensation zones).

In *bottleneck areas*, endeavour is made to design periodic freight train paths with as little stops as possible (in case of need, with slight adjustment of passenger train paths). In this thesis, bottlenecks are understood as condensation zones.

In *compensation zones* (i.e. outside bottlenecks), a freight train path usually connects two strict time slots on their boundaries. If the overtaking of freight train by passenger trains is necessary, it should be designed preferably in compensation zone, because of sufficiency of capacity there. Extension of runtime is also possible (with the consequence of coasting or running at lower speed) rather than stop, when time distance between available slots on the border with condensation zones is too high for regular runtime.

The PFTPs, resulting from implementation of the framework process, are depicted in the form of *netgraph* (network graphics or interval graphic, in German: Netzgrafik). Netgraph can be called an extended plan of PuT lines – it comprises also temporal and qualitative aspects of public transport offer (arrival and departure times in nodes, and thus connections between various PuT lines etc.).

**4. State of the Art**

The basic problems of freight timetabling in the context of passenger IPT were already pointed out by Lindner and von Redern [5] in 1989. They found that it was necessary to let periodic time windows ("canals") free for freight trains. These time windows should be wide enough for required number of freight train paths per hour. *The periodic time windows should be preferably connected in nodes* (if needed, among more than two lines to enable use by freight trains with various origin/destination stations). In the case of insufficient capacity, the authors proposed to *review the structure of passenger transport offer*. Of course, requirements of freight transport should not lead to breakup of important elements of network offer of passenger transport. In closing of their paper, the authors mentioned an important postulate, that *the process mentioned above did not result in periodic freight products (train systems), but in periodic freight train paths, which can be used by freight trains also only partially.*

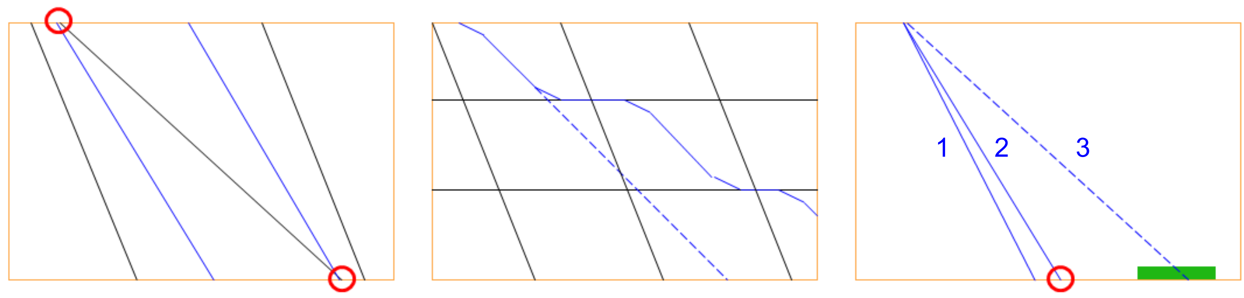


Fig. 1. Various problems of freight train paths (marked blue) in the context of IPT: (a) capacity consumption of IPT-based connections; (b) dense passenger operations vs. freight train; (c) illustrations of various runtimes of a freight train: technical (1), regular (2) vs. system (3) runtime

Wichser [6] described a sharpening conflict in requirements for railway capacity allocation between passenger and freight railway undertakings in Switzerland. He suggested to design freight train paths together with passenger train paths, and he required the same priority for both passenger and freight trains and search for global optimum by solutions for disturbances. He also stressed need of connection of freight train paths in nodes, so that passing of a freight train through the node station without stop would be possible.

Krýže [7] illustrated on several examples problems of frequent stops of freight trains (or even missing capacity for their running) on single-track lines, if the passenger trains operated there in a periodic timetable.

To the author's knowledge, the only infrastructure managers, who have already implemented PFTPs in mixed (passenger and freight) traffic, are Swiss Federal Railways [8] and BLS [8]. PFTPs were also designed on Betuweroute [9] – a dedicated freight railway line, which serves as a feeder for Dutch seaports.

RailNetEurope [10], the association of European infrastructure managers and Allocation Bodies, promotes freight corridors with internationally allocated train paths, partially periodic. However, PFTPs for these corridors do not always respond national timetables.

Periodic timetables of freight trains require appropriate demand for transport. Müller [11] investigated an IPT-based concept (Cargo-Takt-System) for wagonload transport in Germany, with use of conventional or innovative rolling stock (automatic coupling, autonomous drive etc.). Marshalling yards were proposed to correspond to IPT-nodes in passenger transport. The result of Müller's research was a calculation that has shown no significant time- or cost-saving potential for such concept with use of conventional freight wagons.

Penner [12] presented the concept 200X of Railion Deutschland (German national freight RU). This concept should simplify wagonload transport by service of less points in network and train formation in few large marshalling yards. German project LogoTakt [13] seeks to develop technologies, processes and necessary tools that enable putting of whole multimodal logistic chain into periodic operation. Thus, system robustness should be ensured.

Široký and Cempírek [14] developed a model periodic timetable for trains of combined transport within Central Europe and busy European seaports. They used genetic algorithms to minimize sum of waiting time due to transshipment of containers weighted by number of transshipped containers. Periods of 6, 12, and 24 hours were used, but specific train paths were not constructed.

The result of the literature review is that the conclusion made by Lindner and von Redern [5] remains still valid: PFTPs are appropriate for freight trains rather than periodic timetable. In addition to the review, critical parameters of freight trains, which were scheduled through lines with the busiest freight traffic in the Czech Republic, were analyzed. The result was that 84 to 96% of standard freight trains were able run at maximum allowed speed of 90 or 100 km/h and their brutto mass did not exceed 2000 t.

## 5. Theoretical Approach: Analogue to IPT

Looking at IPT in passenger transport, we can ask a question whether some analogue to IPT could be useful for freight railway. This analogue should be applicable in the context of IPT, because of its doubtless contribution to passenger transport quality. Freight transport demand is mostly too heterogeneous, so it cannot be satisfied by PuT lines with regular period and mutual connections in nodes.

The resulting offer of periodic freight train paths should contain certain

- *regularity* (in terms of all-day available capacity in the context of IPT)
- *flexibility* (in terms of flexible connections between various directions in node or possibility to use only part of a freight train path)
- *train path quality* (fewer overtakings).

Contrary of the passenger transport, freight trains mostly need not to stop in significant nodes of railway network, but in certain freight terminals or marshalling yards aside from them. *Passing of freight train through node can save both capacity of bottleneck area and traction energy.*
The idea of offer of network-bound periodic freight train paths is illustrated on Figure 2. Each line represents a periodic freight train path in both directions, in unified period and with zero symmetry (if possible) to ensure symmetric connection of freight train paths in nodes. Boxes stand for node stations (opposite sides represent two switch regions of the station).

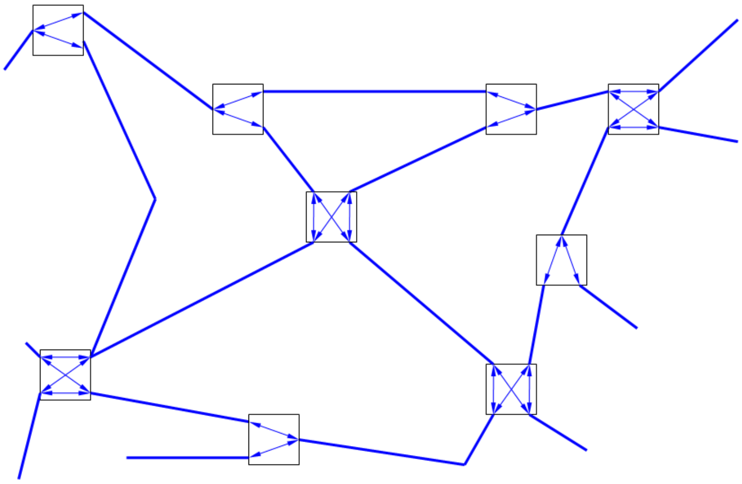

Fig. 2. Illustration of network offer of periodic freight train paths

IPT of passenger trains is understood as offer of periodic train paths (practically identical with timetable), which can be mutually coordinated between more RUs - for instance, in Switzerland. IPT is not comercially profitable, but attractive for passengers, so such services must be subsidized by public sector. Public sector, or charged subject (e.g. coordination body of integrated transport system) plans the offer of passenger services and coordinates it with buses and city public transport. The demand is represented by passengers, who use offered trains in part of their journey, and change them in node stations.
In freight railway, RUs offer to shippers particular time of loading and unloading of cargo. To fulfil this offer, RUs have to request capacity, i.e. train paths, by infrastructure managers. This means, contrary to IPT, that there are two interfaces between offer and demand in freight railway (Figure 3).

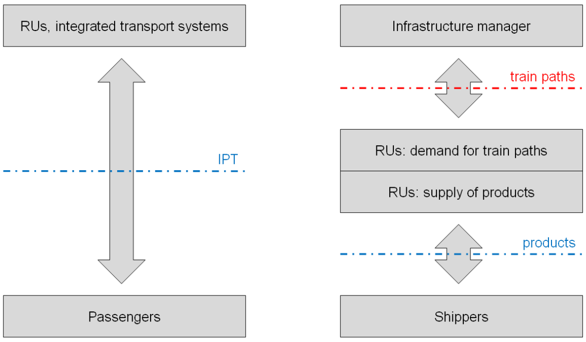


Fig. 3. Interface between offer and demand in the case of IPT (passenger services ordered by public sector) and liberalised freight railway

Common elements and differences between IPT in passenger transport and proposed offer of network-bound PFTPs are listed in Table 1.
Questions of period and PuT lines for freight trains were discussed above.
The period ensures regular offer of capacity, as well as efficient capacity utilisation within IPT. Zero symmetry ensures equal quality of the offer of capacity in both directions. So, if there is ensured passing through node station for freight trains in one ditection, the same passing through works for opposite direction as well.

System travel time in IPT ensures that passenger trains can reach both neighbouring IPT-nodes (and thus mutual connections to all involved PuT lines). *System runtime* for freight trains is slightly different. In ideal case, it would be equal to system travel time. But, in practice, freight trains have to be overtaken by passenger trains. So, primary purpose of system runtime is to avoid unnecessary stops of freight trains – either by speed bundling with slow segment of passenger transport offer, or to reach particular time window to pass through node station or junction without stop. If lengthening of runtime up to particular system runtime is required, coasting can be used.

Connections in passenger transport mean sufficient dwell and changing times to enable the passengers change between two trains. This happens usually in node station. The changing passengers are interested in adequate changing time (with reserve included). The passengers, who proceed further in the same train, are interested in as little dwell time as possible. An ideal IPT-node represents a tradeoff between these interests. However, to enable mutual connections between two trains, both trains have to dwell in the station longer than in the case of connection only from the first to the second train. The difference between resulting dwell time of a train and dwell time, which would be sufficient otherwise, is called synchronization time. The time, which represents a “freight” analogue to synchronization time, can be defined as *system runtime* – in the case when passenger change between trains, freight trains “change” between train paths. The interest of both freight RUs and infrastructure managers is to carry out this change without stop.

Just as system travel times represent constraints for passenger trains – their speed, acceleration or stopping pattern, system runtimes represent similar constraints for PFTPs, and therefore for freight trains which can use it. To fit in certain maximum runtimes through line sections, freight trains must fulfil certain ratio of locomotive power to maximum permissible brutto mass of load of the train, and certain maximum speed, as well as some minimal braked weight percentage.

Table 1. IPT vs. offer of network-bound periodic freight train paths

| Element | Passenger railway | Freight railway |
|---|---|---|
| | PuT lines | network-bound PFTPs |
| period | yes | yes |
| zero symmetry | yes | yes |
| | system travel time | system runtime |
| multiples of period | yes | not necessary |
| connections (customer’s view) | dwell + change | preferably passing through |
| connections (offer planning) | synchronization time | system runtime |

### *5.1. Where to Stop for Overtaking – A Soft Decision Process*

It is evident that any stop of freight train in bottleneck area leads to lower capacity utilisation. So, overtakings should be preferably planned outside bottlenecks – in compensation zones.

Following attributes of overtaking stations have influence on quality of overtaking:

- gradient on following line section (acceleration up the hill lengthens runtime of a freight train significantly and increases consumption of traction energy)
- maximum allowed arrival speed† on overtaking track (usually depends on arrival turnouts)
- gradient on previous line section (braking downhill increases wear of brakes)
- maximum allowed departure speed from overtaking track (usually depends on arrival turnouts)
- usable length of the longest overtaking track in particular direction

In the author’s opinion, it is very difficult (if not impossible) to set exact order of priorities of the attributes listed above. Each line, each passenger timetable and each set of freight trains make together unique combination of specific conditions. So, a choice of the most suitable station for overtaking is always a *soft decision process*.

### *5.2. Influence of Requirement on Unified (Zero) Symmetry*

The impact of requirement for unified (zero) symmetry on PFTPs can be divided as follows:

Stations on single-track lines are often not located ideally for crossing exactly around symmetry time. So, freight trains have to dwell longer. This phenomenon is similar to practical implementation of IPT on single-track lines.

† from infrastructure point of view

On the other hand, if overtaking of freight train by passenger train happens in symmetry time, it means the same event also for opposite direction. This requires a station with at least four free tracks.

For double-track line, in each direction, another station for overtaking can be chosen for various reasons – the most important is gradient of the departure section.

Generally, keeping of zero symmetry is not so important "inside" the line, where no connections between PFTPs occur, as in both ends of certain line – in node stations, junctions etc. So, *inner and outer symmetry of PFTPs should be distinguished*.

## 6. Framework Process for Construction of Network-bound PFTPs

The framework process is soft, and thus should be understood rather as a guideline for IM than strict regulation. The result of its implementation should be sequence of train paths and program of operation in nodes and other significant stations (e.g. overtaking) – mixed operational concept for both passenger and freight trains. The train path construction itself should be done by infrastructure manager – however, to give feasible results, the framework process must adopt empirical headways and other necessary constants.

For the case that simple construction of PFTPs for given infrastructure and IPT cannot fulfil requirements of freight RUs, following additional measures are proposed as a part of the framework process:

Timetabling measures

- artificial slowing down of a freight train
- coupling and uncoupling of rear-end or head-end assistance in compensation zones
- lengthening of dwell time of passenger trains
- adjustment of stopping pattern of passenger trains
- lowering of number of stopping patterns of PuT lines on particular line

Technical measures

- ATO
- real-time rescheduling

Infrastructural measures

- turnouts for higher speed in branch
- new turnouts
- lengthening of overtaking tracks
- lengthening of station tracks on a single-track line
- partial doubling of single-track line
- ETCS

### *6.1. Construction of PFTPs through node stations*

Because of at-grade intersections, it is necessary to develop a method for transparent displaying of conflict run routes within period. For analysis of present state or for construction of PFTPs (eventually with slight adjustment of passenger train paths), a *node diagram* is proposed. Its example is depicted in Figure 4.

Node diagram is designed for periodic time window, here – one hour. In the middle, there is a conflict axis with minute scale. On this axis, there are necessarily marked those PFTPs, which represent conflict run routes (i.e. those run routes, which exclude at least one another run route from another direction). The conflict axis should represent a switch region of a junction or the middle of a station. In the case of larger station, there may be more conflict axes, which may represent more switch regions. Neighbouring line sections are represented by simplified train diagrams. There is always a periodic time window (here one hour) with minute scale. The time may begin in minute 00 or 30 – the more appropriate alternative for particular situation should be chosen. Length of neighbouring sections is generally represented only in a symbolic way, because only technical runtimes (supposed as already calculated) influence construction of PFTPs. The distance has direct influence only in the case that neighbouring section is very short (e.g. one 1 km long block section – this results very often in necessity of stop of some trains).

In some cases, e.g. node station with at-grade intersection of two double-track lines, the node station is critical for capacity utilisation. So, neighbouring sections are compensation zones. Instead of stopping in node station and waiting for free time window to proceed, a freight train can wait in the section, running considerably slower using braking to lower speed and coasting (e.g. 40 km/h) than technically allowed, to meet the time window and pass through node station without stop.

If this measure is feasible in all neighbouring sections, and sustaining of zero symmetry is possible, a *freight IPT-node* can occur. Contrary to passenger transport, all trains pass through without stop, and connections are secured between train paths, not between trains. The example of freight IPT-node is drawn on Figure 4.

Apparently, in some cases it is necesary to run considerably slower to achieve conflict-free passing through node station. In the case of high gradient in some neighbouring section, this slower running can have negative impact on MPM. If there is a single-track neighbouring section, slower running has negative impact on capacity utilisation of the section. Thus, freight IPT-node should be implemented only if a local worsening of capacity utilisation does not matter in particular case. In any case, passing through the node saves traction energy and lowers noise impact on inhabitants caused by braking.

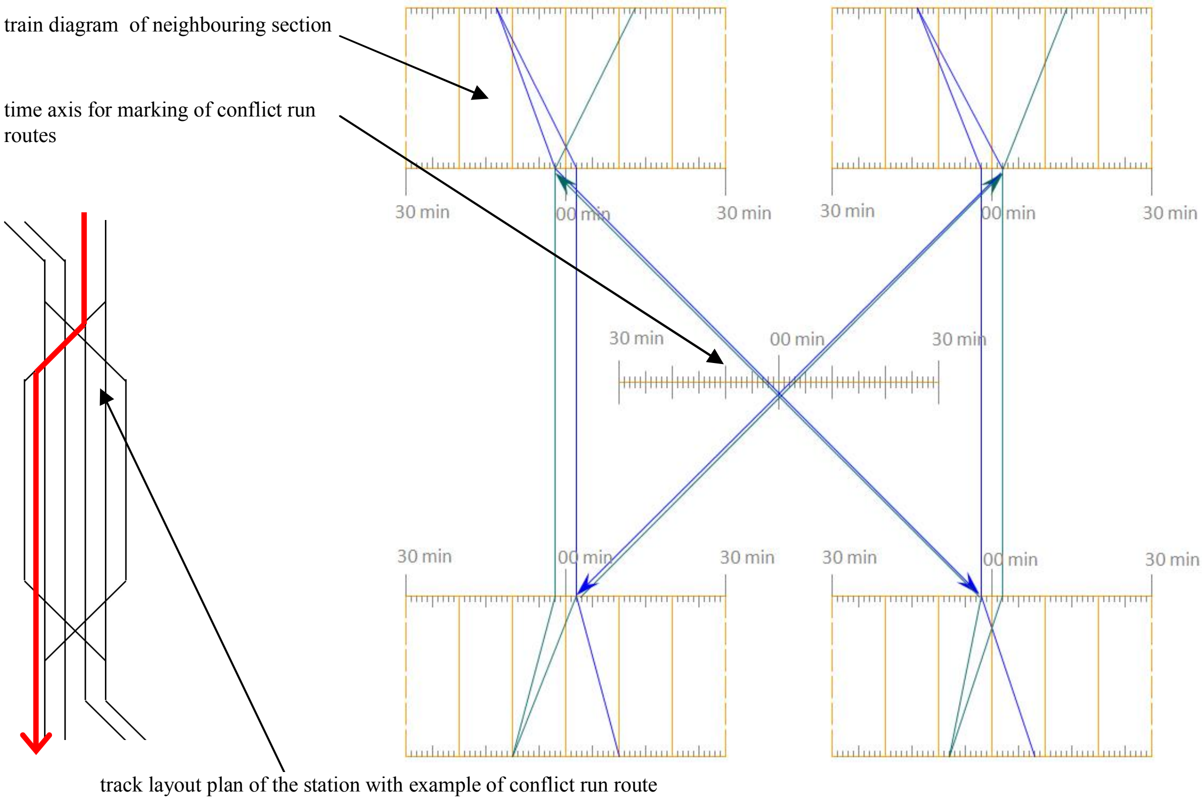


Fig. 4. (a) Example of node diagram with an ideal freight IPT-node

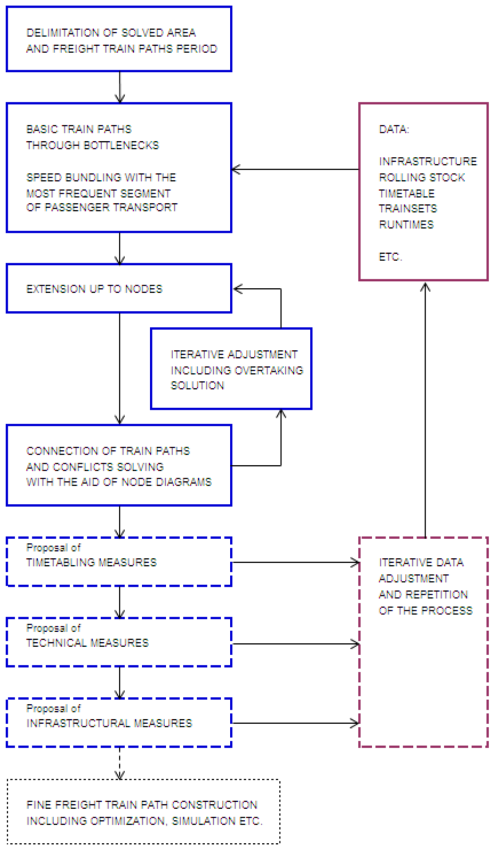


Fig. 5. Framework process for construction of network-bound PFTPs. Fine freight train path construction is not a part of the process.

## 7. Case Studies: Design of PFTPs Within Czech Periodic Timetables 2008/2009 and 2009/2010

### *7.1. Purpose of the Studies*

The framework process introduced above is presented in two studies, where PFTPs were designed on main railway lines emptying into Prague node area, in the context of passenger timetables 2008/2009 and 2009/2010. The resulting PFTPs were flexibly connected together in freight node station Praha-Malešice.

The purpose of Studies 1 and 2 was to implement the framework process derived above, within real SŽDC timetable (of passenger trains), and to discuss number of scheduled stops and symmetry in resulting PFTPs.
The timetable of passenger trains ordered by public sector, valid at that time, was adapted to purely periodic, with at least 60-min-period of all PuT lines. Either daily or peak operation of PuT lines was considered. Passenger trains running outside periodic service and fully commercially operated trains were not considered.

### *7.2. Introduction of the Solved Area*

Following lines[‡] were involved in the studies:

- 501A/011 from Praha-Libeň to Kolín
- 519A/221 from Praha-Hostivař to Benešov u Prahy
- 521A+B/171 from Praha-Vršovice čekací koleje to Beroun
- 525F (freight bypass) from Praha-Hostivař to Praha-Libeň
- 525G (freight bypass) from Praha-Vršovice čekací koleje to Praha-Běchovice
- 526A + 527A/090 from Praha-Libeň to Děčín

[‡] the lines are numbered according to two systems: tables of train parameters/passenger timetable

*7.3. Rules for Comparison of Number of Scheduled Freight Train Stops*

Another purpose of both studies was to affirm or disprove hypothesis formulated above. To fulfil this purpose, *a comparison of scheduled number of stops of freight trains in each study and corresponding SŽDC timetable* had to be worked out.

For the sake of objectivity of such comparison, all irrelevant stops were excluded from the comparison. Irrelevant stops of freight trains are

- in original or destination station of the train
- if the train proceeds further to (or arrives from) another line, not included in the study
- stops for coupling or uncoupling of head-end or rear-end assistance
- any stops caused by requirements of FRUs (e.g. coupling or uncoupling of wagons)

On the other hand, relevant stops of freight train are also stops, which have the only reason in construction of freight train path (scheduled stop instead of scheduled slow running).

Freight trains for local, sidings and special service, as well as locomotiove trains and disturbing trains (the trains whose scheduling requires delay of another trains) were excluded from the comparison.

The time scope for the comparison was the assumed time scope of passenger traffic: from 4:00 to 24:00. For the SŽDC timetables, those trains were included, which entered most significant sections of particular lines between 4:00 and 24:00.

Because of different number of FTPs in SŽDC timetables and PFTPs in the studies, *total number of stops divided by number of FTPs was chosen as quantity for the comparison*.

PFTPs in the studies were calculated as follows. All-day PFTPs were multiplied by 20. The PFTPs, which were available only outside peak hours, were multiplied by particular number of hours.

The part of economic benefit of PFTPs, which can be easily quantified, is a difference in number of scheduled train stops per one FTP between SŽDC timetable of the year *i* and PFTPs designed in Study *k*.

$$B_{Study,k} = n_{Stops,FTPs,SŽDC,i} - n_{Stops,PFTPs,Study,k} \cdot \frac{n_{FTPs,SŽDC,i}}{n_{PFTPs,Study,k}} \tag{1}$$

Relative economic benefit of PFTPs in Study *k* can be calculated as follows

$$b_{Study,k} = 1 - \frac{\dfrac{n_{Stops,PFTPs,Study,k}}{n_{PFTPs,Study,k}}}{\dfrac{n_{Stops,FTPs,SŽDC,i}}{n_{FTPs,SŽDC,i}}} \tag{2}$$

## 8. Results

In the Study 1, 104 stops of freight trains were avoided, which represents 34% of scheduled stops of freight trains from Czech railway timetable 2008/2009 [15].

In the Study 2, 187 stops of freight trains were avoided, which represents 53% of scheduled stops of freight trains from Czech railway timetable 2009/2010 [16].

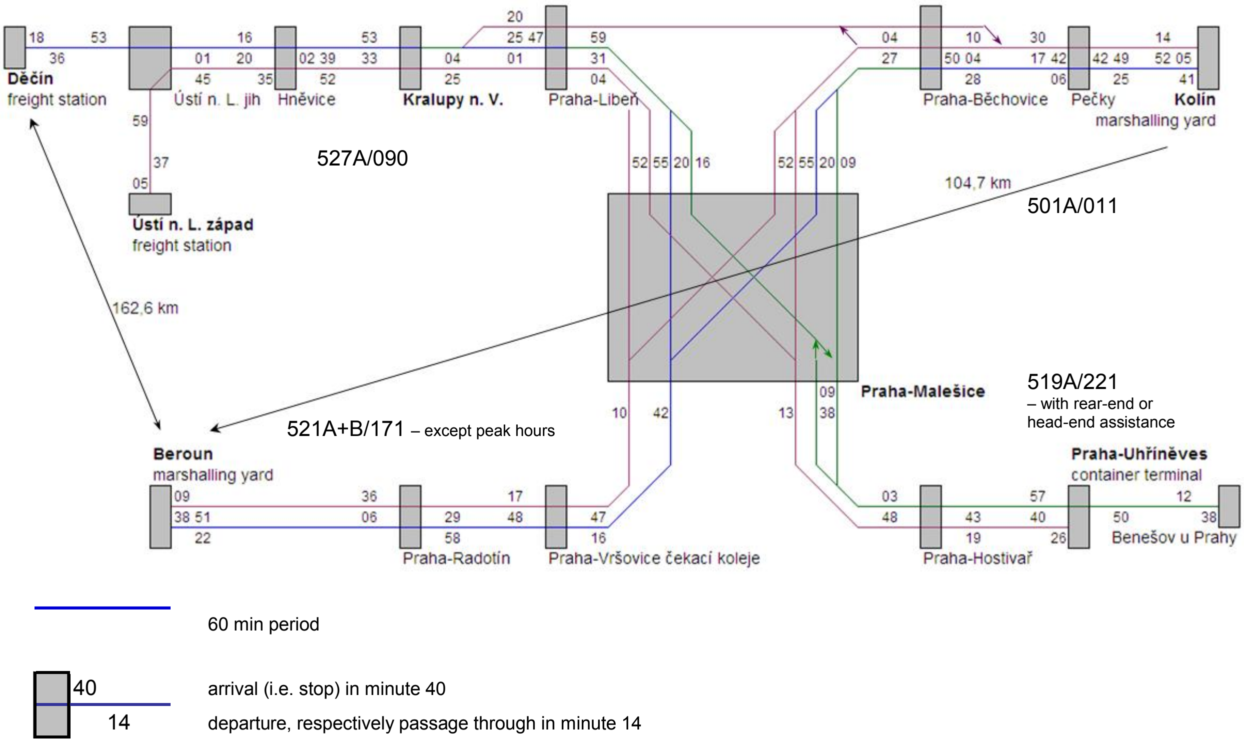


Fig. 6. Netgraph of PFTPs resulting from Study 2. Arrival minutes (close before stations) are marked only in the case of necessary stop.

## 9. Conclusion

The framework process proposed in this thesis was tested in two implementation studies in Prague node area.

The hypothesis expressed in the beginning of the thesis was affirmed in both implementation studies in Prague node area. The number of overtakings increased locally, e.g. on the line Kolín – Praha in the Study 2, but globally it decreased to very low numbers – compared to frequency of PFTPs (2 pairs per hour).

Proposed running of freight train through Prague node mostly without stopping there, and in some cases running more than 100 km without stopping in Prague at all is seldom realized in present daily operation. Because of consideration of all passenger PuT lines as with period 1 hour (because of possible further expansion of service to this period) or less, and comparable number of train paths per hour to freight timetable at that time, higher capacity utilisation with proposed PFTPs can be declared.

The timetable proposals presented in the studies above are likely to fail in timetable simulations as unstable. Moving of passenger train paths few minutes earlier (or later) can lead not only to fewer overtakings and stops of freight trains, but also to sufficient stability of proposed timetable. Technical measures can improve accuracy of train driving and targeted infrastructure measures can remove the most critical bottlenecks. PFTPs as operational concept have great potential to specify requirements of freight railway for infrastructure more precisely.

## 10. Contributions of the Thesis

The most significant scientific contribution of this thesis is *new paradigm of railway capacity allocation for freight trains*. Qualitative research in this thesis has contributed to development of theory of railway capacity management. Contrary to (even periodic) freight train paths for particular railway line, *a new structure of offer of capacity for entire network was developed*.

As this thesis was written in English, there was necessary careful choice of used terms from synonyms, for the sake of consistency. Usually, for basic terms, the most frequent synonyms were chosen (based on internet search on frequency of usage of particular terms). Then, derived terms were chosen (for instance, "signal aspect" from "signal"). In some cases, another synonyms had to be chosen for the sake of unambiguity.

Freight train paths are integrated to a system of network-bound, periodic capacity as an offer for freight RUs, which represents *an analogue to IPT, but takes needs of freight railway into account*. This new structure is regular and periodic in macroscopic scale, but it can be irregular in microscopic scale (different section runtimes or different stations for overtaking for each direction). Special attention was paid to relationship between requirement for unified (zero) symmetry and difference in runtimes of a heavy freight train on various directions in the case of lines with high gradient. PFTPs can be ether used by some freight train or not (or partially), but are periodically available to make freight railway transport more flexible.

From the paradigm mentioned above, an original, *generic framework process for construction of network offer of periodic capacity for freight trains* was derived. Attention was consequently paid to preference of passing through bottlenecks and overtaking in compensation zones.

The framework process is understood as a *building set* – it is possible to use only parts (according to particular topology, lever of interlocking and operational concept of passenger transport, either for annual timetabling, or for strategic planning). The results can be used *for more precise formulation of requirements of freight railway transport for infrastructure adjustments*. Such targeted investments can save public budgets significantly.

The offer of periodic capacity for freight trains is understood not only in the sense of more efficient capacity utilisation, but also as a helping tool for simplification of operative traffic management. Assumed that timetable is being fulfilled on time, a freight train which uses a PFTP has "green wave" until the station of regular overtaking or crossing. Last but not least, PFTPs help to allocate railway capacity to freight RUs, whose trains have "common" parameters. OneStopShop – an international coordination of train paths – can be simplified as well. The proposed framework process makes capacity allocation process more transparent – with less space for discrimination. Train paths or their parts not allocated for annual timetable can be offered in almost real time.

The framework process is applicable "now and here", indifferent to interlocking system or actual values of minimal headways. Generally, both locomotive drivers and dispatchers have to be instructed about necessity of passing through station on exact time. Mutual radio or GSM connection is necessary (or, better, real-time rescheduling system).

A contribution of this thesis, which is specific for Czech railway network, is, that both theoretical approach and presented studies consider in advance 60-min-period of passenger service (or even 30 min) as a standard. The related timetabling problems occur at present only in few agglomerations, and thus are not perceived yet as urgent enough. The author hereby emphasises that capacity conflicts between passenger and freight railway can be conceptually solved using proposed framework process, before launching of denser passenger service.

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# Education Improvement at The Universities by Introducing of On-line Communication Applications

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**Abstract**

This article describes possible ways of using modern on-line communication applications for university studies, especially for distance learning students and students with disabilities. Study environment should be adequately adapted to these students. An appropriate tool is to create an on-line communication web portal connecting e-learning as a form of long distance communication enabling the active participation of the student in lectures and e-consultation providing a support for subsequent individual one-on-one consultations. These e-consultations can be paid and may be provided by teachers or advanced students. By implementing this online communication application, effective distance learning and expert advice will be provided to working age students that have limited time and a tight schedule as well as to students with disabilities who generally have problems with relocation. The interest in this type of study and this kind of individual consultation using a simple web form has been successfully verified in the practical part of the thesis and implemented during doctoral studies at Faculty of Transportation Sciences of Czech Technical University in Prague. These paid individual e-consultations might also represent extra income for students and university professors. The e-learning and e-consultations should be sufficient for a large number of scientific and academic disciplines. Appropriate online communication tools are applications that allow bilateral audio-video streaming, chatting, sharing of documents or performing tests.

**Keywords:** E-consultation, e-learning, persons with disabilities, distance learning

## 1. Introduction

Nowadays, more and more people realize that quality academic education is necessary in order to obtain an adequate and well-paid employment. For this reason, the number of applicants for university studies is growing, not only of the young people who have graduated from high school but of course also among working age people who are employed and have families. At the same time, there are an increasing number of disabled applicants to university education who are also aware of the need for the education. Due to this trend it is necessary to make changes in study plans or introduce new courses and then allow these students to receive quality education e.g. by introducing modern information communication technologies (ICT).

## 2. Education improvement at the universities by introducing ICT,

### *2.1. Availability of ICT in the Czech Republic*

One of rapidly growing trends in the area of university education is implementing distance learning programs. This form of study is nowadays used by more and more students, especially those with reduced mobility or employed persons who cannot spend 5 days a week in the school or persons who live at a large distance from the school itself. Distance education has already been introduced within most universities in the Czech Republic, however, in account of its relatively short history, the ideal form and appropriate adaptation to the needs of those interested in the study is not yet fully resolved.

The use of modern online information communication technologies systems allowing distance study saving time and money while studying in the comfort of your own home have proved to be a very suitable and effective solution. The statistical research "The location and frequency of use of personal computers (PC)" (Source: http://www.czso.cz, 2.quarter 2010), see Fig 1, conducted in the Czech Republic returned the following results:

- 92% of persons above 16 years use PC at home

The statistical research "Households with Internet access" – Household budget survey (Source: http://www.czso.cz/, 2012), see Fig 2, conducted in the Czech Republic returned the following results:

- 65.4% of households with Internet access in 2012

These results confirm that the modern forms of distance learning using online communication can be successfully introduced and practiced at home.

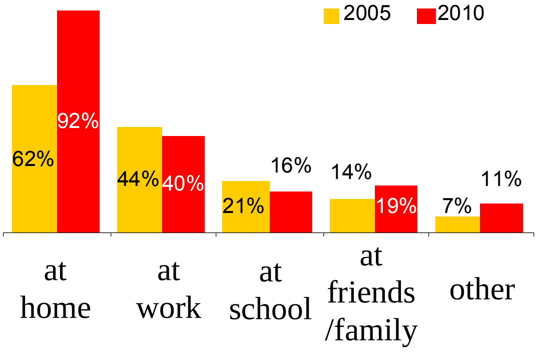


Fig. 1. The location of use of PC, 2.quarter of the reference year (% PC users - age 16+)

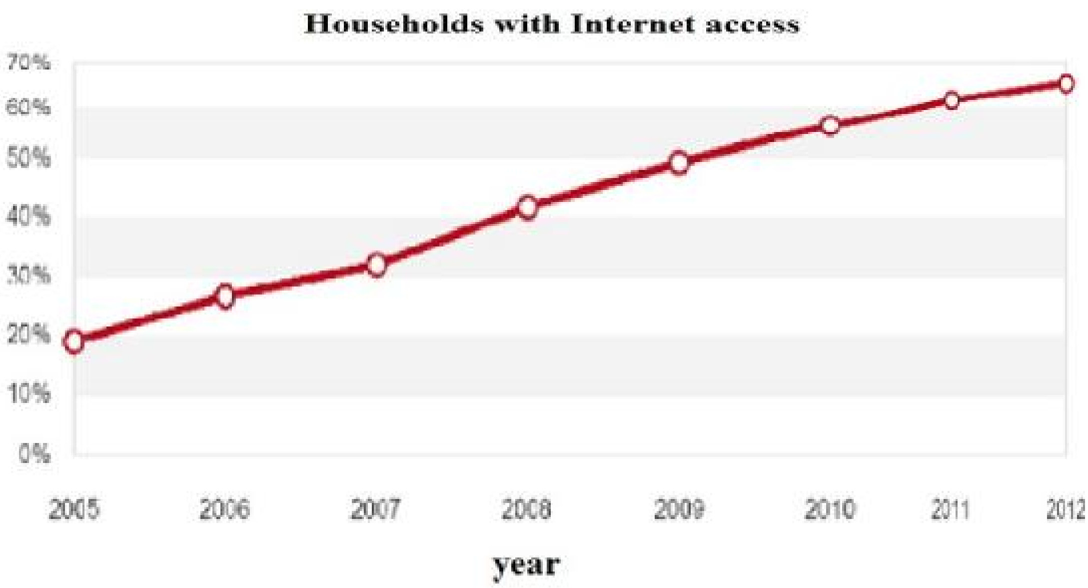


Fig. 2. Households with Internet access

### *2.2. Persons with disabilities and their relation to the ICT*

The adequate tool to support distance learning is the creation of on-line communication application connecting e-learning as a form of distance communication enabling the active participation of a student in lectures and e-consultation that shall serve as a support for subsequent individual one-on-one consultations. These e-consultations can be charged and can be provided by teachers or more experienced students of higher classes. By implementing this online communication application, students of working age who are employed and thus have limited time as well as students with disabilities who generally have a big problem with relocation will be able to study and get expert advice "from a distance".

Among the generally known causes that hinder or disturb the learning process / working process of persons with disabilities, especially those with physical disabilities (wheelchair users) are problems related to transportation to school / work, high costs for operating a specially modified vehicles, high physical demands and time demands related to everyday commuting and last but not least problems with wheelchair access to school / workplace. An easy and working solution to the above problems is the implementation of proposed communication application using ICT-based "distance learning".

A very important research that is related to this subject is the actual research conducted within doctorate program in cooperation with two largest non-profit organizations in the Czech Republic (Helpnet and Konto bariery). The research which took place in 02/2011 questioned about 200 people with disabilities. The research returned a total of 64 correctly completed questionnaires, of which:

- a total of 53 respondents - 82.8% of persons with disabilities that completed questionnaires or 26.5% of the total number of respondents would be interested to use e-consultations

- a total of 55 respondents - 85.9% of persons with disabilities that completed questionnaires or 27.5% of the total number of respondents would be interested to provide e-consultations

### *2.3. Practical part of the solved problem*

The interest in this form of study and this form of individual e-consultations using simple web form has been verified in a pilot study (a web communication portal) implemented in the practical section of the dissertation during doctoral studies at the Czech Technical University in Prague.

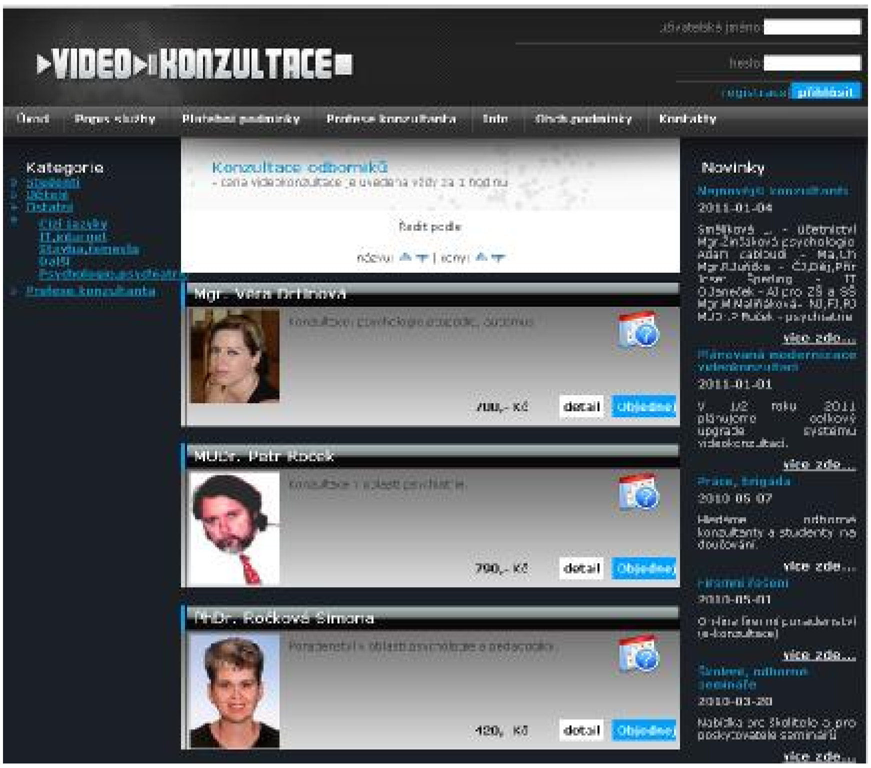


Fig. 3. On-line education and the consultations web environment

The university students and teachers provide individual consultations to particular subjects. These consultations are provided by means of audio-video consultations with chatting and sending documents. Each consultant creates his or her website profile, uploads his or her CV, informs about the professional experience, adds his or her photo and provides updated dates of the offered e-consultations. The current offer of particular e-consultants is divided according to disciplines / subjects. These e-consultations can be charged per hour. The provided e-consultations are very popular among the students from different universities all over the country.

The project uses standard web sites which are directly associated with Flash technology by means of an application provided by Adobe. It is not a specific product to be used, such as Acrobat Connect Pro, but a direct implementation of Flash technology to web sites. This application launches an introductory animation displaying particular categories of consultants, an order form, AV transmission, incl. chat, etc. The ordering system is created by means of Flash technology using PHP programming language in which the entire websites are written.

### *2.4. Features of on-line educational application*

In addition to an easy access to information, the charged e-consultations at the same create a job opportunity to teachers and more experienced university students and the opportunity to additional earnings of persons with disabilities, who are themselves experts in certain fields. This job opportunity can offer a great opportunity for self-realization or help acquire the necessary and valued experience. The possibility to get to know the modern form of teaching and the appropriate communication technologies is another great benefit.

From the technological point of view, for e-learning and e-consultation it is sufficient to enable two-sided application of audio-video streaming, chat, sharing desktops and documents, performing online tests or carrying out automatic translations for students of other nationalities. In case of e-consultations an order system including a calendar for booking the particular consultation should be incorporated as well as the payment system for the actual purchase of e-consultations. The offer of e-consultations should be sorted by particular subjects offered or by the name of universities to allow a better orientation of students. Furthermore, it is advisable to include CV and information about professional experience of each consultant or enable the evaluation of his or her consultations provided.

A very important part of education at universities is of course working with textbooks. These have been recently also published electronically and are available in school e-libraries. The communication application for e-learning and e-consultation also enables to work with these books and share all kinds of these sources.

Various forms of e-learning methods are nowadays quite common. In fact, there are a great number of schools that have started to become familiar with this form of education, nevertheless, it is necessary to realize that the subsequent technical support is the important issue as well. Therefore, the e-consultation “one-on-one” proved to be the most suitable method.

## 3. Conclusion

The online form of education and consultations is regarded as sufficient for a large number of scientific and academic disciplines. Communication application that would include features of e-learning and e-consultations seems to be very suitable tool for distance learning for both students in the productive age as well as for students with disabilities. It is very likely that this form of online distance learning and subsequent supportive educating methods will become a common and indispensable part of education. During the tests of communication web portal, the project has successfully participated in the 5 dozens of students, teachers and other experts in various fields. During the research and the practical section of the dissertation has been verified, that it is a great interest in the relevant service and it would be appropriate to use this method of online communication in education at universities.

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# Supply Chain Security Issues

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**Abstract**

Supply Chain Security (SCS) aims at reducing the frequency and seriousness of the consequences of any crime- (and terrorism-) related incidents in supply chains. This SCS aims, can be reached via a variety of organizational, procedural and technological approaches. Since the terrorist attacks in 2001, governments are playing a big role in the overall management scheme of SCS by bringing into force policies, regulations, voluntary programs and enforcement agencies. Security areas such as facility security, cargo security, human resource security, IT security and business network security each involve at least a dozen if not dozens of different security enhancement measures, either for crime prevention, detection/reaction and/or recover purposes. Problems of supply chain security are solving in EU and US via programs as ISPS Code, AEO, C-TPAT, BTA, TAPA, ISO 28 000 etc. This paper is focusing on supply chain security general model too. It analyzes approach to SCS and presents the author’s future research focus in this area, which is aimed at expansion and completion of the general SCS management model and creation of security performance measurement tool. Such measurement tool would allow complex comparison of security programs from the attained security level point of view.

**Keywords:** supply chain security (SCS), security programs/initiatives, SCS general model, security

## 1. INTRODUCTION

Security is used to describe protection against criminal acts, such as terrorist attacks, sabotage, robberies, smuggling, or illegal immigration. Within the area of security, we create a complex solution, which enables us to prevent said crimes. More specifically, security includes protection of machines, facilities, transported goods, but also buildings, cities, the environment and its inhabitants, against exposure to willful dangerous influence of other people (terrorists, thieves, smugglers etc.).

Supply chain is system of systems, i.e. system of several mutually interconnected systems of supplies, products, shipping, distributing, selling and shopping [1]. After the recent series of terrorist attacks all over the world, corporate subjects as well as governments realized the need for creation of a global threat reduction system. Every economic region created its own security system, utilizing both compulsory and voluntary security programs and initiatives, whose target is ensuring effective controls and prevention of pointless delays at borders. The effectiveness of these programs and initiatives has a significant impact on smoothness of the cargo transport and trade in general.

In literature, there is a wide variety of definitions of supply chain security (SCS). According to Closs (2004) SCS is: „ management is the use of controls, procedures and technology for protection of supply chain assets (product, device, equipment, information, people) against thefts, destruction or terrorism and a prevention of criminal abductions of people and employment of weapons as the destructing element in the supply chain” [2] or SCS is a systematic and continuous process to enhance prevention, protection, preparedness, monitoring, detection, mitigation, response, and recovery from disruptive criminal and terrorist activities and incidents in the supply chain [1].

After the recent series of terrorist attacks all over the world, corporate subjects as well as governments realized the need for creation of a global threat reduction system. Every economic region created its own security system, utilizing both compulsory and voluntary security programs and initiatives, whose target is ensuring effective controls and prevention of pointless delays at borders. The effectiveness of these programs and initiatives has a significant impact on smoothness of the cargo transport and trade in general.

Three of the main participants are the trade, governments and criminals. All of these subjects have their own agenda and conflict interests, considering controls, standards and unique measures. The traders are trying to protect their property and their position with a goal of a financial efficiency of the security measures. The governments protect the society and the citizens against any harm and unlawful behavior. The goal of criminals is to maximize their profit and to minimize legal measures risk.

### *1.1. Treat Assessment in Supply Chain*

Dangers and threats are closely related to the existence of the supply chain. They come either from outside, with the goal of disrupting the chain utilizing criminal activities and terrorist attacks (e.g. airfield or port attack), or from inside, if it is used to carry out and to cover illegal activities, such as smuggling, terrorism or piracy. Of course, included in the threats are environmental disasters and „divine power“ strikes. The supply chain and all its parts are very vulnerable.

There are many different threats to the supply chain which fall primarily into the categories of criminal activities and terrorist threats.

Criminal activities are by far the most important problem in international trade and transport. The criminal threats cover a wide range of aspects cargo theft, conveyance vehicle theft, goods and human smuggling, tax and duty evasion, attack on a transportation node.

The terrorist threats to SCS can be categorized as follows use of the cargo as a weapon, the container as a weapon, the container as a delivery mechanism or to move weapons, explosive, biological and radiological contaminants and their precursors, the conveyance vehicle as a weapon, the conveyance vehicle as a delivery mechanism or industrial espionage, sabotage [3].

With the goal of the terrorist activities being damage, destroy, or exploit the supply chain, logistics systems, infrastructure and information management systems, cause victims and casualties, cause economic harm and cost, results of reduced freedoms and loss of the feeling of well-being.

All threats can be effectively fought on the basis of (1) understanding their nature – identification and understanding of vulnerability and determining potential aftermath – awareness, (2) threat prevention – detection and risk mitigation – prevention, (3) protection against threats – protection of people, critical infrastructure and property – protection, (4) threat response – coordination and control of response to criminal actions – response, (5) renewal of operations – activities focused on resuming normal operations after a criminal act has been committed – recovery.

### *1.2. Threat Repelling Tools in Supply Chain – International Security Programs*

To implement SCS system, programs, initiatives, systems, procedures, technologies and solutions applied to already mentioned threats to supply chain are created. The programs can be global, regional, national, governmental or specialized. The initiatives can be multilateral, bilateral or unilateral. Most importantly, the programs can be either mandatory or voluntary.

These programs and initiatives target basic elements and coherences of operating the supply chain. The initiatives can require use of special technologies or equipment, which is supposed to help counter the threats.

Common point of all these initiatives is minimization of risk of any disruption in the supply chain, to support the fluency of trade flow worldwide.

An overview of main programs and initiatives in the US and EU, which target the SCS problematic, is displayed in table 1. The table provides a name of the program, a year of creation, country, where the respective program is utilized, an SCS area it is used in, type of transportation and the enforceability of the program (compulsory/ green, voluntary/ yellow) [3].

Table 1. Main security programs and initiatives in the US and EU [3, author]

| Program Abbreviation (Year) | Name of Program | Country | Using | Modes |
|---|---|---|---|---|
| Advance Manifest Regulation (2003) | 24 hour rule | US | Advanced cargo information on imports | Sea |
| C-TPAT (2001) | Customs-Trade Partnership Against Terrorism | US | SCS – import to US | All |
| CSI (2002) | Container Security Initiative | US | Maritime container (import to US) | Sea |
| AEO (2008) | Authorized Economic Operator | EU | Trade facilitation and SCS | All |
| WCO SAFE (2005) | World Customs Organization SAFE Framework of Standards | EU | Customs to Business partnership in SCS | All |
| TAPA (1997/1999/2000) | Transported Asset Protection Association | US/ EU/ Asia | Transport of high-value goods protection | Truck Parking Air |
| ISPS Code (2004) | International Ship and Port Facility Security | World-wide | Standardization and consist. framework for evaluating risk | Ships Ports |
| ISO 28 000 series (2005) | Specification for Security Management systems for SC | EU/ US | Application of certification programs | SCS trade facilitation |
| 10+2 rule (2009) | | US | Advanced cargo information | All |
| AMS (2004) | Automated Manifest System | US | Advanced cargo information | All |
| FAST (2001) | Free and Secure Trade | US | US-Canada-, US-Mexico- border protection | Truck |
| BTA (2002) | The Bioterrorism Act | US | Advanced cargo information, food protection - import to US, food facilities | All |
| Pre-arrival and Pre-departure EU (2009 – 2011) | Pre-arrival and Pre-departure | EU | Advanced cargo information - imports and exports | Sea |

## 2. Common Framework for Security Management System

Security systems of economic regions originate in common platforms that guarantee their compatibility, which is an extremely essential feature. Unnecessary complexity and security approach differences may cause counter-effect resulting in actual slowdown of goods flow and increase of costs due to necessity of overcoming incompatibilities between different security systems.

The common platform is composed of three core international standards: WCO SAFE Framework of Standards to Secure and Facilitate Global Trade (WCO SAFE), International Ship and Port Facility Code (ISPS Code) and Specification for security management systems for the supply chain ISO 28000 (ISO 28000).

These platforms have certain differences, however, even though they create a common framework encompassing SCS security issues and pave the way to mutual recognition of certified security programs. As the platforms cover wide area of SCS issues they incorporate government bodies, non-government organizations, private enterprises, customs administrations, manufacturers, transport companies, forwarders, etc. across all means of transport. Common interest here is maintaining of compatibility in SCS on international level. The European program AEO, which is focused on establishing of a certified economic entity, was inspired by WCO SAFE and uses ISPS Code, ISO 28000 and ISO 28001 [4].

The chapter 3 introduces basic approaches defining general security management system components. The focus of the author's research is on expansion of these general models and definition of a new framework for measuring and evaluating of supply chain participants security performance.

### 3. Supply Chain Security General Model

Currently, there is a compatibility process on the international level in terms of these security programs. Hence, important contribution created a general model to describe features of security management and security management system implementation.

Functionality of SCS programs is founded on different principles that all lead to one common goal. The security programs contain basic components that combine measures, tools and procedures. These measures, tools and procedures are present within these components in proportion that ensures efficient maintenance of security. The components form independent entities within the security programs and their combinations ensure efficient security systems management of the future.

Supply chain security general model cover most of the security measures suggested by the current leading SCS programs, it is important to note that there is no exact formula to establish an adequate SCS management system. The security measures that constitute the framework are not all-inclusive; meaning that implementing them all does not necessarily mean that the security system will be complete, and that implementing only part of them does not mean necessarily that the security will be inadequate (Gutierrez & Hintsa, 2006).

In 2006, Gutiérrez and Hintsa from the Cross Border Research Association based in Lausanne, Switzerland, (Gutierrez & Hintsa, 2006) published a study based on analysis of the 9 security programs (PIP, BASC, TAPA, C-TPAT, Secure Export Partnership, StairSec, WCO SAFE, EU AEO, ISO 28 000), in which they created a general SCS management system. Their model has 6 basic components.

SCS general model give necessary framework needed for better understanding of concrete security measures proposed in each of the security programs and may be used for evaluation of how much the programs have in common. The general model allow comparison of the security programs and finding of their common features that create systems interconnection. Detailed analysis is able to identify different levels of security measures implementation and offer possibilities for their completion.

Gutiérrez and Hintsa mean securing premises for production of goods and handling, storing and loading of cargo.

This model facilitates six elements (1) Facility management, (2) Cargo management, (3) Human resources management, (4) Information and communication management, (5) Business network and company management systems, (6) Crisis management and disaster recovery, that express how to manage complex environment of supply chain facilities (Figure 1) [5].

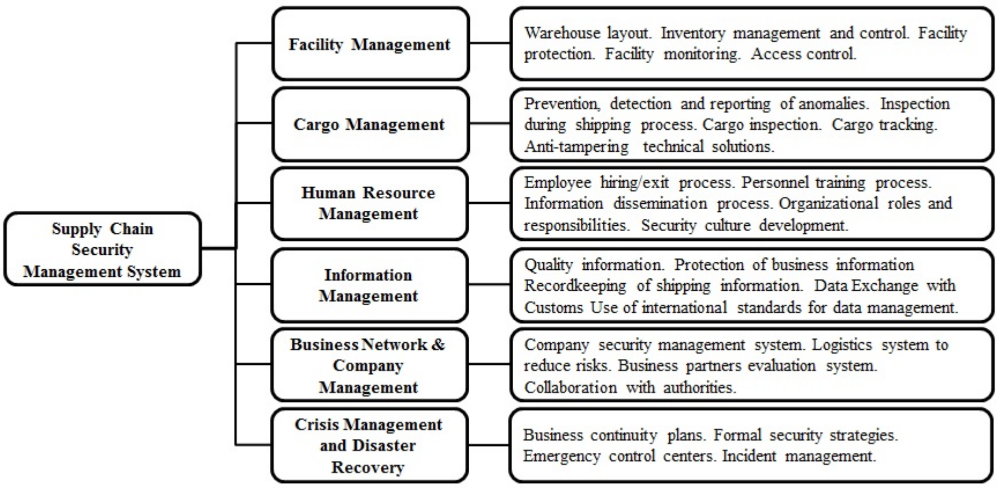


Figure 1. Supply Chain Security General Model [5, author]

### 4. Expansion of Supply Chain Security General Model - Security Performance Quantification

Security management systems structural analysis is important not only from the practical application point of view. Results of such analysis form the base for better understanding of security measures and their impact on the whole security system. Expansion of the general model as well as common and different features location allows further detailed analysis of the core problem and creation of new applications. The expanded model will be used for security performance quantification of organizations and will allow creation of security index that could be used for comparison of organizations.

Supply chain security general model will be expanded to allow performance assessment of security-related measures according to specific security programs certified for use along a supply chain by a specific stakeholder (manufacturer, transportation company, forwarder etc.). This means developing mathematical model able to assess performance of security-related measures applied to the specific stakeholder along the supply chain.

The developed model methodology is inspired by objectivized method for assessment of technical conditions of objects [6]. Expanded SCS general model will be used for objective assessment of concrete security programs. Real-life application in the form of a dialogue software solution will allow stakeholders, i.e. customers planning shipment of goods, selection of the best-rated company. What is more, the companies themselves will get a tool that will allow them to continuously assess performance of the provided security solutions.

## 5. Conclusion

Supply chain security general model (Gutierrez & Hintsa) will be expanded to allow performance assessment of security-related measures according to specific security programs certified for use along a supply chain by a specific stakeholder. The developed model methodology is inspired by objectivized method for assessment of technical conditions of objects.

## Acknowledgements

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# Czech Electronic Toll Systems and Traffic Management

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**Abstract**

In the paper the Czech toll system and its future are presented. The paper describes also the ITS solutions for use of the possibilities of electronic toll system for reducing congestion on the highway network of the Czech Republic, as well as solutions of differentiated toll tariffs and their impact on changes of fleet towards ecological vehicles with EURO V and higher engines. In conclusion, it is presented a new certified methodology used to determine the toll tariffs in terms of EU directives.

**Key words:** toll system, traffic management, congestions

## INTRODUCTION

In response to the situation in the surrounding states, fees started to be charged for the road network in the Czech Republic in 1995 and highway vignettes were introduced for that purpose. The motive was to secure further funds for the development of mainly the highway network and for the prospective solution concerning related applications.

Even when in 2007 an electronic toll system involving output-related payments based on the distance covered within the network of highways, expressways and selected sections of the roads of the 1st class was introduced in the Czech Republic for vehicles in the weight category of 12 t and more, the highway vignettes remained for the other categories of vehicles.

With regard to the interoperability of the toll systems within the EU, there is a European Commission Decision of 6 October 2009 on the definition of the European Electronic Toll Service and its technical elements (EETS). According to this decision, the EETS system should be implemented in the EU within 3 years from the year 2009.

## 1. Implementation of an Electronic Toll System (ETS) in the Czech Republic

In the period of the years 2002 and 2003 and other years, various studies and experts's statements were prepared and works and opinions of experts from the Ministry of Transport of the Czech Republic and other institutions and scientific centres were presented on electronic toll.

Already at the time when the task was defined, it was emphasized that the money collected from the output-related payment system as well as the money collected from the time system (vignettes) would be used solely for reconstruction of, repairs to and construction of the road network, including its development, also connected with the issues of traffic regulation, information, telematics and safety. The preparation of the implementation of the toll system was also based on the European Directives – particularly 1999/62/EC and 2006/38/EC, and the 2004/52/EC directive (interoperability) was also continued to apply to the Czech Republic.

The history of the implementation and changes in the Electronic Toll System (ETS) in the Czech Republic is in Table 1.

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Table 1: The history of changes in the Electronic Toll System in the Czech Republic

| Date | Change |
|---|---|
| 1.4.2006 | Closure of the tender for the toll system - contract signature. |
| 1.1.2007 | Introduction of tolls on motorways and expressways. |
| 1.1.2008 | Introduction of tolls on selected of 1st class roads. |
| 1.1.2010 | Extension of toll on vehicles with weight higher than 3.5 tons. |
| 1.2.2010 | Introduction of increase in toll rates by 50% on Friday from 3pm to 9pm included, which was compensated by decrease in rates during other hours of the day and week. The result was a reduction of traffic on tolled communications by about 11% in the period of increased toll rates. |
| 1.1.2011 | Increase in toll rates by 19% and introduction of an independent emissions group EURO V, which is not subject to an increase in toll rates. Reduction of increased toll rates at selected Friday hours to 40% as compensation for carriers. |
| 1.9.2011 | Introduction of individual reduced toll rates for buses. Toll rates for buses are differentiated only by the emission class and are not increased on Friday. |
| 1.1.2012 | Estimated increase in toll rates by approximately 25%, except buses and vehicle class EURO V and higher. |

*Source: Ministry of Transport of the Czech Republic*

Organisation of the construction and operation management of ETC in the Czech Republic:
**Investor/Buyer:** Ministry of Transport of the Czech Republic (MD ČR)
**Operator:** Road and Motorway Directorate of the Czech Republic (ŘSD ČR)
**Mobile Enforcement:** General Directorate of Customs (GŘC ČR)
**Project Manager:** Consortium of Deloitte Czech Republic and Bovis Lend Lease, a.s.
**General Contractor and operator of services of ETC:** Kapsch Consortium. Kapsch has provided the complete operation services for the Czech Republic since January 2007. The total term of the contract is 10 years.
**Auditor:** Logica

## 2. The results of the operation of the toll system in the Czech Republic

Table 2 shows the development of the toll road network in the Czech Republic with the prognosis of development until 2017. The same table shows the reality and forecast of the revenues from the toll road network ETS. The revenues from time coupons for vehicles less than 3.5 tons are not included in these calculations. In the Figure 1 there is a map of the charged road network in the Czech Republic in the 2012. In Table 3 there are applicable data of toll tariffs on toll road network of the Czech Republic in 2012.

Table 2: Survey of total toll income and total length of toll roads development

| | | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total toll income | [mil. CZK] | 5 433 | 6 012 | 5 431 | 6 422 | 7 994 | 9 571 | 10 069 | 10 334 | 10 606 | 10 885 | 11 352 |
| Toll of vehicles above 3,5t | [mil. CZK] | 5 433 | 6 012 | 5 431 | 6 422 | 7 994 | 9 571 | 10 069 | 10 334 | 10 606 | 10 885 | 11 352 |
| Motorways and expressways | [mil. CZK] | 5 433 | 5 700 | 5 173 | 6 129 | 7 659 | 9 170 | 9 658 | 9 912 | 10 173 | 10 440 | 10 896 |
| 1st class roads | [mil. CZK] | | 312 | 258 | 293 | 335 | 401 | 411 | 422 | 433 | 445 | 4 565 |
| Toll of vehicles below 3,5t | [mil. CZK] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Number of distributed OBU | | 252 628 | 351 124 | 398 079 | 466 796 | | | | | | | |
| Motorways and expressways | [km] | 937 | 993 | 1 034 | 1 149 | 1 368 | 1 391 | 1 415 | 1 440 | 1 465 | 1 490 | 1 516 |
| 1st class roads | [km] | 0 | 180 | 198 | 196 | 196 | 196 | 196 | 196 | 196 | 196 | 196 |
| Total length of toll roads | [km] | 937 | 1 173 | 1 232 | 1 345 | 1 368 | 1 391 | 1 415 | 1 440 | 1 465 | 1 490 | 1 516 |

*Source: (Bina et al., 2011) (Exchange rate of 1 EUR = 24,445 – Czech National Bank, 14.9.2012)*

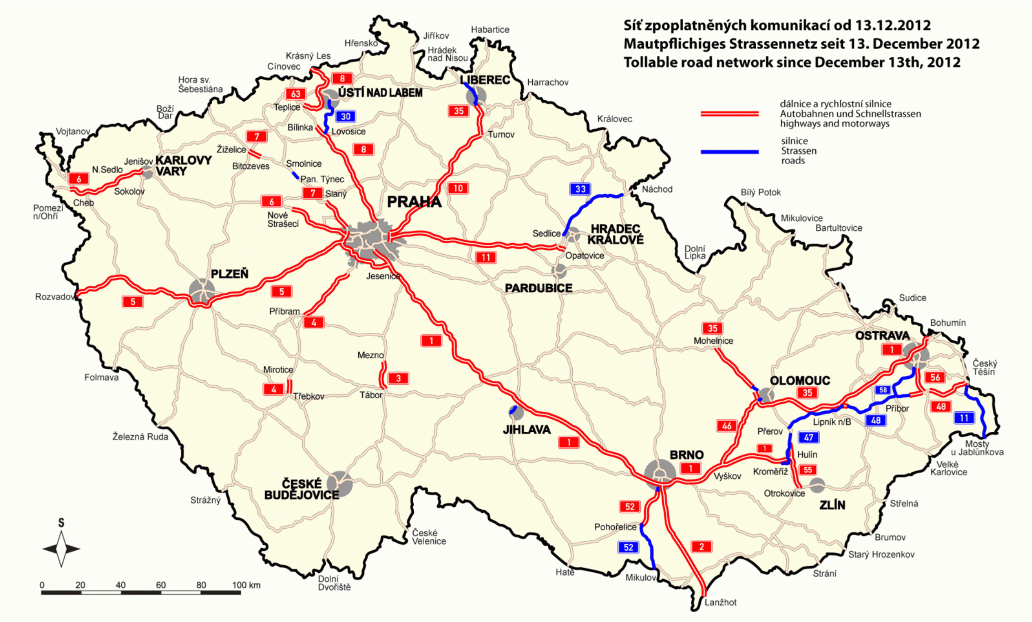


Figure 1: Map of the charged road network in the Czech Republic in 2013

*Source: Road and Motorway Directorate of the Czech Republic*

Table 3: Toll rates table 2013

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Toll Rates for Trucks [CZK/km] in most of weekdays | | | | | | | | | |
| 2012 | Emission Class EURO 0-II | | | Emission Class EURO III-IV | | | Emission Class EURO V+ | | |
| | Axles | | | | | | | | |
| | 2 | 3 | 4+ | 2 | 3 | 4+ | 2 | 3 | 4+ |
| Highways | 3,34 | 5,67 | 8,24 | 2,61 | 4,45 | 6,44 | 1,67 | 2,85 | 4,12 |
| Roads | 1,58 | 2,74 | 3,92 | 1,23 | 2,14 | 3,06 | 0,79 | 1,37 | 1,96 |
| Toll Rates for Trucks [CZK/km] Friday 15:00 - 21:00 | | | | | | | | | |
| 2012 | Emission Class EURO 0-II | | | Emission Class EURO III-IV | | | Emission Class EURO V+ | | |
| | Axles | | | | | | | | |
| | 2 | 3 | 4+ | 2 | 3 | 4+ | 2 | 3 | 4+ |
| Highways | 4,24 | 8,1 | 11,76 | 3,31 | 6,35 | 9,19 | 2,12 | 4,06 | 5,88 |
| Roads | 2 | 3,92 | 5,6 | 1,56 | 3,06 | 4,38 | 1,- | 1,96 | 2,8 |
| Toll Rates for Buses [CZK/km] | | | | | | | | | |
| 2012 | Emission Class EURO 0-II | | | Emission Class EURO III-IV | | | Emission Class EURO V+ | | |
| Highways Roads | 1,38 | | | 1,- | | | 0,8 | | |

*Source: Road and Motorway Directorate of the Czech Republic (Exchange rate of 1 EUR = 25,995 – Czech National Bank, 24.5.2013)*

**The conditions for qualification for the toll discount for 2012 and subsequent years** (according to www.slevymyto.cz). Amendment of the Act no. 13/1997 Coll. on roads, which entered into force in September 2012, profiles for the qualification for the toll discount. The preconditions for qualification for the toll discount are specified in the Government regulation no. 352/2012 dated September 26, 2012.

The effective date of the Government regulation, i.e. October 22, 2012, is at the same time the beginning of the period for which the discounts for 2012 may be awarded. Then, for 2013 and the subsequent years the discounts will be paid based on fulfillment of all determined conditions for the whole calendar year.

The preconditions for qualification for payment of the toll discount in the transition year 2012 and subsequent years are specified as follows:

- The operator shall properly register all vehicles for which he is going to apply the discount in the Toll discount system.
- The value of the toll imposed for the respective registered vehicle of the operator in this transitive period shall achieve not less than CZK 30,000.

The discount percentages for particular vehicles for the transition period of 2012 are provided for as follows:

- the amount of toll imposed exceeds CZK 30,000, the discount percentage provided is 10 %,
- the amount of toll imposed exceeds CZK 40,000, the discount percentage provided is 11 %,
- the amount of toll imposed exceeds CZK 50,000, the discount percentage provided is 12 %,
- the amount of toll imposed exceeds CZK 60,000, the discount percentage provided is 13 %,

The preconditions for payment of toll discounts for 2012 abide by the temporary provisions of the Government regulation. In the transition period of 2012 the precondition which determines that the discount will be calculated only for the period from registration of the vehicle in the Toll discount system till the end of the respective calendar year or till cancellation of registration of the vehicle in the system by the operator of the vehicle shall not be applied. Independently on the date of the registration the discounts for the respective year will be calculated from the effective date of the Government regulation.

The person responsible for administration of the agenda of the Toll discount system is the electronic toll collection system operator – the Road and Motorway Directorate of the Czech Republic.

The discount percentages **for particular vehicles for the period of 2013** and following ones are provided for as follows:

- the amount of toll imposed exceeds CZK 100,000, the discount percentage provided is 5 %,
- the amount of toll imposed exceeds CZK 150,000, the discount percentage provided is 8 %,
- the amount of toll imposed exceeds CZK 250,000, the discount percentage provided is 11 %,
- the amount of toll imposed exceeds CZK 400,000, the discount percentage provided is 13 %,

In Figure 2 and 3 behaviour of the traffic volumes in 2011 (July-August), by the type of roads (Figure 2) and by vehicle category (Figure 3) are shown.
As in previous years, 92% of the traffic volume is on highways and expressways. The remaining 8% of the traffic volume is carried out on selected sections of 1st class roads. Traffic volumes are relatively stable, although there was an increase in 2010 owing to the expansion of the range of vehicles that are subject to the toll and also in recent months following the opening of the heavily used ring road around Prague. It is interesting to notice that the monthly traffic volumes are created by around 190 thousand vehicles, even though the number of registered vehicles exceeds 500 thousand.

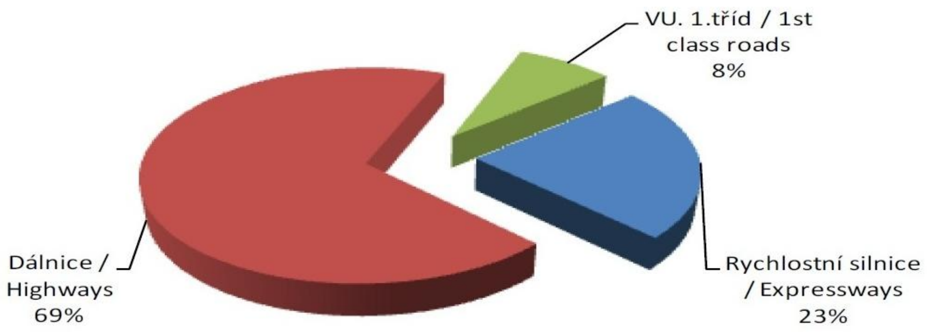


Figure 2: Traffic volume by type of roads (1.-8./2011)

*Source: DWH of the E-toll System (DWH – Data Warehouse of the E-toll System)*

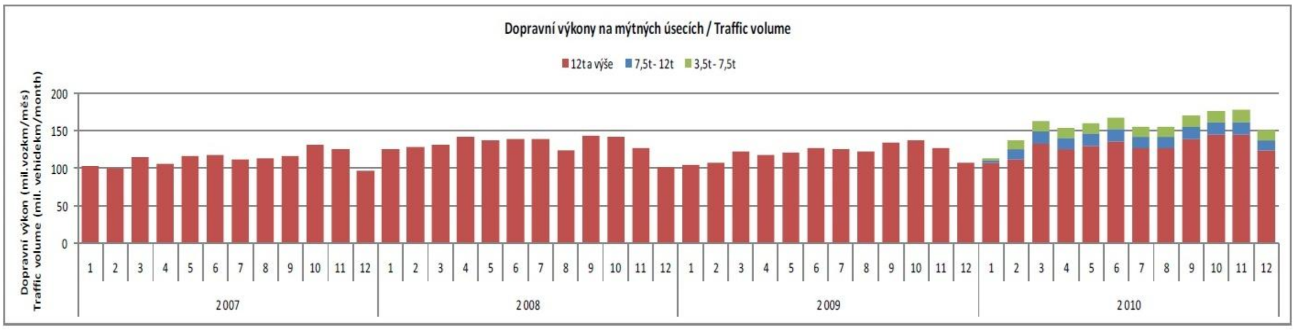


Figure 3: Development of traffic volume in years 2007-2010

*Source: DWH of the E-toll System*

In the monitored period, the traffic volume of vehicles registered in the toll system was approximately the same as we can see for vehicles weighing over 12 tons on the tolled sections that were put in operation on 1 January 2007. In 2009 a moderate downturn can be seen as a result of the economic cycle, followed by a slow recovery in 2010. Under these assumptions, in period from year 2010 till 2017, weighted average tolls of heavy goods vehicles on motorways, expressways and tolled 1st class roads are always below the maximum weighted average toll (following Figure 4).

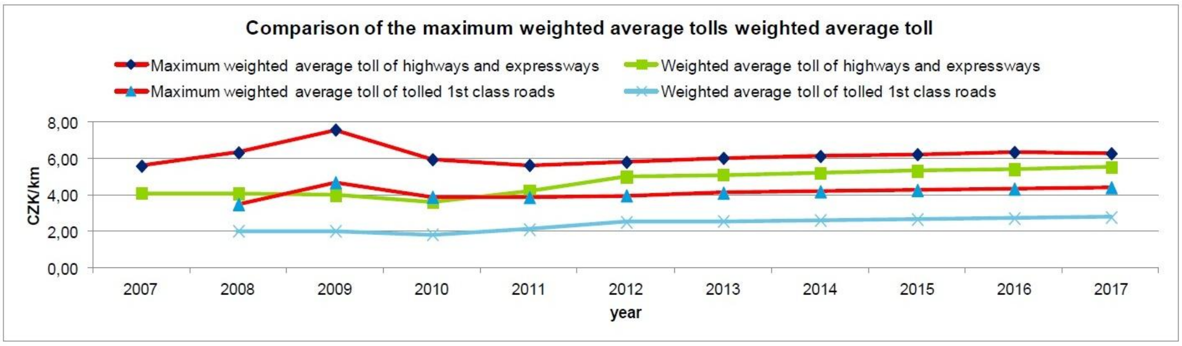


Figure 4: Weighted average tolls of heavy goods vehicles on motorways, expressways and tolled 1st class roads till 2017

*Source: (Bina et al., 2011) (Exchange rate of 1 EUR = 24,445 – Czech National Bank, 14.9.2012)*

**3. Another major application will be introduction of differentiated toll in the afternoon hours on Friday.**

Internalisation of the external costs is the main priority of the transport policy of the EU. The basic principle is to charge the vehicles, which have a negative impact on the environment and health and which generate a noise burden on the surroundings of the roads and congestions. One of the works on the topic of charging transport externalities in road transport is the work of the Joint Research Centre – JRC European Commission.

In the Czech Republic, it was necessary to address the situation concerning the restriction of operation of vehicles in the Czech Republic. Section 43 of the Act No. 361/2000 Sb. (*Sb. = Collection of Laws*) on the traffic on roads and on changes to some Acts (the Road Traffic Act) defines the scope and the periods of restrictions on the travel of some vehicles. Trucks and special automobiles and special vehicles with the maximum admissible weight exceeding 7,500 kg and trucks and special automobiles and special vehicles with the maximum admissible weight exceeding 3,500 kg with an attached trailer vehicle are prohibited from driving on a highway and a 1st class road:

a) on Sundays and on public holidays as defined in special legislation (hereinafter referred to as the "rest day") from 13.00 to 22.00;
b) on Saturdays in the period from 1 July to 31 August from 7.00 to 13.00;
c) on Fridays in the period from 1 July to 31 August from 17.00 to 21.00.

Within the governmental and parliamentary activities and a number of negotiations with road forwarders and their professional organisations, a proposal for higher charges for the Friday trips of vehicles weighing more than 3.5 tons on Friday afternoons was accepted as a measure to reduce congestions on the highway network of the Czech Republic during Friday afternoon hours on an all-year-round basis and on the following conditions:

- The existing legislation restrictions on the vacation traffic remain in effect.
- On Fridays from 15.00 to 21.00, the toll rates are increased by 25 % for vehicles with 2 axles and by 50 % for vehicles with 3, 4 and more axles, on an all-year-round basis. The earlier starting hour for application of increased rates before the period of the legislation restriction (17.00 – 21.00) has been chosen because there is an increased traffic intensity level of passenger cars on Friday afternoons already after 15.00.

**Increased Friday rates were launched on 1.2.2010 and it was the first measure concerning differentiated rates in the EU with the aim of reducing congestions in the highway network.**

In the Figure 5 and 6 the average number of domestic vehicles and foreign vehicles on Fridays in the 4th quarter of 2009 and 2010 on tolled network of the Czech Republic is shown. Number of vehicles in the 4th quarter of 2010 is converted to a comparable level of 2009. From these graphs you can see:

- Decrease of number of vehicles in the time period from 15.00 to 21.00
- The difference in the behaviour of domestic and foreign vehicles

In the comparable period (the 4th quarter of 2010) after the introduction of higher tariffs on Friday according to the previous it lead to decrease of vehicles on the tolled road network in the time period from 15.00 to 21.00:

- 2.8% of domestic vehicles (registered in the Czech Republic)
- 6.4% of foreign vehicles

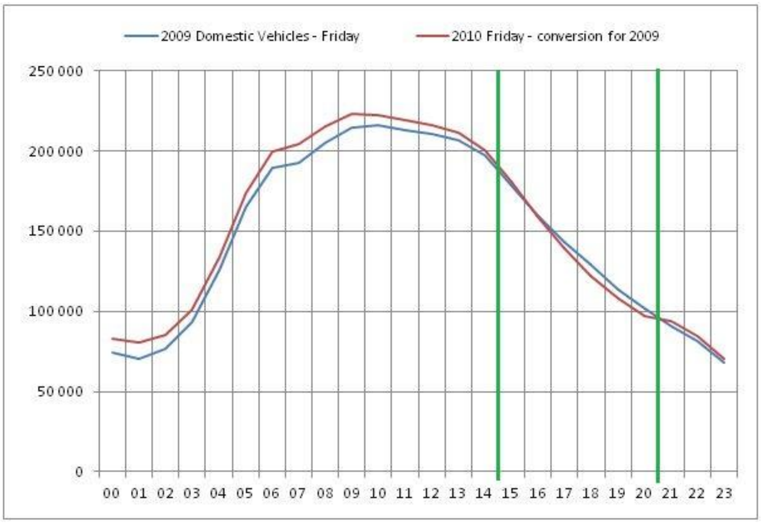


Figure 5: The average number of domestic vehicles on Fridays in the 4th quarter of 2009 and 2010 on tolled network of the Czech Republic

*Source: DWH of the E-toll System (DWH – Data Warehouse of the E-toll System)*

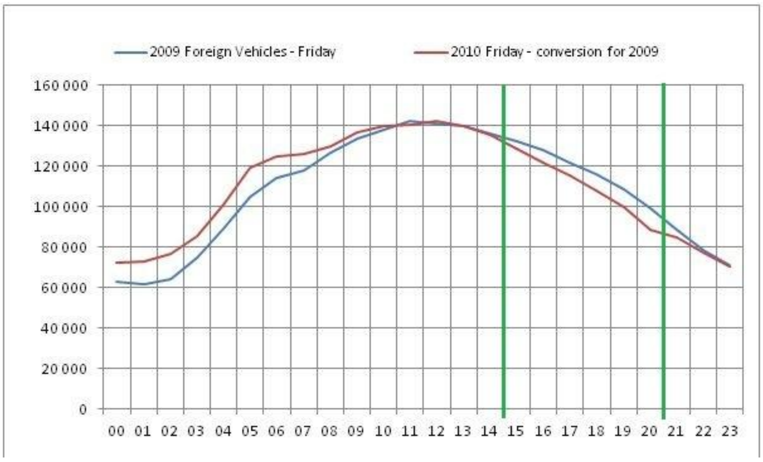


Figure 6: The average number of foreign vehicles on Fridays in the 4th quarter of 2009 and 2010 on tolled network of the Czech Republic

*Source: DWH of the E-toll System (DWH – Data Warehouse of the E-toll System)*

We can say that a significant decrease in trucks and thus a decrease of congestion especially around large agglomerations on the tolled road network in the Czech Republic in Fridays afternoon (15.00 to 21.00) were not found. For domestic vehicles (registered in the Czech Republic) the main reason is probably the end of the work week even the costs are higher. In any case, the whole situation calls for a detailed analysis, because there is (after a very simplified calculation) of approximately CZK 100 million (EUR 4.1 million) an increase in the annual collection of the electronic toll system in the Czech Republic on Friday due to by 50% higher tariffs in the time from 15.00 to 21.00. There is also a recognizable effect on the congestion reduction on the tolled highway network in the country.
This Government decision to implement **increased Friday rates** has been done on the base of the research study done by team of authors Bína, L. at el. (2009 - Czech Technical University in Prague, Faculty of Transportation Sciences and Deloitte Advisory s.r.o.). That study is named "The implementation of the differentiated tariffs for the traffic management of the toll vehicles in Friday´s afternoon hours".
**This work was in 2010 awarded with the prize of the minister of transport of the Czech Republic in the Czech competition 2010 – The best transport construction and transport technology.**

## 4. The effect of differentiated tariffs of toll system on increasing the number of "green vehicles"

The effect of differentiated tariffs of toll system in the Czech Republic on increasing the number of "green vehicles" proved in 2011 and in this year, when the toll rates increased on the 1st of January 2012 for the second time by 25 percent. This change did not affect vehicles with EURO V engines. After the increase of toll rates in the Czech Republic by 25 percent, it should bring by calculation through each emission category a result in increased collection of nearly 20 percent. But the reality is only about ten percent. Many carriers have invested in vehicles meeting the EURO V standards. These vehicles have both lower consumption (by 5-10 percent), and also the carriers save on tolls significantly, because the default toll rate is lower than for vehicles meeting only older emission standards and remained at the level of toll tariffs in 2010.

As a basis for the introduction of higher toll tariffs in 2011 and 2012 an analytical report "**Proposal of new toll rates for 2011. Final Report**" from the 10th of December 2010 has been prepared by the Faculty of Transportation Sciences Czech Technical University in Prague and the company Deloitte Advisory s.r.o.
In this report as default assumptions have been defined the following changes in the toll rates made in 2011:

- Introduction of a separate emission class EURO V
- Keeping the EURO III and EURO IV emission classes combined
- Increasing the toll rates applicable to the EURO 0 to EURO IV emission classes by 25%
- Keeping the toll rates applicable to the EURO V emission class at the 2010 level
- Keeping the time differentiation of toll rates during Friday afternoon hours
- The weighted average toll rate shall not exceed the maximum allowable amount derived from the costs of the toll road network and the costs of the toll system.

Subsequently, the average toll rate limit was calculated from the viewpoint of the road costs paid. (Tolls shall be based on the principle of the recovery of infrastructure costs only. Specifically the weighted average tolls shall be related to the construction costs and the costs of operating, maintaining and developing the infrastructure network concerned. The weighted average tolls may also include a return on capital or profit margin based on market conditions - see Article 9 of the Directive - Directive 2006/38/EC ) The calculation is based on the following presumptions:

a) The constructions costs also took EU subsidies into account, in accordance with Article 9 of the Directive. (Tolls should be based on the principle of recovery of infrastructure costs. In cases where such infrastructures have been co-financed through the general budget of the European Union, the contribution made from Community funds should not be recovered through tolls, unless there are specific provisions in the relevant Community instruments which take into account future toll receipts in establishing the amount of Community co-financing). Whereas the amount of the subsidies allocated towards the construction of roads takes the envisaged toll revenue into account, the authors consider these EU subsidies to be eligible construction costs.
b) The operating costs of maintaining and repairing roads were taken into account in full for motorways and expressways, with the appropriate costs for selected tolled sections of class I roads being set proportionally to their length.

**Comparison of the newly proposed toll rates with those in surrounding countries**

Those rates lower than those of the said option are highlighted in colour in the following mutual comparison of the toll rates with those in surrounding toll systems. These are namely the rates applicable to vehicles having more than three axles – Table 4 and Figure 7.

Table 4: Toll rates with those in surrounding countries (2011)

| 2011 | Toll rates for M and E and vehicles weighing 12 tonnes or more | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| exchange rate CZK 24,32 /EUR | EURO I,II - S1 and S2 exc. PMK | | | | EURO III - S3 exc., S2 with PMK | | | | EURO IV - S4, S3 with PMK | | | | EURO V - S5 and EEV | | | |
| Number of axles | **2** | **3** | **4** | **5** | **2** | **3** | **4** | **5** | **2** | **3** | **4** | **5** | **2** | **3** | **4** | **5** |
| **Czech Republic** | 2,83 | 4,54 | 6,63 | 6,63 | 2,09 | 3,56 | 5,15 | 5,15 | 2,09 | 3,56 | 5,15 | 5,15 | 2,09 | 3,56 | 5,15 | 5,15 |
| **Slovak Republic** | 4,69 | 4,91 | 5,08 | 5,01 | 4,45 | 4,69 | 4,84 | 4,69 | 4,35 | 4,6 | 4,77 | 4,6 | 4,35 | 4,6 | 4,77 | 4,6 |
| **Germany** | 6,64 | 6,64 | 6,98 | 6,98 | 5,11 | 5,11 | 5,45 | 5,45 | 4,09 | 4,09 | 4,43 | 4,43 | 3,4 | 3,4 | 3,75 | 3,75 |
| **Austria** | 4,28 | 5,99 | 8,99 | 8,99 | 4,28 | 5,99 | 8,99 | 8,99 | 3,75 | 5,24 | 7,87 | 7,87 | 3,5 | 4,9 | 7,35 | 7,35 |
| **Czech Republic** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** |
| **Slovak Republic** | 166% | 108% | 77% | 76% | 213% | 132% | 94% | 91% | 209% | 129% | 93% | 89% | 208% | 129% | 93% | 89% |
| **Germany** | 235% | 146% | 105% | 105% | 245% | 143% | 106% | 106% | 196% | 115% | 86% | 86% | 163% | 96% | 73% | 73% |
| **Austria** | 152% | 132% | 136% | 136% | 205% | 168% | 175% | 175% | 179% | 147% | 153% | 153% | 168% | 138% | 143% | 143% |
| **Czech Republic** | **100%** | 161% | 235% | 235% | **100%** | 171% | 247% | 247% | **100%** | 171% | 247% | 247% | **100%** | 171% | 247% | 247% |
| **Slovak Republic** | **100%** | 105% | 108% | 107% | **100%** | 105% | 109% | 105% | **100%** | 106% | 109% | 106% | **100%** | 106% | 109% | 106% |
| **Germany** | **100%** | 100% | 105% | 105% | **100%** | 100% | 107% | 107% | **100%** | 100% | 108% | 108% | **100%** | 100% | 110% | 110% |
| **Austria** | **100%** | 140% | 210% | 210% | **100%** | 140% | 210% | 210% | **100%** | 140% | 210% | 210% | **100%** | 140% | 210% | 210% |

*Source: (Bina, et al., 2010)*

S1 – S4 – Emission classes according to the Guide for determining the emissions classes of heavy commercial vehicles, valid as at 1 January 2009

PMC – Particulate reduction class – standards for additional adjustments reducing the emissions of vehicles

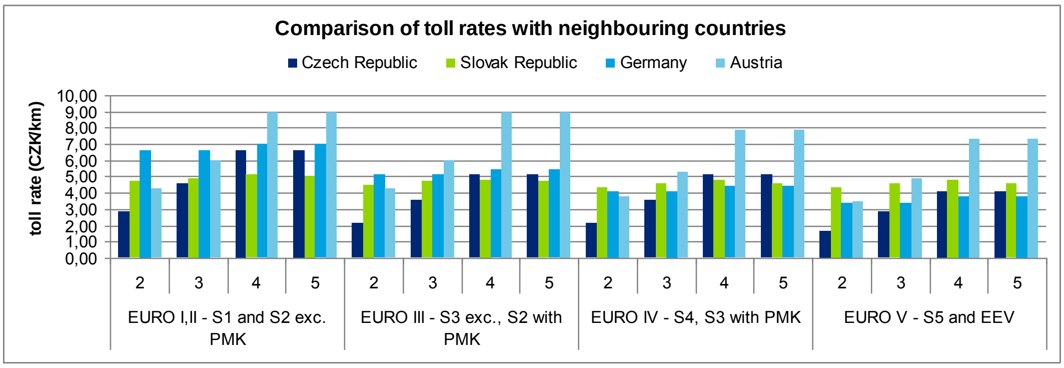


Figure 7: Comparison of toll rates with neighbouring countries (2011)

*Source: (Bina, et al., 2010)*

The same philosophy aimed at supporting green vehicles has also the Federal Republic of Germany, where the amount of toll tariffs strongly supports the introduction of green vehicles with Euro V and higher engines. In Germany dominate in car fleets of transport and logistics companies modern trucks with a weight from 12 tons with low emissions after eight years from the start of toll. In 2005, the share of vehicles with emission class EURO V was less than one percent of overall driving performance, in mid-2012 it was already 77 percent. The share of the trucks mileage of all three emission classes S0, S1, S2 (EURO I, II) - from 36.5 percent in 2005 to 3.7 percent in 2012 decreased proportionally. The share of emission class S3 (EURO III) in driving performance have decreased from 64.2 percent to 14.0 percent.

In the Czech Republic during the monitored period the share of vehicles in higher emission classes was gradually increasing. The change in emission ratio of traffic volumes reduces the value of weighted average toll. Keeping the toll rates applicable to the EURO V emission class at the 2010 level meant a significant increase in green vehicles with EURO V engines, which is shown in Figure 8. On the other hand, this measure meant as previously mentioned that after the increase of toll rates in the Czech Republic by 25 percent, it should bring by calculation through each emission category a result in increased collection of nearly 20 percent. But the reality is only about ten percent.

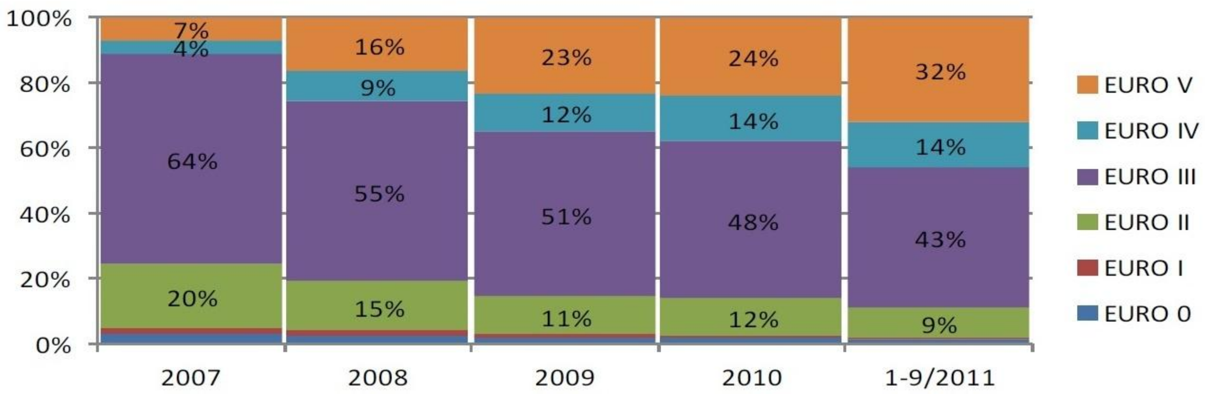


Figure 8: Year over year changes of traffic volume by emission classes of tolled cars in the Czech Republic

*Source: DWH of the E-toll System*

**5. The new methodology for determination of toll tariffs**

In 2011 an analytical team of the Czech Technical University in Prague, Faculty of Transportation Sciences prepared a report on the new methodology for calculating the maximum weighted toll „Report on the Methodology used to Calculate the Maximum Weighted Average Toll prepared in connection with the Notification of the Czech E-Toll System for the European Commission". This work was a base for The Methodology of calculating the weighted average toll rates in the Czech Republic, of authors Bína, L. et al , Lehovec, F., Nováková H. (all from the Czech Technical University in Prague, Faculty of Transportation Sciences) Vítek, J., Šnévajs, I. (Deloitte Advisory s.r.o.).

**This work was in 2012 awarded with the prize of the Rector of the Czech Technical University in Prague in the contest of Czech transport construction, Czech transport technology and Czech transport innovation of the year 2011.**

In the following text basic directions and parts of the methodology used to calculate the maximum weighted average toll for vehicles subject to the tolling system operated in the Czech Republic, in accordance with the requirements of Directive 1999/62/EC, as amended by 2006/38/EC are described. The methodology is based on the costs incurred on toll roads as of 1978, i.e. 30 years before the introduction of the tolling system in the Czech Republic in 2007. The maximum weighted average toll was calculated separately for each year (2007–2017). The overall development of selected parameters of the tolling system in the Czech Republic, including the comparison of the reached or planned weighted average toll with the maximum weighted average toll, is presented in the following table.

Table 5: The overall development of selected parameters of the tolling system in the Czech Republic

| Notion | Description |
|---|---|
| **Overall allocated investment costs** | Investment (capitalized) costs allocated on heavy goods vehicles above 3,5t incurred in the respective year. Output of the Capex model. Consist of investments in roads and investments in the tolling system, which includes telematics. EU grants allocated in the respective year are deducted. These costs are then allocated equally starting in the year of expenditure and through the depreciation period. |
| Allocated investment in the road network | Construction costs consist of incurred construction costs and costs of structural repairs, modernization and reconstruction. |
| Allocated investment in the tolling system | Capitalized investment costs of acquiring the tolling system are included. |
| **Annual share of overall allocated annual costs** | Sum of all relevant costs for the relevant year, of which the maximum weighted average toll is calculated in that year. |
| Annual share of allocated costs of roads | Annual shares of allocated investment costs (interest cost), annual costs of maintenance, and small road repairs. |
| Annual share of allocated costs of the tolling system and telematics | Operating costs of the tolling system. Also, costs of the tolling system operator, who belongs to a special division of RSD [3]- E-Toll Operator Division (ÚPEM[4]) and activities of inspection bodies of the Czech Customs Administration that provide enforcement are also included. |
| **Total income from toll collection** | Sum of collection/plan/regulations of tolls, both actual and expected. Only for heavy goods vehicles. |
| Toll income of goods vehicles | Toll collection for tolled goods vehicles, ie goods vehicles with a weight above 3,5t, separately for motorways and expressways and for tolled sections of 1st class roads. |
| **Length of network and traffic volume** | Contains the basic parameters of the tolled road network, length of tolled sections of roads and traffic volumes, both actual and expected. |
| Length of tolled network | Lengths of tolled road network. |
| Traffic volume of heavy goods vehicles on tolled roads | Traffic volumes in millions of vehicle kilometres per year listed according to the type of road of heavy goods vehicles. |
| Annual change in traffic volume | Annual change in traffic volumes. Influenced by the change in traffic intensity, length of tolled sections of roads and changes in the scope of tolled vehicles. |
| **Toll rates and ratios** | Contains the final calculation of maximum weighted average toll and its comparison to actual or expected weighted average toll. |
| **Maximum weighted average toll** | **Calculated maximum weighted average toll that should not be exceeded.** |
| **Weighted average toll** | **Calculated actual or expected weighted average toll that is counted as a share of the collected toll to traffic volumes.** |
| Share of tolling income on allocated costs of the network | Percentage share of toll collection on allocated costs of network. |
| Allocated costs per 1 km of tolled section | Allocated costs per 1 km of tolled section of a road. |
| Income per 1 km of tolled section | Income from toll collected per 1 km of tolled section of a road. |
| Share of allocated costs of the tolling system to incomes from the tolling system | Expresses what the share of costs of the tolling system on the total collected toll amount is. |

*Source: (Bina et al., 2011)*

Based on EC Directive 1999/62/EC as amended by 2006/38/EC, Annex III, the maximum weighted average toll shall be calculated from the introduction of the tolling system in the Czech Republic in 2007 to 2011, with an outlook until 2017.

Under these assumptions, in period from year 2010 till 2017, weighted average tolls of heavy goods vehicles on motorways, expressways and tolled 1st class roads are always below the maximum weighted average toll. Comparison of the maximum weighted average tolls to weighted average toll is in the Figure 4.

### *5.1 Method of determining the costs of road infrastructure*

Either the perpetual inventory method (PIM) or the synthetic method can be used to determine the costs of roads. Based on the acquired data series of incurred costs, the PIM method was preferred mainly owing to the possibility of predicting further development of toll rates and owing to the possibility to quickly evaluate the impacts of future investment strategies on the size of toll rates.

**a) Synthetic method**

The synthetic method is based on the current amount of assets and depreciation periods of the infrastructure. However, determining the initial value of the assets requires a significant share of qualified estimates, which is why this method was not chosen.

**b) Perpetual Inventory Method (PIM)**

The PIM method is based on the knowledge of annual costs incurred in the past on the road network. The advantage of this method is that toll rates in the future can be modeled easier, using the trends of the variables monitored.

**c) Selection of the method used**

All available information was assessed before the method to calculate the average weighted toll rate was chosen. Historical data for the 1990–2000 periods and a model of price norms from 2008, which were used to determine the value of the road network completed between 1978 and 1989, were available. For the period of 2001 and after, the data is already available in the required structure.

*5.2 Historic data until 2010*

Data on costs incurred on the construction, maintenance and repairs of motorways, expressways and 1st class roads was obtained from the sources stated below:

*1. Information provided by the Ministry of Transport of the Czech Republic*

a) List of EU grants between 2002 and 2010, with outlook for 2013.

*2. Information provided by the Road and Motorway Directorate of the Czech Republic (hereinafter "RSD"):*

a) Historical series of costs of construction, maintenance and repairs of roads and motorways for 1990–2000 published on www.rsd.cz;
b) Annual accounts data between the RSD and the State Fund for Transport Infrastructure (SFDI) for 2001–2010. The review of grants is based on RSD accounting, which contains the actual use of costs in individual years;
c) RSD annual reports.

*3. Information provided by the Faculty of Transportation Science of the Czech Technical University in Prague ("CTU"):*

a) Price norms of construction of roads 2008 which were prepared for the Ministry of Transport of the Czech Republic

*4. Information on the transfer price indexes of construction sites*

a) Transfer price indexes of construction sites from 1971 to 2009 (Institute of rationalization of the construction industry, URS Prague, 2009).

*5. Information on the volume of traffic on motorways and roads obtained from the data warehouse of the tolling system*

a) Traffic volumes on the network of motorways, expressways and selected sections of 1st class roads for 2007–2010;
b) Planned toll amount for 2007–2010;
c) Division of traffic volumes according to weight categories of vehicles and emissions groups for 2010;
d) Based on the 2010 national transport census, the estimate of the future development of traffic intensity, toll rates and length of toll roads was prepared for the 2011–2017 period.

*6. Information on the volume of traffic on 1st class roads obtained from the national transportation census in 2010*

a) Nationwide transport volumes on 1$^{st}$ class roads.

*7. Information on damage caused by vehicles on the state of the roads*

a) Report by the Transport Research Centre (CDV), „Analýza trendů silniční nákladní dopravy v letech 1995-2003, březen 2005".

*5.3 Expected future period from 2011 to 2017*

Estimations for the period after 2010 were prepared based on the following data:

*1. 2011–2013*

a. SFDI budget for 2011 with outlook for 2012 and 2013, which has been passed by the parliament.

*2. 2014–2017*

a. Extrapolation of historical trends in the future development of costs spent on the road infrastructure and planned new toll rates.

Regular annual update of outlook of size of maximum weighted average toll is expected.

*5.4 Costs of construction - Motorways and expressways*

*a) Origin of construction costs*

The PIM method requires knowledge of the lifetime of construction costs that were incurred annually and completed at least 30 years before 10 June 2008. Thus, the relevant year is 1978 because the tolling system in the Czech Republic was launched on 1 January 2007 (see Article 2, paragraph aa) of Directive 1999/62/EC as amended by 2006/38/EC).
Given the fact that accounting reports were not available for such a long period, the following method was chosen:

1. Costs of construction between 1978 and 1989 are derived from the price norms by the CTU, which were prepared to assess the basic costs of construction of the road network. 6% of the costs of the project work were added to the prices. Further evaluation was not conducted. Price norms are prepared at the 2008 price level. Prices of roads between 1978 – 1989 were then determined using transfer price indexes of construction objects set by an engineering and consulting organization (URS Prague, see Annex 14.3).
2. Construction costs between 1990 and 2000 were taken by RSD from publicly available sources. As the costs were stated in aggregate, they were allocated to motorways, expressways and toll sections of 1st class roads.
3. Construction data for the 2001–2010 periods was obtained from billing documents between RSD and SFDI that contain detailed information (in contrast to the previous data).
4. Construction costs for 2011–2013 were received from the SFDI budget for 2011, which also contains a mid-term outlook for 2012 and 2013.
5. Construction costs for 2014 - 2017 were based on experts estimate.
6. Incurred investment costs are allocated equally throughout the 30-year depreciation period.

*b) Method of allocating construction costs*

Construction costs were distributed and then allocated to toll roads as follows:
The 1978–1989 construction costs were fully allocated from the price norms on motorways and expressways. Construction costs on 1st class roads were not taken into consideration in this period.

1. The 1990–2003 construction costs are stated in aggregate for motorways, expressways and 1st class roads. By the method presented above, the construction costs of 1st class roads were allocated gradually at 36%, using the same average rate as in the case of 2001–2010 construction costs.
2. The 2001–2010 construction costs were distributed according to the basis for recognition between RSD and SFDI.
3. The 2011–2013 construction costs were allocated based on the SFDI budget, pass
4. Construction costs for 2014 - 2017 were allocated on their previous trends.

*5.5 Other costs*

In the calculation were included: maintenance costs, investment costs of the tolling system, investment costs of telematics, operating costs of the tolling system and telematics, financial costs, EU grants.

*5.6 Calculation of the maximum weighted average toll*

This section presents the method of calculating the maximum weighted average toll by Directive (see Article 2, paragraph ba) and Article 7, paragraph 9 of the Directive11). "Directive" means EC Directive/62/EC as amended by 2006/38/EC.
**Toll collection cannot exceed the costs incurred on construction and operation of tolled roads and on the construction and operation of the toll and ITS system, including dissolved investment costs for the considered period:**

**INC <= Ca**

*INC – Income of toll (CZK) - toll collection in the period,*
*Ca – Cost allocated to heavy vehicles (CZK) – construction, operating and financial costs allocated on tolled roads and the respective traffic volumes of tolled goods vehicles above 3,5t,*

a) *Method of calculating the maximum weighted average toll*

In accordance with Article 2., Annex III. of the Directive, the weighted average toll is calculated as a division of the allocated costs of the road network and tolling system on the traffic volume on the respective road expressed. In compliance with the Directive the buses are not included in the maximum weighted average toll calculation.

**Maximum weighted average toll allocated on heavy goods vehicles is set by the following ratio:**

**Rmax = Ca / Vh**

*Rmax – Maximum Toll Rate (CZK/km) – Maximum weighted average toll*
*Ca – Cost allocated to heavy goods vehicles ( CZK) – costs of roads and toll system allocated to vehicles subject to the toll based on the ratio of traffic volume of tolled vehicles to the overall traffic volume on the toll road.*
*Vh – Traffic Volume (vehicle kilometre) is the traffic volume of heavy goods vehicles.*

a) *Counted costs*

The types of costs that can be counted into the calculation of the maximum weighted average toll consist of:

1. Investment costs that are counted for the respective year in a size based on the period of depreciation. These include costs of construction, costs to purchase land, costs to conduct an archaeological survey, cost of project and inspection activities, costs of modernization of roads, telematics, and other related costs. EU grants are deducted from the investment costs depending on how they are used and they are eventually deducted appropriately in the respective programming period.
2. Operating costs, which include the costs of maintenance and operation of roads, tolling system, telematics, and interests of loans, are counted all in the respective year.
3. Costs of the toll system include investment costs on its construction and further expansion on motorways and expressways and they include also operating costs until 2016 when the contract with the present provider of services terminates.

Because planned costs are set by the SFDI budget for individual years, the discount rate and inflation are not included in the calculations and the maximum weighted average toll is calculated repeatedly for each year.

**Costs included in the calculation of the maximum weighted average toll according to Article 2, Annex III. of the Directive:**

**C = I – G + E + T + M + F + O**

*C – Total Costs (CZK) – total costs included in the calculation of the maximum weighted average toll before allocation*
*I – Investment Costs (CZK) – annual share of construction costs on the road network, distributed equally along the period of depreciation starting in the year of expenditure*
*G – EU Grants (CZK) – annual share of received EU grants*
*E – E-toll Costs (CZK) – annual share of investment costs on the tolling system, distributed equally along the amortization period starting in the year of expenditure*
*T – Telematic Costs (CZK) – annual share of investment costs on road telematics on motorways, distributed equally along the period of depreciation starting in the year of expenditure*
*M – Maintenance (CZK) – annual costs of repairs and maintenance, including operating costs of the tolling system and telematics*
*F – Financial Cost (CZK) – annual financial costs – interests of credits*
*O – Operational Costs (CZK) – annual operating costs of the road network operator*

a) *Allocation of costs according to Annex III., Point 4. of the Directive*

Both groups of costs stated above were further allocated:

1. In proportion to the traffic volumes of tolled vehicles to the overall traffic volume which includes also vehicles that are not subject to toll. Traffic volumes were adjusted by the coefficient of allocation and then the coefficient of allocation Kv was calculated, which takes into account the level of road network damage by the operation of heavy goods vehicles;
2. Owing to the reasons of known costs of the total length of tolled roads, the costs of maintenance were allocated in proportion of the tolled and total length of respective class of road by the coefficient Ks. The proportion of the traffic

volume on tolled part and total roads length was used for allocation of investment, reconstruction, modernization and repair.

**Incurred costs are allocated on tolled heavy goods vehicles and on tolled lengths of roads:**

**Ca = C x Kv x Ks**

*Ca –*
*Ca – Cost Allocated to heavy goods vehicles*
*C – Total Costs (CZK) – total costs that are included in the calculation of the maximum weighted average toll rate before allocation*
*Kv – coefficient of cost allocation on tolled heavy goods vehicles*
*Ks – coefficient of reduction of toll road length or their traffic volume*

## 6. Conclusion

The paper contains the overview of the basic specifications and activities connected with the implementation of the electronic toll system in the network of highways and other roads of the Czech Republic. The implementation of this system is an example of an indirect PPP model of financing, in which the investment and operating payments of the system are covered from the collected toll. The roll-out of the system to cover the full scope of the road network of the Czech Republic requires extensive cooperation among a number of entities participating in the implementation and operation of the system. It is also necessary to mention the cooperation of the research capacities of the Faculty of Transport of the Czech Technical University in Prague, particularly the FT CTU Expert Group of the Minister of Transport. With regard to the pressure on reduction of congestions, the proposal for differentiated toll during Friday afternoon hours when the traffic intensity level substantially rises in the highway implies recognizable effect on congestion reduction on the toll highway network in the Czech Republic. In any case, the whole situation calls for a detailed analysis, because there is (after a very simplified calculation) of approximately CZK 100 million (EUR 4.1 million) an increase in the annual collection of the electronic toll system in the Czech Republic on Friday due to by 50% higher tariffs in the time from 15.00 to 21.00.
In the end of the paper principles and results of a new methodology for calculating the weighted average toll rates in the Czech Republic are described. The methodology has been applied in the revision of this calculation by the European Commission in 2011.

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# Infrastructure charges can solve transport problems

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**Abstract**

Transport infrastructure is of great importance for economic growth, labour mobility, consumers, and the competitiveness of the economy. Achieving of efficient use of infrastructure is among other questions dependent on how users are charged for infrastructure. Infrastructure charges have a very clear role to play in addressing all issues like escalating congestion and pollution raise doubts about the sustainability of transport. The author explains in the article how infrastructure charging system can solve many of the transport sector's problems, and help find the measures to make the best use of the existing infrastructure, to achieve a shift to less environmentally damaging modes of transport, and the use of economic instruments to reduce fuel consumption, emissions, and noise. Fees for the use of infrastructure should be neither too low nor too high. The upper limit of the hairpin would be conditional to the transport market-segment price, while the lower one would be a function of the transport infrastructure costs.

**Keywords:** infrastructure, charges, fee, marginal costs, railway, sustainability, faire competition, transport policy

## 1. INTRODUCTION

The article presents executive summary on findings resulted from the research regarding to an appropriate system of infrastructure charging for railway operators, harmonized between transport sectors.

### *1.1. Marginal costs*

The need to promote efficient use of railway infrastructure and fears of distortions to intermodal competition particularly from road transport are the main problems for the rail sector. Charging the use of railway infrastructure according to marginal costs would send appropriate price signals to railway operators about their better price competitiveness with road transport. The reason for marginal cost approach relates to lower external costs of railway than some other modes. Marginal costs are those variable costs that reflect the cost of an additional train using the infrastructure. They can vary at different times, in different conditions and in different places. Marginal costs may at times merely reflect an average of variable costs. Marginal costs include use related infrastructure maintenance and operating costs. In the long term (e.g. 50 years relating to depreciation) all costs (even investment and capital costs) become variable, and so marginal costs tend to converge with average costs (because the distinction between fixed and variable costs is abolished). When the policy focus is efficient use of existing infrastructure however, it is the short run version of marginal costs which is important. Whilst charging based on marginal costs approach leads to efficient use of infrastructure, for sectors with economies of scale (such as railways) it doesn't recover all costs. Second, other objectives such as development, safety and mobility may lead to investments above the theoretical optimum and so marginal cost charging may again, not cover all costs. Third, stepped, rather than finely graded charges are all that is feasible at the moment, so marginal costs may not be perfectly reflected. Fourth, imperfect markets elsewhere, may call for the implementation of an adjusted marginal cost scheme.

### *1.2. The Scandinavian approach*

The Scandinavian approach is based on both short run marginal costs (SRMC) and core goal of common transport policy like "*optimising the performance of multimodal logistic chains, including by making greater use of more energy-efficient modes*". SRMC relates to the use of existing infrastructure without considering a capacity increase. The level of infrastructure charges (and hence the total income from these charges) is determined mainly by cost conditions and crucial comparisons with other modes of transport, so that the level of state contributions required is then determined by the difference between total rail infrastructure costs and the revenue raised from infrastructure charges.

### *1.3. Maximum utilization of infrastructure capacity*

It seems that the optimum price maximising the infrastructure capacity utilisation is based on the Scandinavian approach based on SRMC but adjusted to take into account of common transport policy goals like making greater use of more energy-efficient modes with lower external costs. If infrastructure manager (IM) invoices railway train operator (RO) according with its SRMC in respect to comparative road infrastructure charges, RO will demand maximum utilization of the infrastructure capacity. The fixation of an incorrect fee leads always to the selling of capacity minor than the optimum. If IM fixes the price for using infrastructure this one will exceed the optimum and RO will demand less than the optimum volume. In general the nature of the sub-optimisation in the problem of the fixation of the fee for the use of the infrastructure is that it is transferred and sold less of the optimum for the profitability of railway sector. By the other hand, the rule of the marginal cost begins to collapse itself when IM operates near to a capacity constraint. In contrary to that if IM invoices RO, having previously maximised its benefit, the fee would be too much high and RO would demand less capacity. Higher fee means lower volume of allocated paths which results in next promotion of price consequently…

### *1.4. Rail sector practice*

Rail infrastructure fees vary significantly each other across the EU member states. It seems that key criterion is coverage of rail infrastructure costs instead of (required) intermodal competitive ability towards road transport on common internal market.

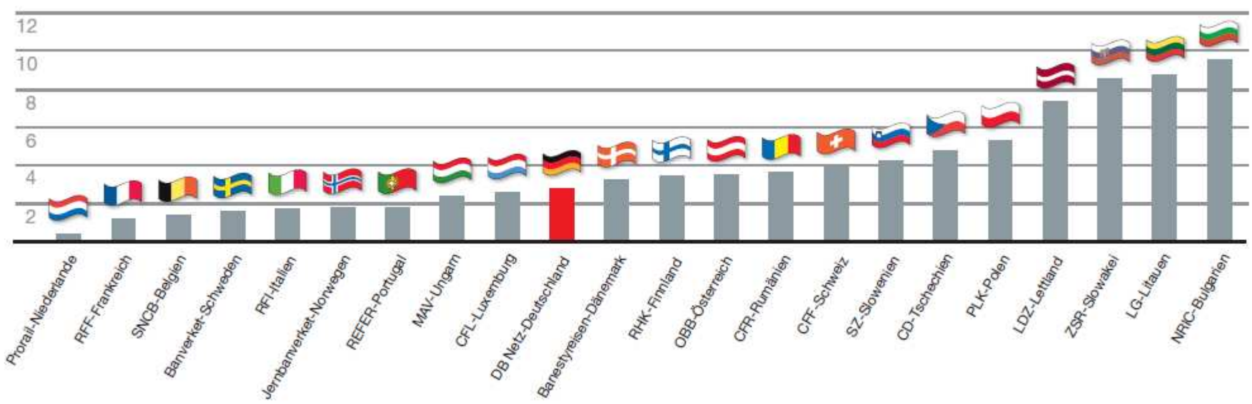


Fig. 1. Rail infrastructure fees for freight trains with total weight of 1400 tonnes in Europe (€/path.km)

*Source: Deutsche Bahn, Wettbewerbsbericht, Berlin, 2005 www.deutschebahn.com*

## 2. Infrastructure fee on Czech transport market

Simple comparative analyses between road and rail modes can imply (un)fair competitiveness among individual transport modes in the Czech republic.

*2.1. Czech public passenger traffic performances in 2012 (in mil. passenger-kilometres)*

| Passenger traffic performance | Mil. pkm |
|---|---|
| Rail )* | 7 258 |
| Bus )** | 8 907 |

*)* revenue-earning traffic in national territory*

*excl. free-of-charge and flat transportation services*

*)** only Czech operators regardless on national territory*

Fig. 2. Czech passenger traffic performances in 2012

*Source: Ministry of transport www.mdcr.cz*

Rail public passenger traffic performance on the national territory amounted to 7 258 mil. pkm in 2012. On the other hand, road public passenger traffic performance carried by Czech bus operators including whole carriage distance regardless of national territory amounted to 8 907 mil. pkm in 2012.

*2.2. Czech public freight traffic performances in 2012 (in mil. tariff-tonne-kilometres)*

| Freight traffic performance | Mil. ttkm |
|---|---|
| Rail )* | 14 263 |
| Road )** | 51 228 |

*)* revenue-earning traffic on national territory*

*)** only Czech operators regardless on national territory*

Fig. 3. Czech freight traffic performances in 2012

*Source: Ministry of transport www.mdcr.cz*

Rail public freight traffic performance on the national territory amounted to 14 263 mil. ttkm in 2012. On the other hand, road freight traffic performance of Czech truck operators including whole carriage distance regardless of national territory amounted to 51 228 mil. ttkm in 2012.

*2.3. Rates of infrastructure fee for passenger transport*

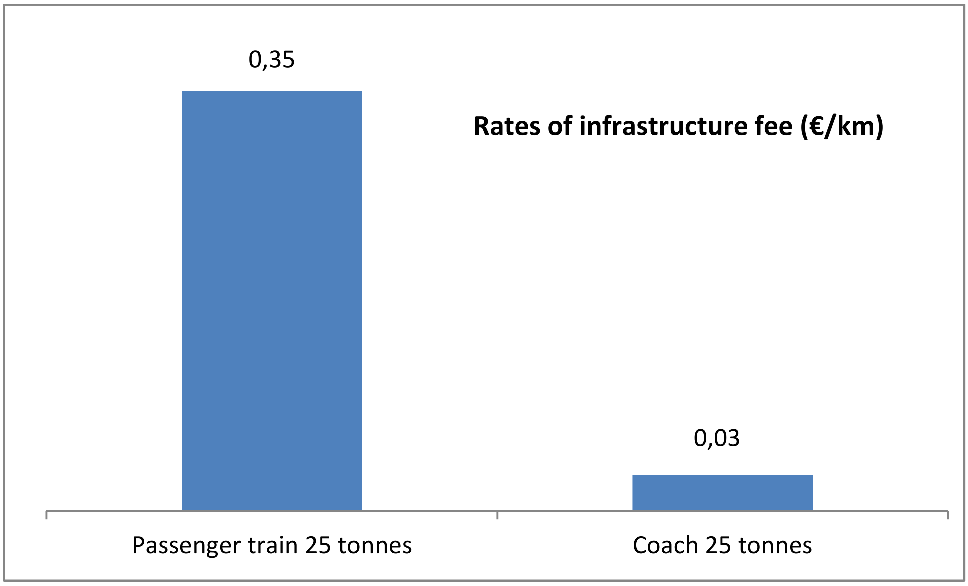


Fig. 4. Rates of infrastructure fee for passenger transport

*Source: www.mytocz.cz; www.szdc.cz*

Rate of Czech highway toll is based on both the number of axles and the emission (EURO 0 to VI). Rate of Czech infrastructure fee is based on both train-kilometres and gross-hauled tonne-kilometres in three line categories. In order to ensure comparability, indicated rates refers to the passenger transport unit with total weight of 25 tonnes. The rate of rail infrastructure fee is by 11.7 multiple higher than in case of road toll.

*2.4. Rates of infrastructure fee for freight transport*

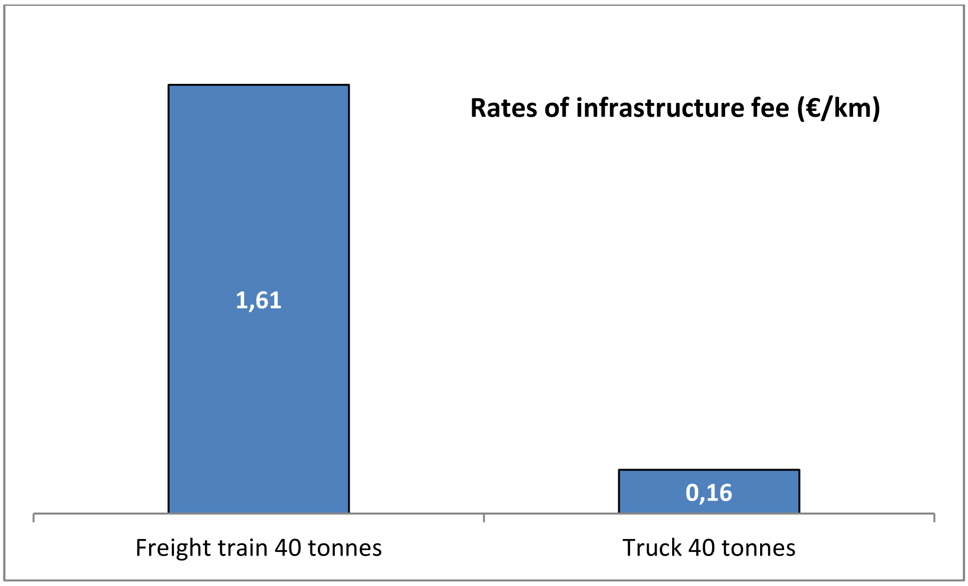


Fig. 5. Rates of infrastructure fee for freight transport

*Source: www.mytocz.cz; www.szdc.cz*

Rate of Czech highway toll is based on both the number of axles and the emission (EURO 0 to VI). Rate of Czech infrastructure fee is based on both train-kilometres and gross-hauled tonne-kilometres in three line categories. In order to ensure comparability, indicated rates refers to the freight transport unit with total weight of 40 tonnes. The rate of rail infrastructure fee is by 10.1 multiple higher than in case of road toll.

## 3. Conclusion

Re-balance of Czech transport market in compliance with the goal of common transport policy can be achieved by means of better modulation of infrastructure charges. Fees for the use of rail infrastructure capacity should be neither too low (in order to cover marginal costs of infrastructure) nor too high (in order to ensure competitiveness of rail sector in relation to road transport). In other words, the upper limit of the hairpin should be conditional to the transport market-segment price in respect to modal competitiveness of rail transport, while the lower threshold should be a function of the rail infrastructure marginal costs. Let's say that the first one is modulated by intermodal demand and the second one is modulated by capacity supply. Crucial harmonization of infrastructure fees between rail and road has to be guaranteed in order to achieve a goal of common transport policy "*optimising the performance of multimodal logistic chains, including by making greater use of more energy-efficient modes*".

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# DEPARTMENT OF MECHANICS AND MATERIALS

# K618

The Department of Mechanics and Materials (DMM) has two main interacting activities:

- university education in all the three levels: bachelor, master and doctoral
- research of structures, materials and processes in the transport

DMM guarantees and performs all forms of education in both compulsory and optional subjects on the bachelor, master and doctoral levels of study and in the project-oriented teaching in the fields of study:

- statics, kinematics and dynamics, theory of elasticity and strength of materials, experimental and computational mechanics, theory of plasticity and failure, fracture mechanics, biomechanics;
- dynamics of transport routes and vehicles;
- behaviour and properties of structural and functional materials - classical materials, ceramic materials, composite materials, materials with controlled properties;
- traffic safety, interaction of system: man - vehicle - route;
- introduction to rolling stock;
- technical documentation in the field of civil, mechanical and electrical engineering.

The research focuses on the analysis of deformation processes of structural systems in transport, taking into account different materials and different loading conditions, the investigation of deformation and failure of materials, testing and diagnostics of structures and materials, computational and experimental modeling of mechanical systems and analysis of reliability and service life of structures. There are solved biomechanical problems musculo-skeletal system and its implants and injury biomechanics too.

Both education and research activities are also carried out in the Laboratory of Experimental Mechanics of the Department of Mechanics and Materials. The laboratory is furnished for testing and diagnostics of mechanical behaviour and properties of structures and materials during static and dynamic loading.

# Planning Rail Transportation for Further Decades

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**Abstract**

In the on-coming years and decades the European Union is going to face in the freight sector the challenges to ensure and increase economic growth and to cope with an increase of freight transport demand and limited transport infrastructure, while at the same time the transport system should become sustainable. The freight sector has had and will continue to have very strong growth rates in the latest decades and this development is generally not considered as being sustainable. The following article is going to deal with the problems of "sustainable development" as well as main conflicts with freight transport. The author was involved at the FreightVision project that had dealt with the mentioned problems.

**Keywords:** rail transportation, freight transport, logistics, strategy scenarios, transportation planning, greenhouse gas emissions

## 1. INTRODUCTION

Typical phenomena of modern times in developed industrial countries include steep growth in the volume of transported goods and materials, which in turn increases challenges for the freighting sector. To be able to satisfy this demand and keep up with the overall economic progress, the freighting sector too has to develop both quantitatively and qualitatively and undergo a number of changes. At the same time it has to deal with a number of issues inevitably caused by the increasing intensity of freight transport. Among the most prominent issues is a requirement to reduce dependence on fossil fuels, cut the accident rate and curb greenhouse gas emissions (particularly $CO^2$) as well as other environmentally damaging activity.

But the transport sector is an immensely complex and extensive system with major external interconnections, and comprises many different entities and interest groups. Many of these actors are proposing different ways of intensifying freight transport, yet their solutions only address part of a broad spectrum of issues.

### *1.1. Scenarios building-up*

A major component in the process of comprehensive optimization of rail haulage – which is expected to deliver a set of executive tools for the management and planning of further rail haulage development – is the creation of framework strategy scenarios for freight transport and logistics. These scenarios address expected transport volume needs, the expected impact of the changing scope and capacity of the infrastructure, and the influence of advancing transport technologies on the energy demands of rail transport.

The first step towards compiling such scenarios is to work out an energy analysis for rail transport. Drawing on statistics reflecting the most recent trends in rail transport, such an analysis will then apply appropriate extrapolation methods to this input data to arrive at a prognosis of development outlooks for required target dates. The prognoses must also consider the socioeconomic impact as well as the influence of technological innovations on rail transport.

These scenarios, each adopting different methodological approaches, will provide analysts and experts in the management and planning of rail haulage with a view to the future formed by dissimilar assumptions. As such they will help them compare multiple possible variants of forthcoming reality. The basic methodology, successfully used in practice in recent years, works with three types of scenarios (although, for more detailed analysis, additional scenarios may be created or the existing ones may be combined). The first is a conservative scenario, which assumes the extension of existing trends in transport volumes, infrastructure development based on current plans, and slow but gradual advances in transport technologies. The second scenario, called extensive, assumes increasing requirements for transport capacities linked to overall economic developments, more substantial infrastructure development and faster advances in transport technologies. The third and last is an innovative scenario, assuming a moderate increase in required transport volumes linked to overall economic developments, a rationalization of transport, and, in addition, the introduction of innovative technological solutions supporting higher transport efficiency. These individual scenarios are then evaluated and the findings synthesized, to form the basis for formulated recommendations and supporting tools for the planning and development of the rail freight system.

*1.2. Innovative scenario*

Since modern railway system development must be sustainable from an economic, social and environmental point of view, the innovative scenario seems to represent the optimal solution under current conditions, and as such should become the basis for planning and other related activities. This scenario presents acceptable options in terms of the energy needs of the rail freight sector, accommodates increasing requirements for security of energy supplies and for better environmental protection, and reflects faster growth in energy prices resulting from an expected decline in the availability of fossil fuels.

Another important factor considered by the innovative scenario is very dynamic scientific and technological progress that yields frequent innovations and calls for their implementation in transport systems. This process in turn helps to better exploit the benefits of intelligent rail infrastructure and telematics for the energy efficiency of transport and to introduce more energy efficient pulling vehicles (such as hybrid engines with energy recovery, or even hydrogen traction at some point in the future). The innovative scenario also assumes rationalization and reorganization in the rail system and reflects increasing requirements for expanding the share of combined transport through an efficient exploitation of rail haulage.

*1.3. Modal split scenarios and their impact*

The modal split impact is derived from the assumed modal shift: A higher modal shift to rail and IWW (inland waterways) reduces emissions more than a lower modal shift. This special aspect was therefore analyzed in more detail: Different modal split scenarios were developed and their impact analyzed.

Scenario 1: This Scenario assumes a very unfortunate development with regard to rail and IWW. It assumes that rail and IWW transport performance (tkm) stay at 2005 level. All additional transport is delivered by road. The growth of the each mode in percent and the modal split in 2050 is shown in Fig. 1.

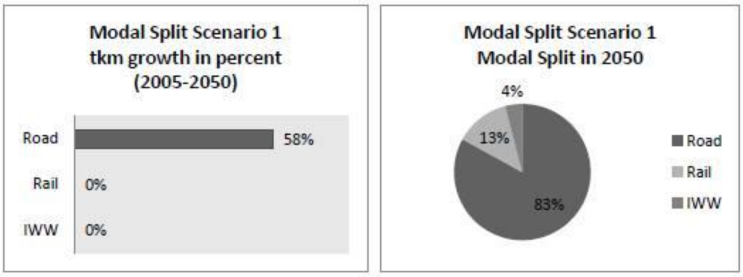


Fig. 1. Modal Split Scenario 1

Scenario 2: Modal split stays at 2005 levels. This assumes that rail and IWW will have the same growth in percent as road. For growth and modal split of this Scenario see Fig. 2.

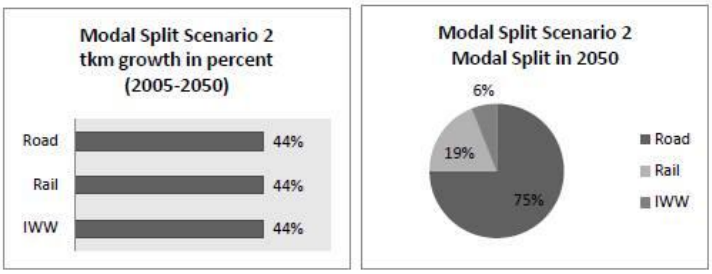


Fig. 2. Modal Split Scenario 2

Scenario 3: This Scenario assumes that rail and road will have about the same transport performance growth in billion tkm (Road 410 billion tkm, Rail 370 billion tkm). IWW is assumed to grow with 180 billion tkm, which corresponds to an ever stronger growth in percent. (This is the modal split scenario assumed in the FreightVision Scenario. Our project team considers this Scenario to be ambitious, but possible. See Fig. 3.)

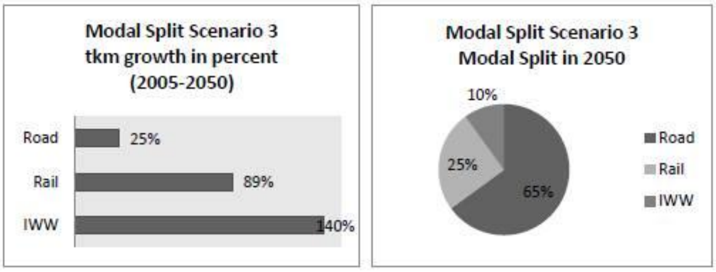


Fig. 3. Modal Split Scenario 3

Scenario 4: This Scenario assumes an equal growth in IWW and rail in percent, and a much higher growth in rail. In absolute numbers the growth in road transport is about 400 billion tkm, Rail is 530 billion tkm, and IWW is 30 billion tkm. This scenario, shown in Fig. 4, is a very optimistic one for rail transport.

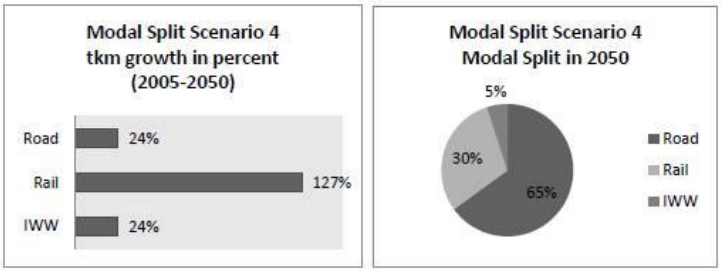


Fig. 4. Modal Split Scenario 4

Scenario 5: Road tkm stay at 2005 levels, whereas all additional tkm are transported by rail and IWW. This scenario, shown in Fig. 5, is considered by the project team as rather unrealistic, but this rail market share (above 30%) has been claimed by rail stakeholders as being realistic.

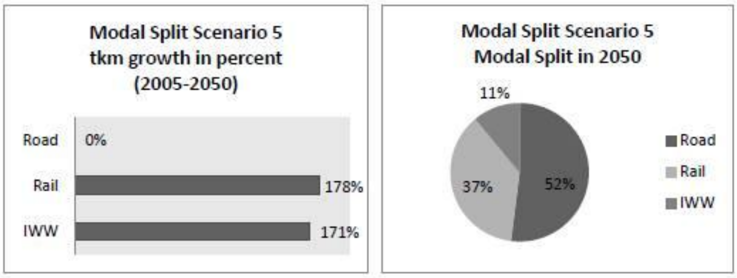


Fig. 5. Modal Split Scenario 5

Fig. 6 shows the result of the impact analysis of the various modal split scenarios on GHG emissions. The impact analysis assumes that all other key characteristics (except transport performance) stay at 2005 levels. I.e. the impact analysis shows what the impact will be on GHG emissions in 2050, if only modal split improves. It is of course up to political decision makers which modal split target they define, but what can be seen is the possible impact of these different scenarios. This is especially interesting if policy strategy is to focus on rail transport for reducing emissions and neglecting the development in road transport.

Fig. 6 also includes for comparison reasons the vision for 2050 and the GHG Emissions in 2005. As can be seen by these numbers that even, if scenario 5 became true, the GHG Emissions would still be above 2005 levels. The "plausible" modal split scenarios (2-4) show that the impact is relatively limited compared to the Vision defined. The conclusion from this impact analysis is that it should be avoided to have too high expectations on modal shift's impact on reducing GHG emissions.

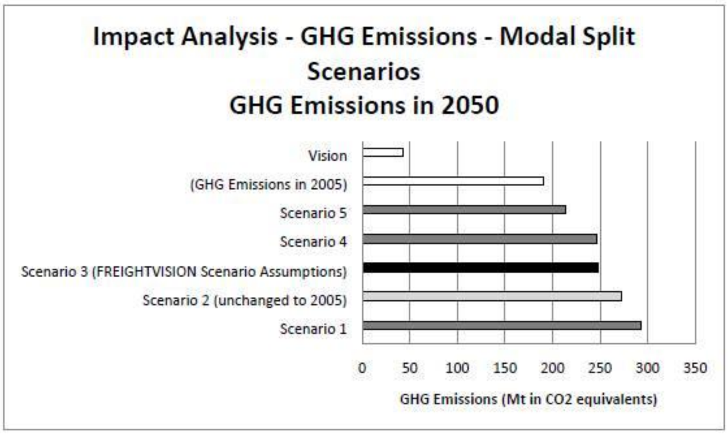


Fig. 6. Impact Analysis on GHG Emissions - Modal Split Scenarios (in Mt CO2 equivalents)

On Fig. 7 the results of the impact and sensitivity analysis are opposed. By comparing them it can be seen, if a certain key characteristic depends on the development of another key characteristic.

As can be seen the results of the impact and sensitivity analysis are quite similar. The main difference is in "low carbon electricity" which has a low impact, but the scenario is very sensitive on it. This is because electricity production will be only relevant for transport's GHG emissions, if electricity is used in road transport.

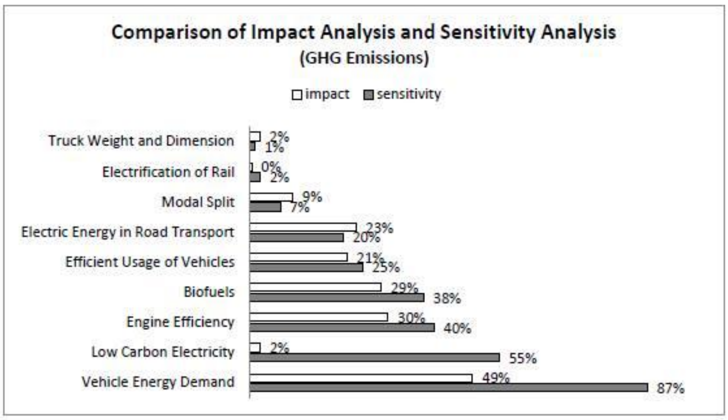


Fig. 7. Comparison of Impact and Sensitivity Analysis (GHG Emissions)

### *1.4. Research and FreifgtVision project*

Institutions currently addressing the issues outlined above include the Austrian company AustriaTech and its FreightVision project, which is part of the European Commission's Seventh Framework Programme. EU countries are trying intuitively to revitalize rail haulage by improving and modernizing infrastructure, by introducing the European Rail Traffic Management System (an unified standard for cross-border train traffic control), and by opening up the transport market and improving the interoperability and safety of haulage. All these efforts represent important factors and input criteria for the system optimization described above.

Rail haulage displays some significant advantages over road freighting: it is safer and friendlier to the environment (particularly by producing fewer greenhouse gas emissions). Despite all the European Commission's efforts to revitalize rail haulage in EU member states, the share of railways in total freight volumes in recent years has not been developing in the desired direction. In 2008, rail moved only 16 percent of all freight. This share is forecasted to grow by 1.6 percent a year between 2005 and 2030, mainly thanks to projects to build new and improved railway infrastructure – which will in turn accommodate denser and faster freight traffic – and to introduce a dedicated freight rail network.

### *1.5. Conclusion*

Besides the environmental drawbacks of road haulage mentioned above, an increasing share of the rail sector is expected to be further aided by factors including ever-increasing road congestion, rising accident rates, growing road tolls, and restrictions for heavy lorries on certain routes. However, a basic prerequisite for increasing the share of rail haulage is that the railway infrastructure be ready to take over a larger slice of total transport volumes. It must provide perfect services at affordable prices, secure sufficient capacity including reserves, and integrate with the system of intermodal transport (e.g. by participating in the development of modern logistics centers and providing rail haulage of whole lorries and passenger cars).

Still the most important prerequisites for increasing the share of freight moved by rail include the right investment policy on the part of the European Commission towards railway infrastructure in new member states, international cooperation and better efficiency to cut costs and increase profitability. If the rail freighting sector develops into a strong, reliable, efficient and flexible system, it can successfully compete with other modes of transport and their operators.

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# Modeling of Motorcycle Helmet Drop Test

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**Abstract:**

The work deals with the simulation of the motorcycle helmet drop test with the numerical software LS-Dyna. The aim of study was to obtain acceleration values of the headform gravity center. The factors of head injuries HIC were determined from the acceleration values.
The model of motorcycle helmets was created by using of a 3D handheld scanner. An impact pad was created and the headform model was modified. The draft for the model was represented by a real motorcycle helmet. Properties of materials used for making the actual helmet were assigned to the motorcycle helmet model. The quality of helmets is assessed in terms of damping properties at the drop test. Damping properties were assessed on the basis of the acceleration values of the head gravity center. A drop test was also performed on the pads rotated in different directions.
The problems of motorcycle helmets testing in Europe is adjusted by the ECE 22-05 standard. The standard primarily determines how to make drop tests.

This project was performed within the scope of the institutional research plan, identification code MSM6840770043 and Grant of Czech Technical University, Student's Grant Competition SGS 12/163/OHK2/2T/16.

**Keywords:** motorcycle helmet, 3D scanner, MKP model, LS-DYNA, droptest, simulation

# 1. INTRODUCTION

Testing of motorcycle helmets by experiments is very expensive. Therefore, in the process of motorcycle helmets development and innovation numerical modeling is suitable. Use the finite element method represents one of the possibilities. Numerical modeling allows tests that cannot be performed by any experiment.

This work is based on creation of a motorcycle helmet geometric model and a head scale model. The model was used at the drop test simulation by help of the LS-Dyna software. In terms of geometry, the model had to match a real motorcycle helmet as perfectly as possible. For maximization the model accuracy t3D scanning by the hand-held 3D scanner was used. The boundary conditions and material properties were assigned to the model by the FEM software. The model was developed and solved in the LS-PREPOST application. The analysis was carried out by the LS-Dyna software.

The aim was to obtain the acceleration of the headform gravity headform. HIC factors were determined by the acceleration values. The simulation drop test was performed in several versions with different angles of the impact pads.

# 2. ECE 22-05 STANDART

The ECE 22-05 standard is the most widely used standard in the world. Standard does not define any motorcycle helmets production procedure. The standard specifies the test methods and parameters that motorcycle helmets must fulfill. The standard specifies the exact test procedure for the drop test. The helmet is attached to a dummy head. A headform with the attached helmet is inserted into the falling dart. The helmet is dropped on the pad from height of 2.85 meters. The accelerometer measures the resulting acceleration of the headform during impact. The accelerometer must be located in the head gravity center. According to the standard, the resultant acceleration must not exceed the value of 275 G. The drop test simulation was performed according to the criteria specified in the Standard.

# 3. HIC – HEAD INJURY CRITERIA

Creation of one head injury criterion for different skull and brain dynamic properties is a very difficult job. Brain and skull injuries are very diverse. There are several criteria for a head injury evaluation. For this work there was selected the HIC criterion. The HIC criterion is based on acceleration absorbed by a human head. The HIC criterion seems to be very suitable for evaluating the results of this work.

## *3.1. HIC criteria principle*

Internal shear and tensile strength are the main mechanisms causing brain injury. However, it is very difficult to measure these variables objectively as well as to interpret their effects. Generally, skull injuries are caused by translational acceleration. Therefore, this translational acceleration was designed as the criterion for the HIC value determination. Calculation of the HIC criteria is performed according to the equation (1). The result is determined by the size acceleration and action duration. By use of biomechanical tests the curves of injury extent correlating with the acceleration values were obtained. The equation (1) matched with these curves best. The limited value of max. HIC=1860 at which fatality most probably occurs (Tab. 1) was determined on the tests basis. On Fig. 1, there are curves showing the probability of injury individual degrees at certain HIC value achievement. The injuries are graded from trivial to fatal ones.

$$HIC = \left\{(t_2 - t_1)\left[\frac{1}{(t_2-t_1)}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}\right\} max, \quad (1)$$

In Equation (1) t1 indicates the beginning and t2 indicates end of the interval. In this interval, the HIC reaches its maximum. The value of a (t) is the resultant acceleration expressed in "g".

Tab. 1. Injury level in connection with HIC factor

| HIC head injury criteria | AIS code | level of concussion and head injury |
|---|---|---|
| 135 – 519 | 1 | headache, dizziness |
| 520 – 899 | 2 | unconscious less than one hours, Linear fracture |
| 900 – 1254 | 3 | unconscious 1-6 hours depressed fracture |
| 1255 – 1574 | 4 | unconscious 6-24 hours Open fracture |
| 1575 – 1859 | 5 | unconscious >25 hours large hematoma |
| > 1860 | 6 | death |

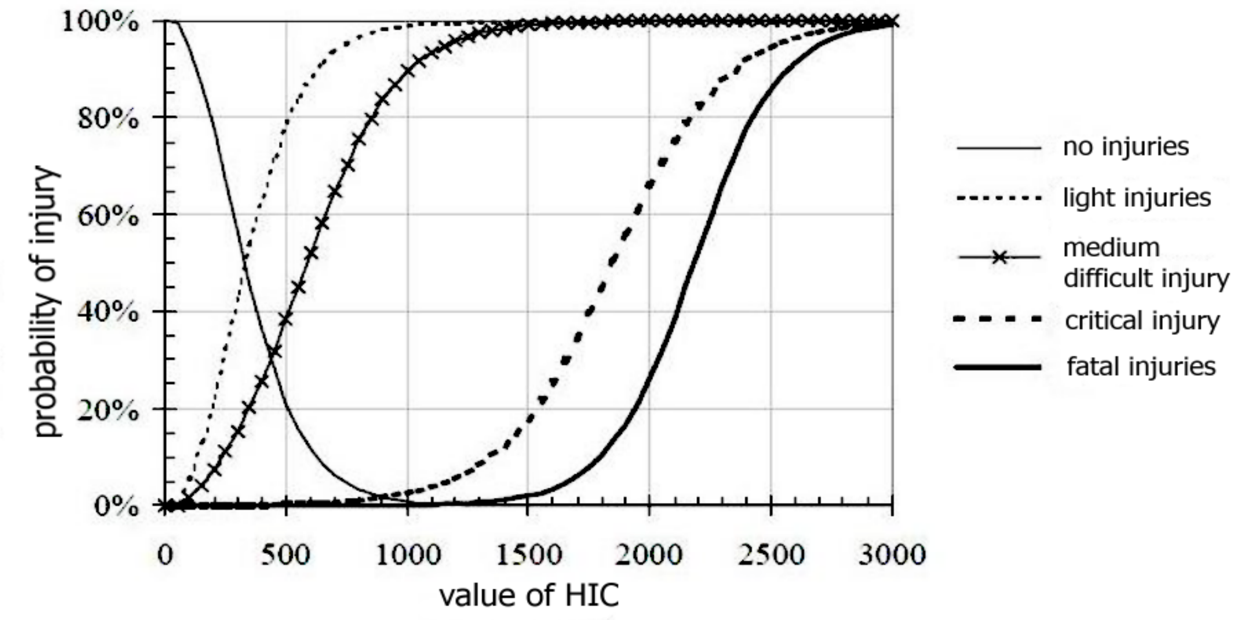



Fig. 1. Injury probability

## 4. MODEL

The numerical model of the motorcycle helmet drop test consists of three main parts: motorcycle helmet volumetric model, headform model rigid surface model, and impact plate flat rigid surface model. The rigid headform surface model was created from a solid headform model used in previous works. As a template for the helmet model, we used a helmet with the thermoplastic shell whose inner part was made of polystyrene foam (EPS). The helmet geometric model was created by 3D scanning with help of the VIU-scan hand-held scanner. The plate on which the helmet crashed during the tests was created in the LS-PREPOST application.

*4.1. Motorcycle helmet modelling*

The motorcycle helmets geometric model basis was created by 3D scanning with the handy scanner. The VIU-scan handheld laser scanner was used. This technology allows touchless 3D scanning. This scanner allows relative movement of the scanner and a scanned object during scanning process. Further, the model was modified in several applications up to the final application form.

While scanning, the helmet was covered with positional targets allowing the scanner spatial orientation. The Fig. 2. depicts the motorcycle helmet covered with all targets and the model during scanning.

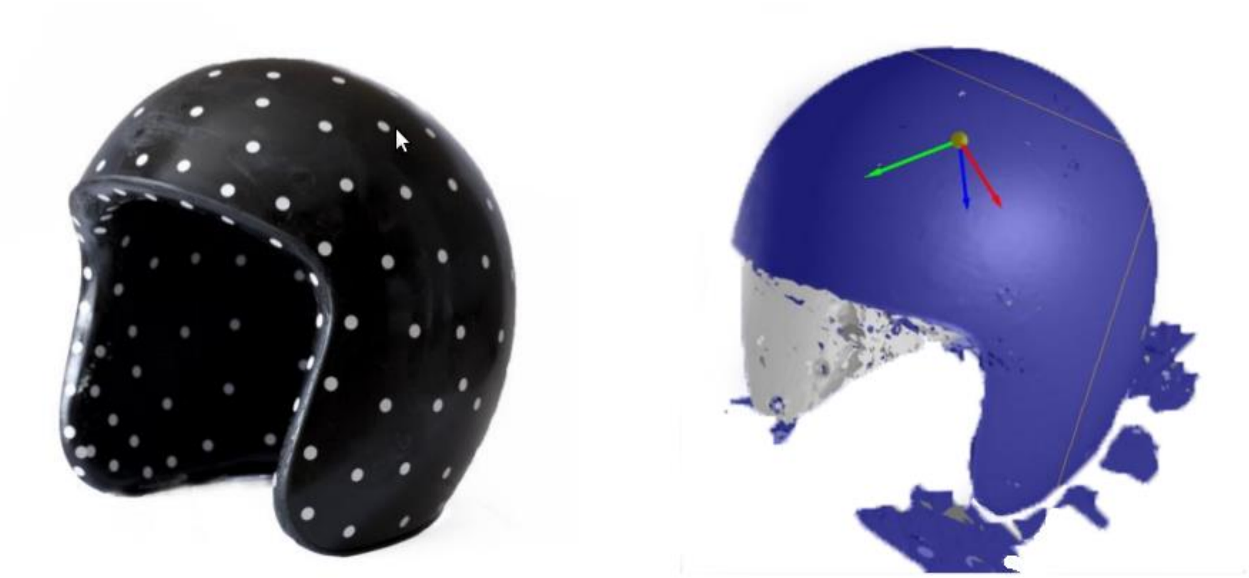


Fig. 2. Motorcycle helmet, model during scanning process

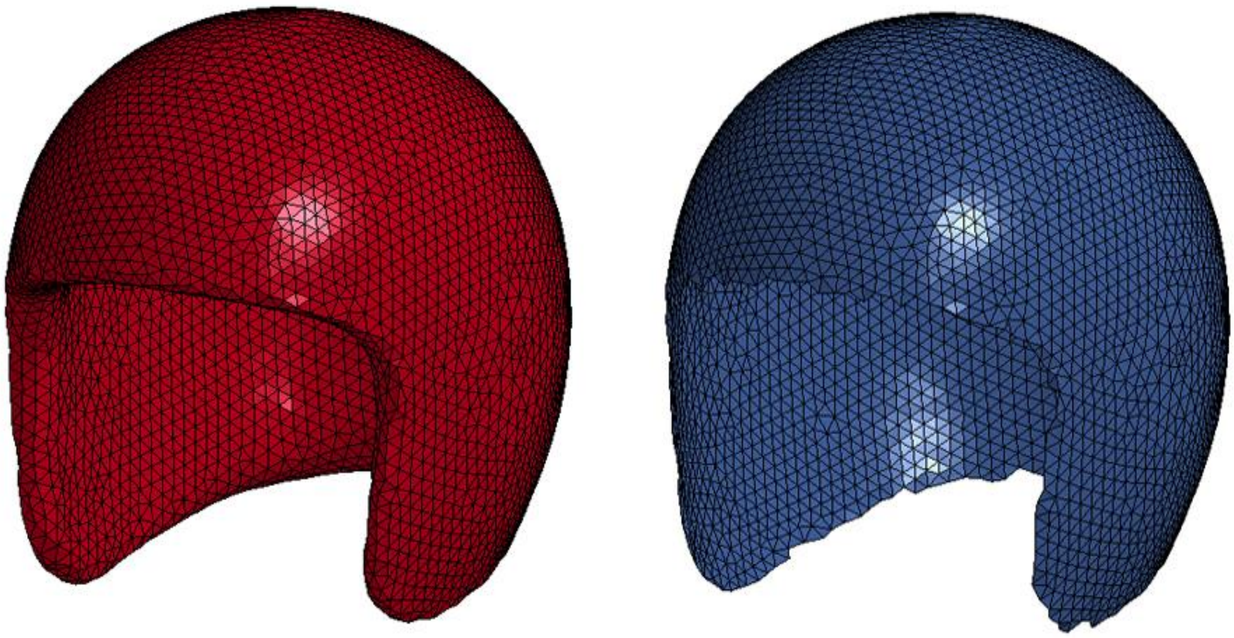
The scanned model was saved under *.stl file format. Fine errors during scanning were modified in the Blender application. The adjusted geometric model was loaded into the ANSYS ICEM CFD application. ANSYS ICEM CFD is very suitable for creating of FEM mesh models obtained from various CAD software or *.stl files. A network was set up on a geometrical model. We obtained a *.k (k-file) that was opened in the LS-PREPOST application and then it became a part of the source code in the LS-DYNA solver. In the LS-PREPOST, the volumetric FEM helmet model was assigned with material properties of polystyrene foam (Tab. 2). The shell was formed with the thickness of 3 mm on the outer model surface. The material properties of thermoplastic foam (Tab.2) were assigned to the shell. Both parts of helmet are non-contact and form one body. For illustration, they are shown separately in Fig. 3.

Tab. 2. Used materials properties

| the inner part of helmet (foam) EPS | | outer part of the helmet (shell) ABS | |
|---|---|---|---|
| Yioung's modulus | 62,73 MPa | Yioung's modulus | 3 Gpa |
| density | 85 kg/m3 | density | 1040 kg/m3 |
| Poisson's ratio | 0,01 | Poisson's ratio | 0,4 |
| maximum tensile stress | 1,3 MPa | Yield stress | 60 MPa |
| Damping coefficient | 0,2 | ultimate strength | 70 MPa |

*4.2. making headform model*

At creation of the headform geometric model we worked with the existing model used by the Department K618. The headform model was made according to the ČSN EN 960 standard addressing the issue of headforms for protective helmets testing. The used headform model and headform size-copy are shown in Fig. 4.



Obr. 3. Outer and inner helmet parts

Fig. 4. Geometric headform model and head size-copy

### 4.3. MODEL COMPILATING IN LS-PREPOST

For the drop test the non-deformable rigid base in the LS-PREPOST was created. At the rigid plate, all degrees of freedom (rotations and shifts) were fixed. The model was assembled in the LS-PREPOST application. The helmet was mounted on the headform so that it may correspond to reality (Fig.5) The headform with the helmet was placed above the impact pad.

Fig. 5 Set-up model and real situation

## 5. SIMULATION

Fall simulations were carried out in several variants. The impact on the flat surface was simulated as the first. Further, another falls were simulated on the pad turned at the angles of 15 and 30 degrees to the helmet face and of 15 and 30 degrees to the helmet nape (Fig. 6). The last simulated falls were performed on the pad turned by 15 and 30 degrees to one side to the temple (Fig. 7). The rotation was performed only in left side because the model is symmetrical and the results would be identical.

According to the standard, the helmet hits the surface from the height of 2.85 m. From the physical equations the impact velocity of 7.5 m/s was determined. The impact speed was assigned to the headform model and motorcycle helmet model.

The accelerometer is located in the headform gravity center during the drop test. A reference point was created in the model for corresponding with the headform gravity center. The acceleration was measured in the gravity center . This acceleration was measured within the time periods of 0.001 seconds. General contacts of the Automat c type – Surface to Surface – were defined on the system. The first contact was defined between the headform and helmet while the second one between the helmet and impact plate.

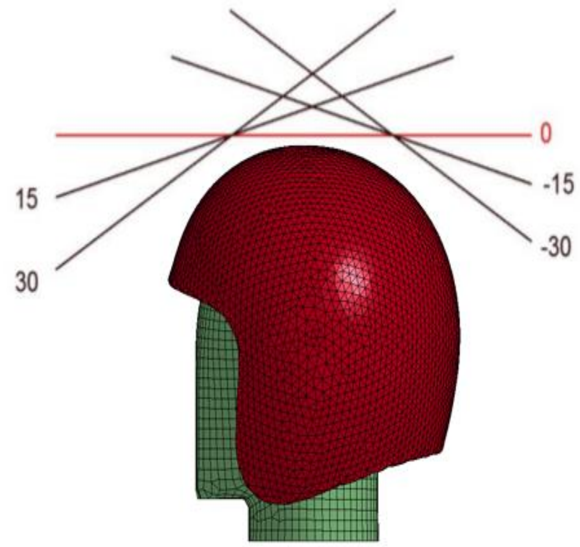



Fig. 6. Impact pad turning angles

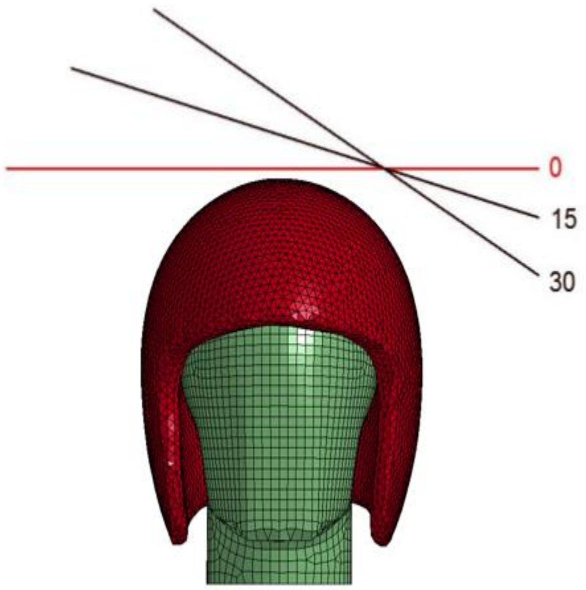



Fig. 7. Impact pad turning angles

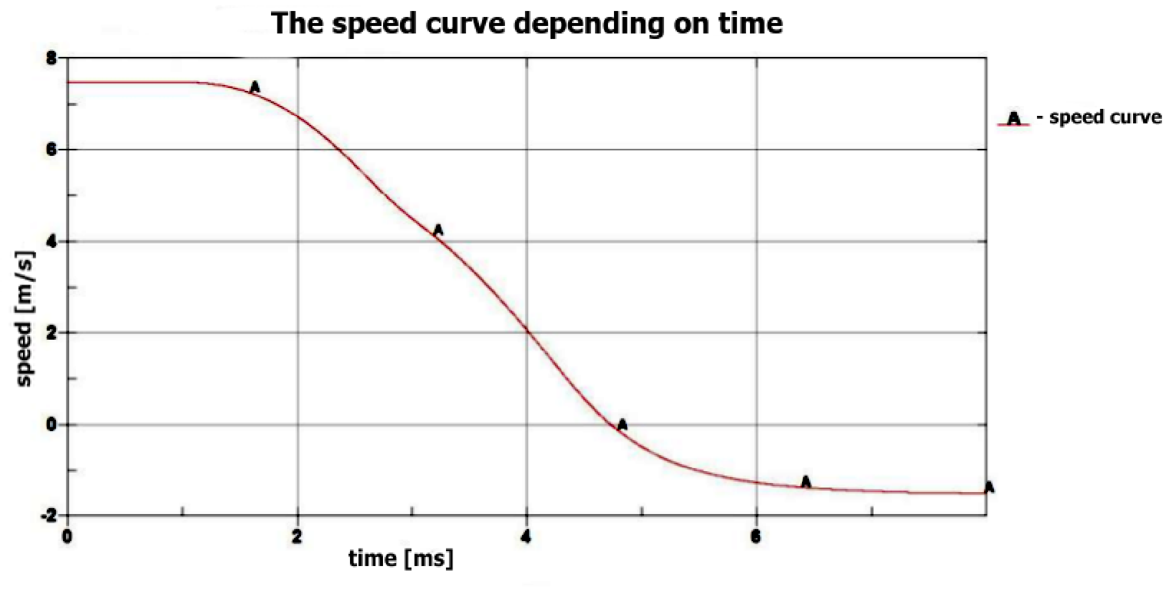
**6. RESULTS**

The results were obtained after the simulation in solver LS-DYNA. LS-DYNA provides many types of advanced analysis of the results and their software modifications. The helmet fall to the pad was paced at the period of 0.2 ms with total of 42 steps. The picture enclosure 1 shows the loading shells progress. Three selected steps before the point of maximum acceleration condition, maximum acceleration state, and three selected steps after maximum acceleration are shown. The maximum tension is reached at the contact surface between the model helmets and impact plate. The maximum voltage value is 6.04 MPa. On the picture enclosure 2., seven-step course load inside of the helmet are shown. Again, the maximum tension was reached between the model helmets and impact plate. Its value was 2.13 MPa.

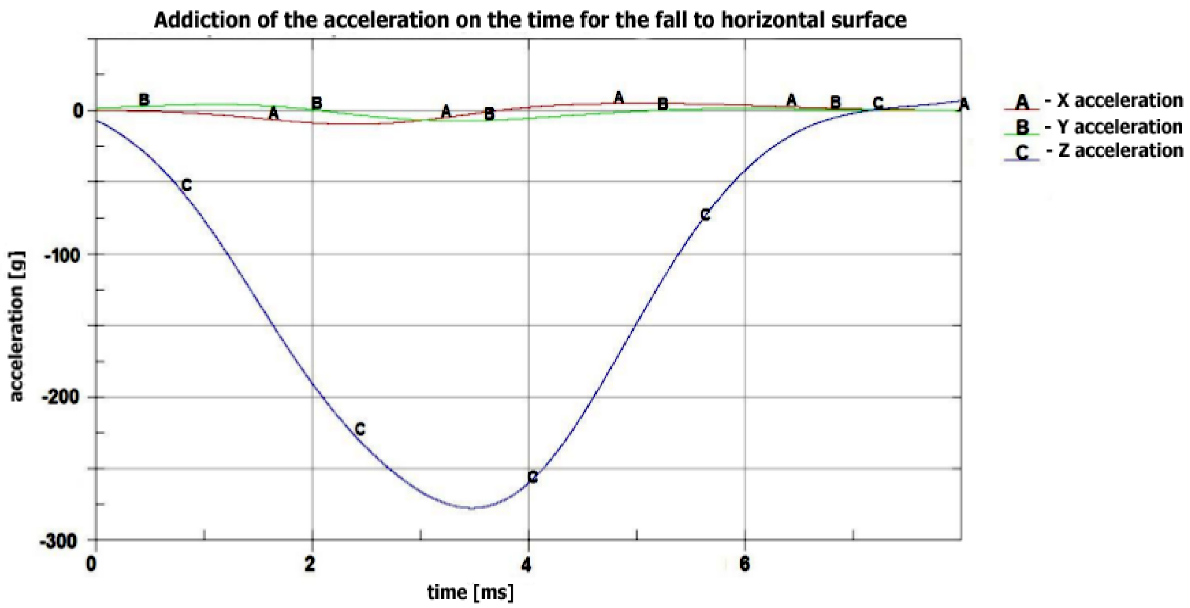
*6.1. Impact on horizontal surface*

The helmet model hit on the rigid horizontal surface by speed of 7.5 m/s. The velocity and acceleration courses were measured at the headform model gravity center . The speed curve in the headform gravity center is shown in Graph 1. Graph 2. shows the acceleration in each x,y,z axis coordinate system. The acceleration resulting progress is shown in Graph 3. The HIC factor was determined according to the procedure specified by the manufacturer shown in Graph 4.

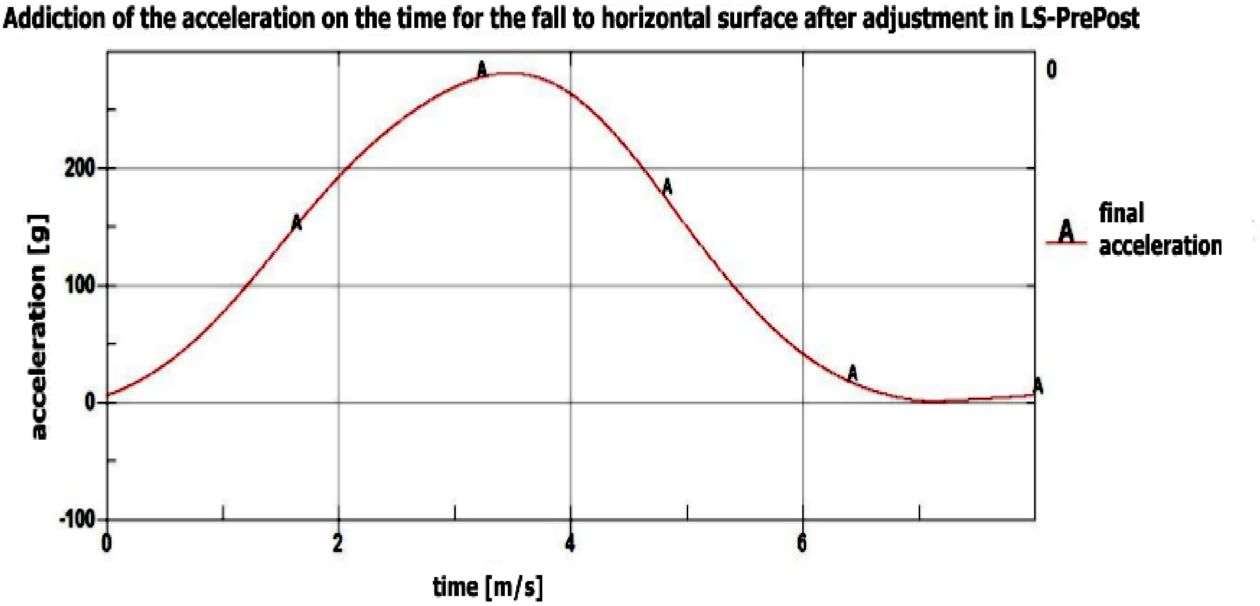
Graph 1. Velocity course




Graph 2. Acceleration course in each axes

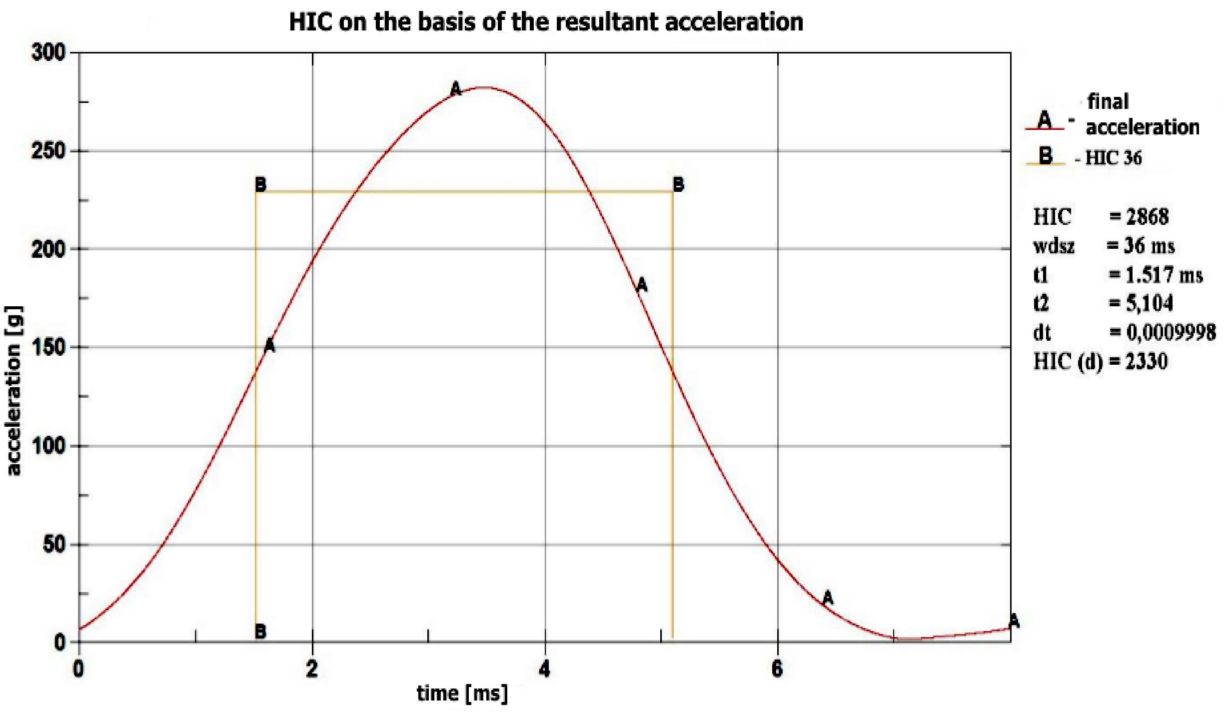


Graph 3. Resultant acceleration after LS-PrePost editation




The HIC 36 factor was used. The HIC36 calculation factor is performed in the range of 36 ms. This range is positioned on the time axis so that the HIC may become as high as possible of the whole process. Graph 4., shows the resultant acceleration course and surface representing the resulting HIC 36. The legend contains more important information to the HIC 36 criterion.

Graph 4. HIC 36



### *6.2. Impact to rotated pads*

Fall simulations to the turned pad were made similarly as the falls to the horizontal surface. The falls on the turned pad verified different acceleration values acting on the headform at different incidence angles. The supreme acceleration value was achieved at the impact on the horizontal surface. The individual HIC values are shown in Table 3.

Tab. 3.

| **HIC factors for impact to rotation pad (by Fig. 6.)** | |
|---|---|
| rotation angle [°] | HIC [-] |
| -30 | 1440 |
| -15 | 2018 |
| 0 | 2330 |
| 15 | 2028 |
| 30 | 1443 |
| **HIC factors for impact to rotation pad (by Fig. 7.)** | |
| rotation angle [°] | HIC [-] |
| 0 | 2330 |
| 15 | 2101 |
| 30 | 1553 |

## 7. EVALUATION

The work successfully validated the methodology of modeling motorcycle helmets. Procedures for drop test simulations were verified. Value of the resultant acceleration were obtained for several types of impact. Size of criteria HIC were determined from the measured acceleration values. The results show that, the helmet does not comply requirements of the standard. This finding was expected. The construction of helmet is an old type. At the time of manufacture that helmet was different evaluation criteria of safety. To verify the results, would be useful to realized drop test. Continuation of the work is planned. Simulation on new types of helmets will be made. On new types of helmets will be realized drop tests. It is planned to create a proven methodology for testing motorcycle helmets in the future.

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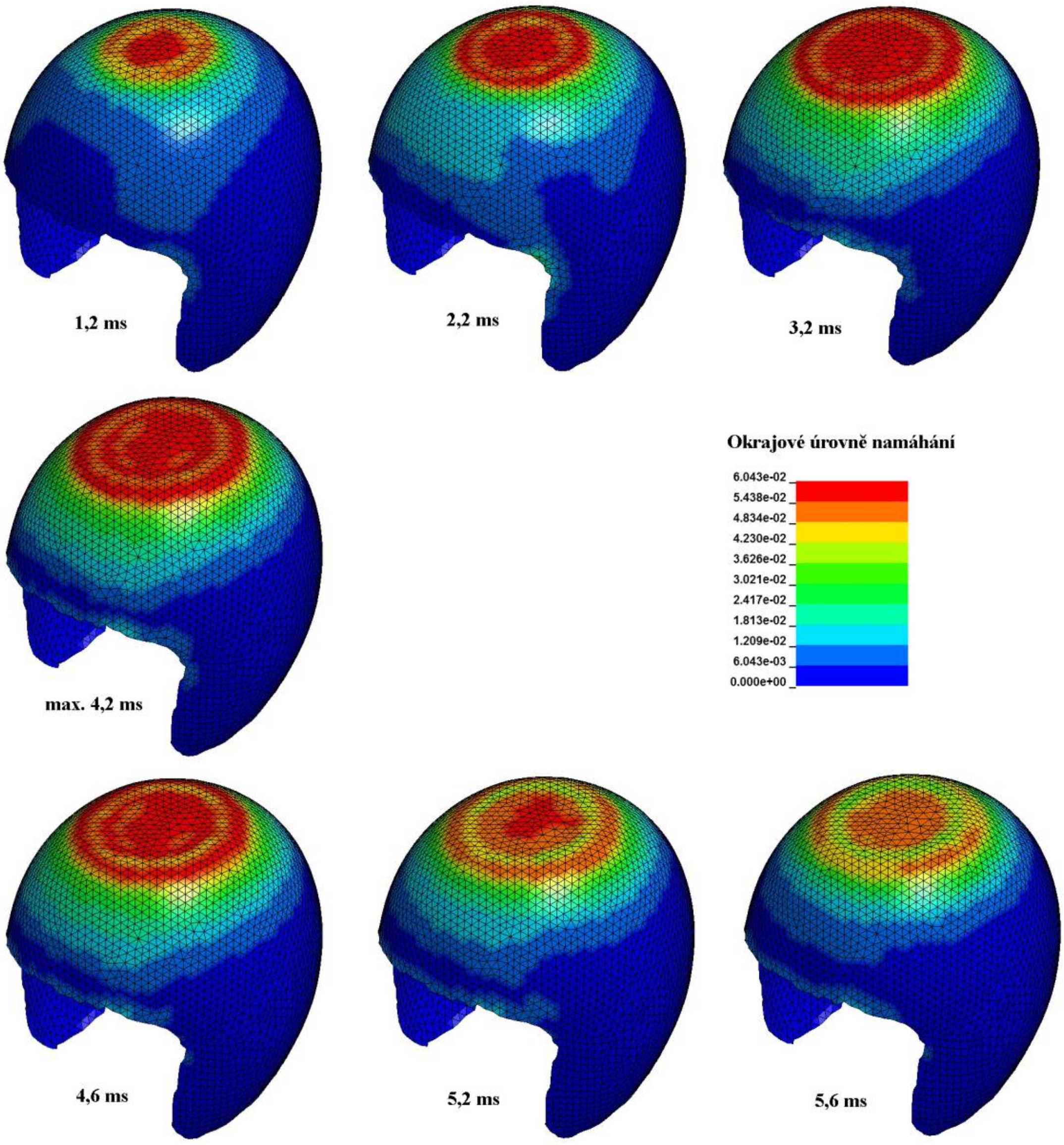
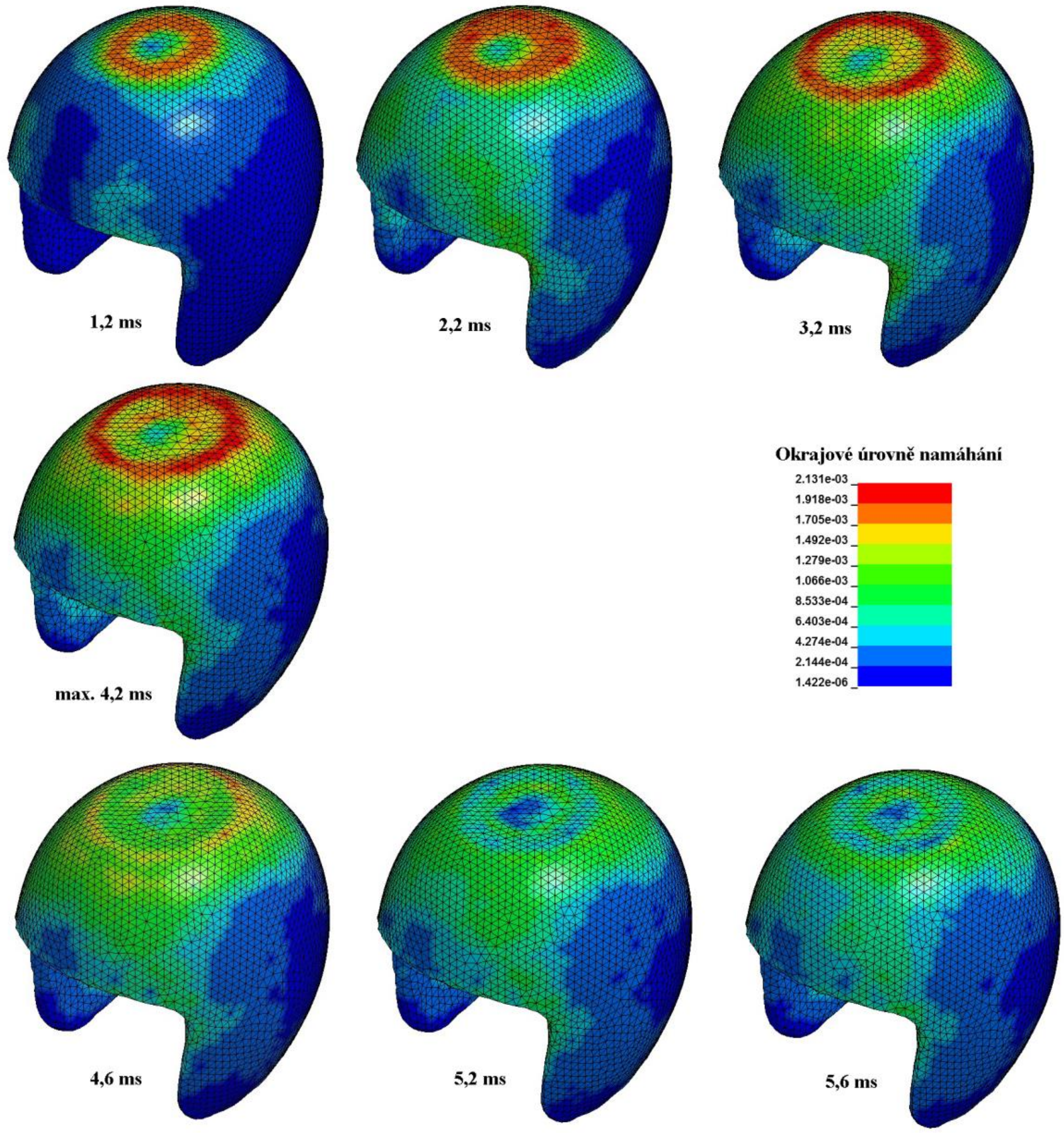
## 8. ANNEXES




picture enclosure 1 - the course of load of shell




picture enclosure 2 - the course of load of inert part

# DEPARTMENT OF TRANSPORT TELEMATICS

# K620

Department of Transport Telematics guarantees and performs education in both compulsory and elective courses on the bachelor's, master's and Ph.D.'s levels of study and in the student's projects at the Faculty of Transportation Sciences in five core branches:

- Theoretic telematics, Systems sciences
- Traffic control and modeling
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- Safety and reliability of systems, Interlocking systems
- Human factor in transportation

The education is specifically aimed at the application area of intelligent transport systems and interlocking technologies. The department guarantees study field Intelligent Transport Systems both in bachelor's and master's study programme.

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All parts of the department are open to all interested people and institutions for future cooperation.

# A Statistical Approach to Planning Reserved Electric Power for Railway Infrastructure Administration

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**Abstract**

One of the requirements on railway infrastructure administration is to provide electricity for day-to-day operation of railways. We propose a statistically based approach for the estimation of maximum 15-minute power within a calendar month for a given region. This quantity serves as a basis of contracts between railway infrastructure administration and electricity distribution system operator. We show that optimization of the prediction is possible, based on underlying loss function derived from the contract, using either a parametric or non-parametric approach.

**Keywords:** reserved capacity planning, railway infrastructure, statistical modeling, extremal distribution, customized loss function

## 1. INTRODUCTION

In this paper, we will describe a formalized statistical approach to electric power consumption planning for railway infrastructure administration purposes. The underlying problem of substantial practical importance (but also of substantial theoretical beauty) arises quite generally in front of a railway infrastructure administrator, who is regularly faced with the necessity to plan the amount of electricity to be contracted in future for the railroad infrastructure under his/her management. The horizon for the future typically means whole calendar year ahead for basic capacity planning. There is also a possibility to make month-ahead finer adjustments throughout a year.

The natural goal of railway infrastructure administrator is to estimate and contract power capacity as precisely as possible. This is because both over- and under-estimations are penalized (by increasing the total costs), albeit with different penalties. From statistical perspective, the problem is somewhat non-standard due to the fact that the penalty function is asymmetric – and the form of the asymmetry can be quite complicated, as will be shown in the body of the paper. Nevertheless, the main ingredient, typical for decision theory, Berger (1980), Schervish (1995) is exhibited here quite visibly: the goal is to minimize a given loss function in the presence of uncertainty. Therefore, we have to minimize its expectation with respect to the random variable capturing the source of uncertainty. Such a random variable can but need not be modeled by a statistical model, Gumbel (1954), Meeker & Escobar (1998). This is a framework which enables us to formalize the original hard-to-capture practical problem which has been solved informally by the Czech railway infrastructure administration (SŽDC) in the past. The main advantages of this formalization are:

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- objectivization (independence on personal views of a particular person preparing the capacity plan) – the year-ahead power consumption plan for the purpose of “capacity planning” is obtained as a solution of clearly defined optimization problem which is obtainable by means of probability and optimization theory
- optimization (choosing the decision which is optimal under clearly defined set of circumstances)
- generalizability (different loss functions arising from different electricity market regulations can be handled in a modular way, by appropriate replacement of the loss function used here)
- the loss function itself, as well as statistical model behind it are amenable to various expansions/improvements useful for data-rich environments (e.g. when longer consumption history is available for a particular railway administrator) – then one can implement e.g. various custom-made adjustments to meet particular needs of a local railroad infrastructure administrator in addition to the original loss structure given by law or contract itself (e.g. those motivated by accountant’s requirements of smooth cash flow and hence by requiring the solution to be more risk-aversive than required by law, etc.).

In the rest of the paper, we will describe a solution of the railroad infrastructure power planning problem in the settings given by the Czech legislative and tradition of contracts between SŽDC and electric power distributors. The subject of regulation (and also of contract agreements, of penalties etc.) are monthly 15-minute consumption maxima. This fact brings a whole lot of quite complex statistical problems. Nevertheless, we want to stress the full generality of the approach that is quite easily amenable to different regulations (giving rise to different loss and risk functions).

To demonstrate the feasibility of our approach, we do real-data computations in the widely accessible R system, Chambers (2008), Venables, Ripley (2000), R (2013), Therneau (2013), where we use both available packages and program few routines of our own.

The final plots and results have been rescaled to protect privacy since the data are proprietary.

## 2. Electric power and capacity planning for railway infrastructure administration

### *2.1. Criterion for contract between power distributor and railway infrastructure administrator (as a customer)*

For the purpose of the contract signing and for determining payments for the electricity consumed, an agreement between electricity distributor (as supplier) and railway infrastructure administrator (as a consumer) has to be reached on which variable the consumption measurement and pricing will be based. In the Czech Republic, the key variable to control in this context is the maximum 15-minute power reached within a given calendar month, ERU (2012). The power purchase process then proceeds in two steps. First, in December SŽDC has to plan and contract the capacity (maximum 15-minute interval power) for each of 12 months ahead. The reserved capacity is charged at a given (electricity-distributor-specific) price per MW. Then, before the end of each calendar month, adjustments to this plan can be made by SŽDC, but only in the sense of increasing the previously reserved capacity. Already reserved capacity cannot by disposed of by SŽDC. The price (per MW) for this adjustment buy is higher than for the yearly annually planned buy from the previous step.

Once a particular calendar month is over, the maximum 15-min consumption is known and any excess of the reserved capacity is penalized, according to an algorithm given by the Czech Energy Regulator Office (ERU). It comes as a function of a general form, with several price adjustment coefficients for a particular year, see e.g. ERU (2012). If we combine this penalty with the reserved capacity price, we get a *loss function* ($L$). The terminology comes quite obviously from the viewpoint of the SŽDC which we adopt in this paper. Optimization of the costs means “minimization of a loss” in some sense. The structure of the loss function is described in the section 3.1 thoroughly.

Here, we note in passing that the practical problem of capacity planning is a bit more multifaceted that it might seem from the previous description. In fact, the electricity can be bought from several different regional distributors at different voltage level and these variants, in turn differ in price per MW. Moreover, different geographical regions have different history to be taken into account in modeling and optimization. For example, in the Czech Republic, there are 10 combinations of region and voltage level to consider. This needs more computations, but no theoretical nor statistical complications are added. All this means that each of the “regions” (in fact combinations of region and voltage) has to be fitted and optimized separately, i.e. all computations are stratified this way.

*2.2. Statistical analysis of how the electricity consumption depends on various covariates explanatory variables*

Before attempting loss optimization, it is necessary to explore various covariates upon which the control variable (maximum 15-minute power within a calendar month, say MQPCM for short) can depend. This might help to make the subsequent analyses and optimizations more precise or more efficient.

To explore the systematic effects of various covariates upon the MQPCM, we set a formalized statistical model. It is quite obvious that to explore influence of an explanatory variable (say *X*) upon dependent variable MQPCM (say Y), we should work with a regression model. On the other hand, it is quite clear that standard assumptions for the linear Gaussian regression model are not suitable here, Rawlings (1988), Graybill (1976). For instance, the random errors are not homoscedastic. The MQPCM's have highly skewed distribution. In fact, from the very definition, we are dealing with extremal distribution (distribution of maxima) which is by its very nature very much different from normality.

As usual, we should be (and we actually are) driven here by the common-sense imperative "a model should be brought closer to the reality rather than reality being forced to approach a model at hand".
In this context, quite obvious candidate for a model which would respect salient features of the MQPCM behavior is a regression with extremal distribution (of maxima, i.e. with the so called Gumbel distribution) for the random errors, Meeker & Escobar (1998), Gumbel (1954). The Gumbel distribution of a variable *Y* has the following density:

$$f(x;\mu,\sigma)=\frac{1}{\sigma}.\phi_{LEV}\left(\frac{x-\mu}{\sigma}\right) \tag{1}$$

where $\mu,\sigma$ are parameters (to be estimated from the data) and $\phi_{LEV}(x)$ is given as:
$\phi_{LEV}(x)=\exp(-x-\exp(-x))$.

We then have the statistical regression model (more general than the "usual" linear regression):

$$Y_t \sim LEV(\mu_t,\sigma) \tag{2}$$

where $Y_t$ is observed MQPCM at month *t*. Time-dependent $\mu_t$ is then given as a linear function of covariates ( $x_1,\ldots,x_K$ ) with unknown coefficients ( $\beta_0,\beta_1,\ldots,\beta_K$ ) to be estimated from data:

$$\mu_t=\beta_0+\sum_{k=1}^{K}\beta_k.x_{kt} \tag{3}$$

As for the estimation of the parameters, we use the method of maximum likelihood, Schervish (1995), Meeker & Escobar (1998) with its numerous superior theoretical and practical advantages. For the numerical estimation, we utilize the R package survival, Therneau (2013).

As the electricity consumption for the railway infrastructure is obviously seasonal (more heating in colder months, different amounts of traffic volumes in different parts of a year), the first choice of the explanatory variables are the indicators of months (in the style of ANOVA or analysis of variance models, Graybill (1976)):

$$\mu_t=\beta_0+\sum_{k=1}^{12}\beta_k.I(t\,corresponds\,to\,month\,k) \tag{4}$$

where $I(.)$ is an indicator function (assuming value 1 if the condition in its argument is true and zero otherwise). For uniqueness, we have to impose an identifiability restriction (just as in the ANOVA models), say $\beta_1=0$ . Fit of the model (2), (4) can be seen in Fig 1 for one particular region. Vertical (consumption) axis has been rescaled to respect privacy of data which are proprietary. One can see that the model fits reasonably well, except perhaps for occasional outliers caused by unpredictable events of large magnitude.

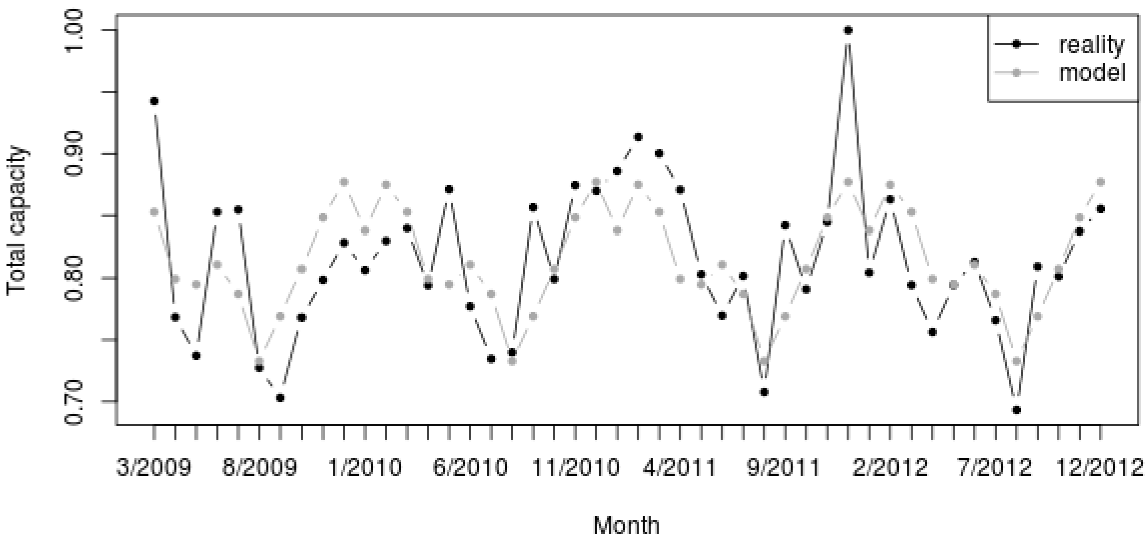


Fig. 1. Model (2), (4) and raw data (time series of MQPCM from a particular region)

Since it is natural to expect that the annual periodicity just detected is caused mainly by weather, we analyzed the influence of various meteorological variables (temperature at two heights above the ground, wind speed) upon MQPCM series. The meteorological data were obtained from high-quality MERRA database which consists of state-of-the-art NASA reanalysis results, Reinecker (2011). The data were pre-processed by careful spatial averaging to match various distribution regions. Quite naturally, we considered monthly aggregates of meteo data in the MQPCM regressions (by adding more variables in the style of the general model (3)). Surprisingly, addition of the meteorological variables into the model did not bring significant improvement over the simple seasonality model (e.g. the p-values obtained from asymptotic likelihood ratio test were 0.3190 and 0.2300 for monthly minimal temperature and monthly maximal windspeed, respectively).

This does not mean that the railroad infrastructure electricity consumption is independent of weather conditions, however. On the contrary, careful non-parametric analysis shows quite detailed trend e.g. in consumption versus temperature on the 15-min level, see Fig. 2. From the loess, Cleveland et al. (1992) fit there, we can see that there is a definite downward trend in the consumption with increasing temperature up to about 12 degrees, as expected. The increasing right part then reflects (quite subtle and a priori unsuspected) effect of cooling. Detailed, physically interpretable features of the dependence have been successfully recovered also for windspeed despite the fact that the random variability around the trend is substantial.

In summary, there is an important general lesson to take here: weather influences the consumptions on the 15-min data level (which can be used for other purposes than monthly capacity planning), but at the monthly aggregate level (especially at the monthly maximum functional which is much more subtle than e.g. monthly means), the influence is rather week and cannot be easily used for predictions and subsequent optimization.

## 3. Optimization of a given loss function with respect to the capacity to be contracted

### *3.1. Loss function and derivation of the risk function to be optimized*

The loss function (i.e. the cost induced to the SŽDC by a particular choice of monthly maximal power contract) is given by the following formula:

$$L(Y,k;c_m,c_y) = I(k < Y \leq 1.1k).(Y-k).c_m + I(1.1k < Y).(Y-k).4.c_y + k_m.c_m + k_y.c_y \qquad (5)$$

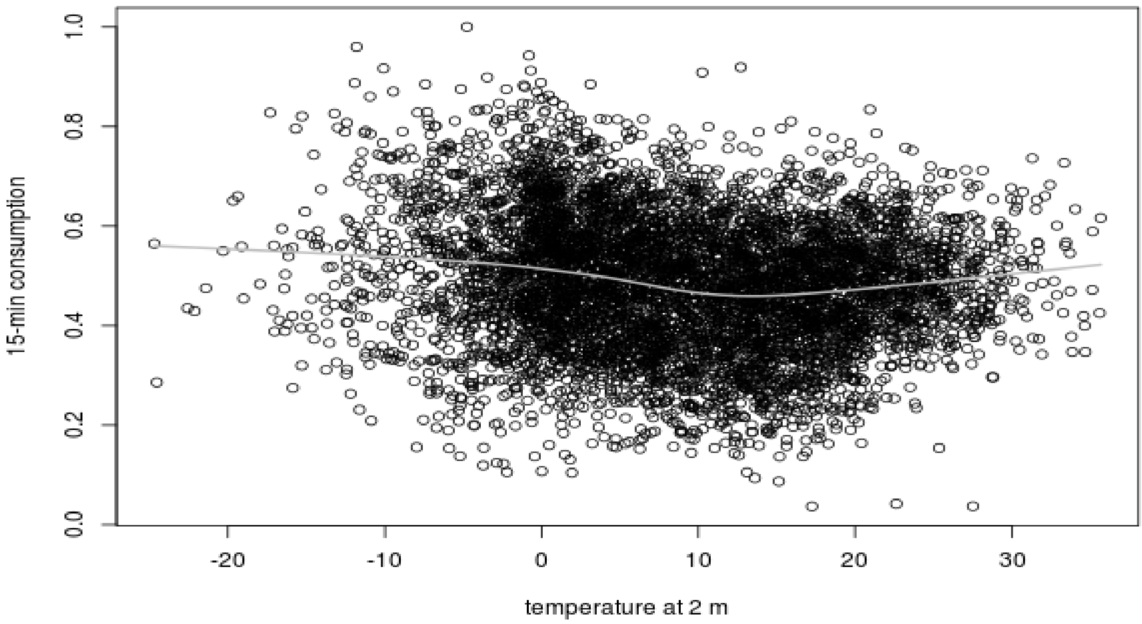


Fig. 2. 15-min electricity consumption versus temperature at 2m for a particular region. The fitted curve obtained by the nonparametric loess smoother, Cleveland et al. (1992) is superimposed. Random subset of data is depicted for better visibility.

with the restriction $k = k_m + k_y$ . Variable $Y$ corresponds to the MQPCM. That is a random quantity, whose value is not known ahead. Constants $c_m, c_y$ are prices per MW for monthly respectively yearly power capacity purchases. They can be considered as parameters determining a particular decision problem within the family of problems given by (5). The prices are given by the Energy regulator annually in the Czech Republic, see e.g. ERU (2012).

Because of the presence of random variable $Y$ in the loss definition (5), $L$ cannot be used for optimization directly. Instead, we consider its expected value (which we will call risk function, in accord with standard terminology, Schervish (1995)):

$$R(k; c_m, c_y) = E_Y\, L(Y, k; c_m, c_y) \tag{6}$$

The risk function (6) is what we optimize with respect to $k$ (which correspond to the planned capacity sought), for given prices $c_m, c_y$ . The optimization is done for each month separately yielding $k_1, k_2, \ldots, k_{12}$ . Then we take $k_y = \min_{l=1,\ldots,12} k_l$ and $k_m$ by subtraction.

### *3.2. Parametric statistical model based on extremal (Gumbel)distribution*

Although the optimization of the risk function (6) with respect to unknown $k$ is quite straightforward, at least in principle, the computation of the risk itself is not so easy. One possibility is to use the extremal model (1) and evaluate the $E_Y$ expectation operator with respect to the Gumbel distribution (with parameters estimated from the data).

$$R_{G,a}(k; c_m, c_y) = \int f(y; \hat{\mu}_a, \hat{\sigma}).L(y, k; c_m, c_y)dy \tag{7}$$

where $f(y, \hat{\mu}_a, \hat{\sigma})$ is the Gumbel density (1) evaluated at the parameter estimates for month $a$ ($a = 1,2,\ldots,12$) from the seasonal (i.e. monthly) model (2), (3). In fact, we use maximum likelihood estimates (MLE's) here.

In the context of our model (4) and in view of the structure of the loss function (5), evaluation of (7) essentially means to compute partial moments of the Gumbel distribution (plus cumulative distribution function which is easy). Integrations for evaluation of partial moments are not straightforward here and one can resort to numerical integration routines.

The results are relatively good for some of the 10 Czech regions, but not uniformly so. In fact, there are regions where the optimization of the risk based on the fitted seasonal Gumbel model is substantially worse than an ad hoc solution adopted in previous years without any theoretical justification. After substantial effort, we found that the occasional problems are not caused by the numerical integration (whose working horse is based on the R native function integrate), but by the occasional wild observations present in the data which might spoil the Gumbel fit. While the Gumbel distribution fit is OK in general (respecting most salient features of empirical data distribution), it cannot cope easily with occasional fat right tails that cannot be accommodated by the two-parametric model only.

To that end, we sought for a more flexible alternative of the optimization based on a distribution which would not be so tight by a priori assumptions which can go wrong occasionally in an hard-to-control way. This alternative route is described in the next section.

*3.3. Non-parametric (empirical) statistical model*

A flexible (nonparametric) alternative to the Gumbel-based optimization from the previous section is to evaluate the expectation operator $E_Y$ in the risk function (6) using the empirical cumulative distribution function (CDF). Integrating with respect to the empirical CDF is easy (it means essentially to compute empirical averages of appropriate indicators and truncated data). To this end, we stick to the seasonal model and do the optimization with respect to seasonally (monthly) estimated CDF, quite in line with the general stratification approach outlined at the beginning of the section 3. For a given month, we have:

$$R_{empirical,a}(k;c_m,c_y) = \frac{\sum_{b=1}^{B} L(Y_{b,a},k;c_m,c_y)}{B} \quad (8)$$

where $Y_{b,a}$ is monthly maximum in the year *b* ( $b = 1,2,\ldots,B$ ) and month *a* ( $a = 1,2,\ldots,12$ ). Quick inspection of the structure of the loss function (5) reveals that $R_{empirical}$ , taken as a function of *k* is piecewise linear, changing its slope either at data points or at their 1.1 fractions. This helps in the implementation of the optimization substantially. Fig. 3 shows an example of such a function for a sample of data from a particular month and region.

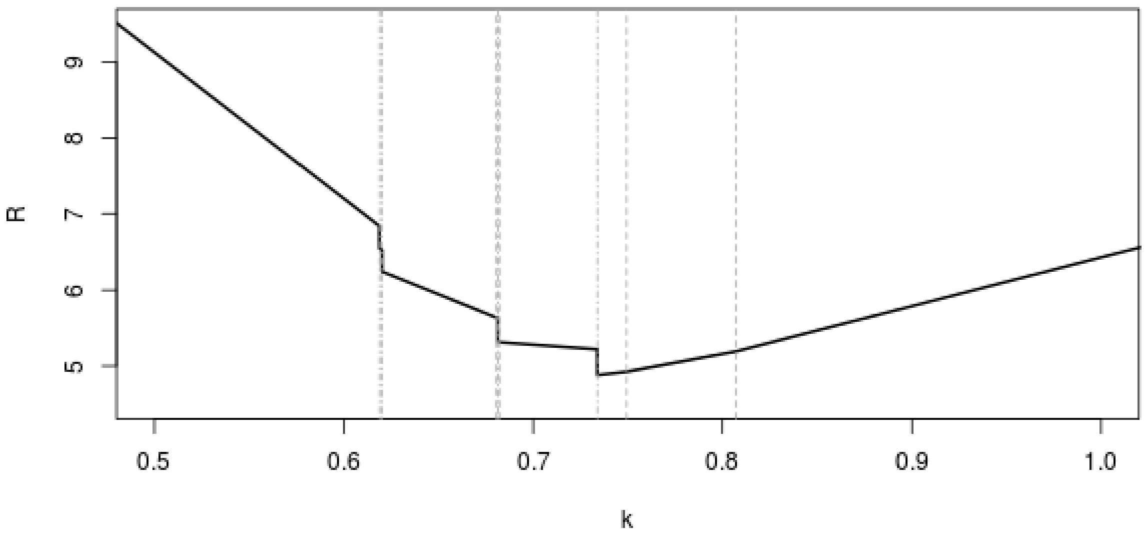


Fig. 3. Empirical risk function, $R_{empirical}$ .from (8), taken as a function of *k (datapoints and their 1.1 fractions are marked by vertical lines).*

It is easy to perform the optimization for a given month and a given distribution region and then derive $k_y, k_m, m = 1,2,\ldots,12$ as described at the beginning of the section 3. One of 10 Czech distribution regions was a priori not suitable for conducting statistically based optimization whatsoever kind, since this region experienced heavy structural break in the past (change from electric traction to diesel traction). This prevents any reasonable statistical learning from the past about present and future and calls for expert opinion based on recreational diesel schedule planning.

For the other 9 regions we computed the optimized capacities and compared them to the "traditional" solution obtained by ad hoc means. Fig. 4 compares the reserved power capacities (reserved MQPCM) for traditional solutions, optimized solutions and actual MQPCM as functions of calendar month *m* for a particular region. From there, we can see that the optimized solution tends to be closer to the actual MQPCM than the traditional. Even though it gets occasional penalty for under-reservation, overall it saves on cutting the over-reservation typical for the traditional solution. This (quite desirable) behavior is qualitatively similar to the other regions.

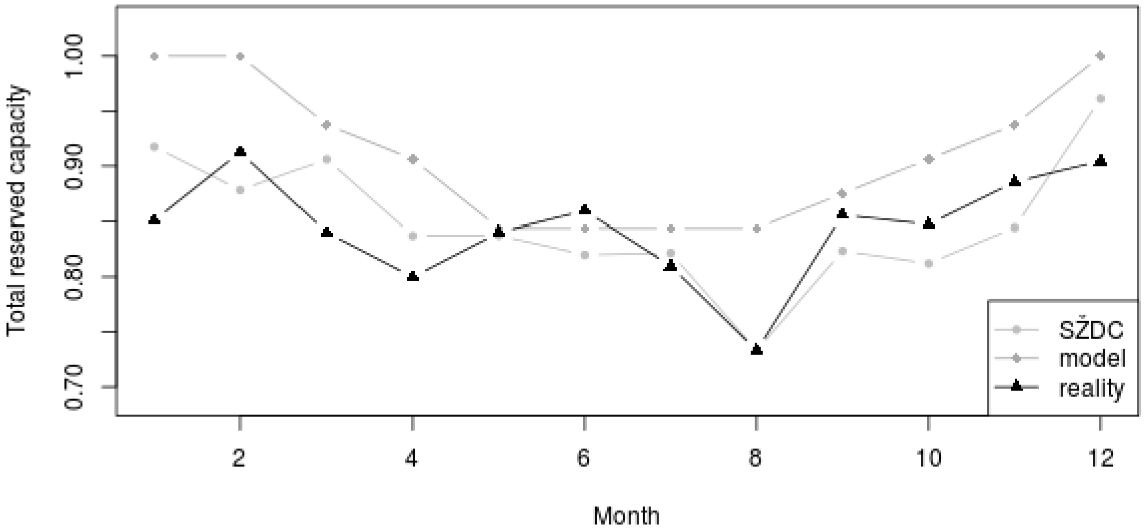


Fig. 4. Reserved power capacities for a given region by month. Comparison of traditional,

Table 1 shows total costs (i.e. total loss function (5) which includes both reserved capacity prices and under-reservation penalties) for 2012 data and compare them between traditional and optimized (fitted) solutions. The values of the costs were originally in monetary units (millions of Kč), but they have been rescaled to preserve privacy of the proprietary data. From the Table 1, we can see that the optimized solution indeed goes in the direction of non-negligible savings for most of the regions (one exception is a reminder of the random nature of the data and subsequent procedure based on them).

Table 1. Costs for different reserved power solutions and % of savings obtained on fitted data

| Region | Traditional solution | Optimized solution | % of savings |
|---|---|---|---|
| 1 | 0.592 | 0.566 | 4.43 |
| 2 | 0.338 | 0.318 | 5.95 |
| 3 | 1.000 | 0.952 | 4.75 |
| 4 | 0.375 | 0.357 | 4.68 |
| 5 | 0.187 | 0.178 | 4.44 |
| 6 | 0.291 | 0.267 | 8.12 |
| 7 | 0.119 | 0.120 | -0.67 |
| 8 | 0.370 | 0.364 | 1.65 |
| 9 | 0.050 | 0.047 | 5.83 |

**Acknowledgements**

The authors would like to acknowledge fruitful, friendly and expert cooperation from the railway infrastructure administrator, SŽDC, support from the UI-FD research and development project (financed by RIA/SZDC).

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# Line Emission Model above the Czech Highway Network

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**Abstract**

The paper focuses on the description of design of the original linear model of the emission load. Discussed model, built on wide input information, is capable to determine the emission load from road vehicles (mobile sources) in the vicinity of the road and motorway network, where highway toll gates are localized. The main goal of the work was to create an original functional model application, which is able to process available traffic data to fully utilize the important parameters affecting the production and the amount of the emission load from the road traffic. Main input of the mobile sources emission load model is represented by data, which are gathered on highway toll gates situated on motorways of the Czech Republic (primarily for traffic intensity assessments). All these data are collected on the server of the Telematic application. The Telematic application runs under the Czech Technical University in Prague, at the Faculty of Transportation Sciences. The work defines important input parameters of the model in terms of the transportation itself, parameters of the road and motorway network construction and the transport design. Moreover, the discussed work describes the proper mathematical model, which has been fully tested and written into the final program script created for MATLAB, The MathWorks. The program is designed as a computer application for reading and processing input information, to communicate with the model and for the interpretation of results. Outputs are created by mathematical numerical matrices and illustrative graphical emission space-time maps.

**Keywords:** model, emission load, transport, road mobile sources, toll gates

## 1. INTRODUCTION

The reduction of the emission load is one of the targets of the planning of the transportation infrastructure at the national level as well as at the local level. For dealing with the environmental pollution it is necessary to understand existing processes of pollution, be able to identify specific sources of pollution, be able to record and measure the factors of the pollution, etc.

Currently, in research area of the emission load estimation and modeling from mobile sources in the Czech Republic exists a description of methodology of a very simplified model based on a data which involve just some of the important input parameters ("Emission Load Estimation and Modeling in Relation to the Real Traffic Input Data" [1]). The USA state project MOBILE6 Vehicle Emission Modeling Software [2] shows on its project web site complete support for their environmental model. The model is specifically designed for the conditions of the US countries and the model usage in the different countries does not involve all the parameters in the applicable way. The best approach to the solution of the same research covers the article "The Integrated Computer System for Modeling of Air Pollution Based on the Digital Data" [3]. The paper shows the rough description of the integrated computer system for the car emission load modeling and the load spread.

This presented paper shows the final results of the PhD thesis „Emission Load Modeling Caused by Road Vehicles in the Vicinity of the Road and Highway Network Toll Gates“ [4] developed at the Czech Technical University in Prague, Faculty of Transportation Sciences, by one of the authors, Ing. Přemysl Derbek, Ph.D. The results present an expansion of the strategy of the transport assessment not only in terms of the operational effectiveness, but also in terms of the environmental protection. Therefore the work has an importance for the following areas of transport and environmental engineering: impact on new infrastructure, planning of work zones, reduction schemes of traffic/emission load, setting of production limits for carbon emissions, situation comparing before and after analysis, analysis of the following years.

The work focuses on the design of the original linear model of the emission load. The model, built on specified input parameters, is capable to determine the emission load from road vehicles (mobile sources) in the vicinity of the road and motorway network, where highway toll gates are localized. The main goal of the research was to create an original functional model application, which is able to process available traffic data to fully utilize the important parameters affecting the production and the amount of the emission load from the road traffic.

## 2. Model

Main input of the mobile sources emission load model is represented by data, which are gathered on highway toll gates situated on motorways of the Czech Republic (primarily for traffic intensity assessments). All these data are collected on the server of the Telematic application. The Telematic application runs under the Czech Technical University in Prague, at the Faculty of Transportation Sciences.

The work defines important input parameters of the model in terms of the transportation itself, parameters of the road and motorway network construction and the transport design. Moreover, the work describes the proper mathematical model, which has been fully tested and written into the final program script created for MATLAB, The MathWorks.

The program is designed as a computer application for reading and processing input information, to communicate with the model and for the interpretation of results. Outputs are created by mathematical numerical matrices and illustrative graphical emission space-time maps.

The model testing was performed on the data of intensities of heavy vehicles over 12 tons and buses. However, the model is able to work with complex input data containing all different classes of vehicles. The model is universal. The spatial and time resolution of this linear emission model along the chosen route is 100 meters according to the route stationing, in the axis of time resolution is in hours, always for specific day and the specific year.

### *2.1. Mathematical Core*

The aim of the emission load model is to process mainly already captured traffic data to reach the results for these main measurable pollution factors: NOx, NO2, SO2, C20H12, PM, PM10, CxHy. The concept of the model is prepared as follows.

The emission load for one direction of the constant velocity traffic flow $E_{dtpi}$ for day type *d* (Mon, …, Sun), time of day *t*, pollutant *p* and road inclination *i* is estimated using the model

$$\boldsymbol{E_{dtpi} = I_{dt} \times e_{pi}} \tag{1}$$

Symbol $I_{dt}$ denotes the average of the traffic intensities in both directions for the given day type and time of day. By $e_{pi}$ we denote a coefficient corresponding to a selected emission factor and given road inclination. (Coefficients *e* may depend, in general, on the car type and velocity, too. In this step, the model is simplified, considering only registered heavy trucks at constant 80 km/h speed.)

For the emission load over the entire section of both traffic flow directions with varying car velocities, the model uses the following equation

$$\boldsymbol{E_{dtpirs} = \sum_{s=1}^{N} (I_{dts} \times e_{pirs})} \tag{2}$$

Where, in addition, *r* is the velocity of the corresponding traffic flow in respective section of the road in [km/h], *s* is selected side of the traffic flow and *N* is the summary count of the traffic flows (equal to two, naturally).

### 3. Results in Examples

The model of the line emission load is generally presented by selected graphical examples. These examples, beside the data sets in matrices, are composed into the time-special graphs. Therefore the total output sets generated by the mathematical model always include all sub-models related not only to the selected track, the type of day, but also to one of the chosen emission factor.

As already written, each emission load model depends on the selected track, above which was this model calculated. On the shown map, all modeled tracks are highlighted.

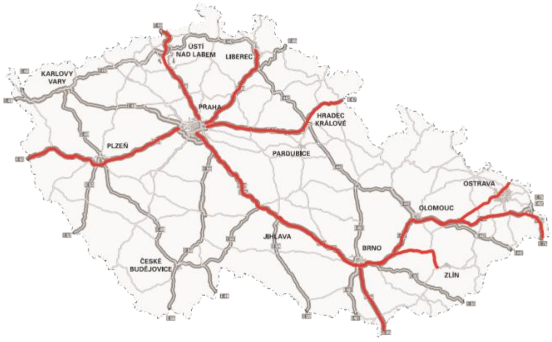


Fig. 1. All tracks involved in the processing of the emission load models above the Czech Republic [5]

#### *3.1. Model Praha – Otrokovice (D1 + R55)*

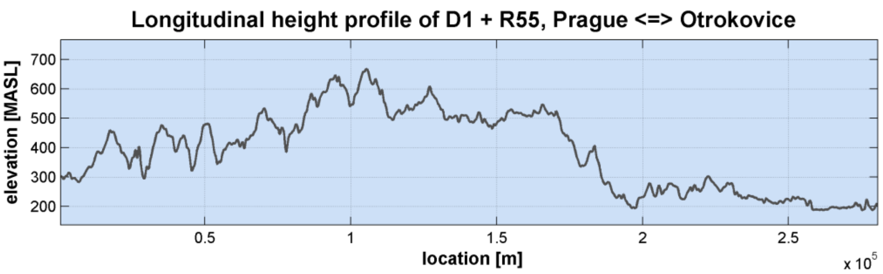


Fig. 2. Road altitude profile along the track Prague - Otrokovice, D1 + R55

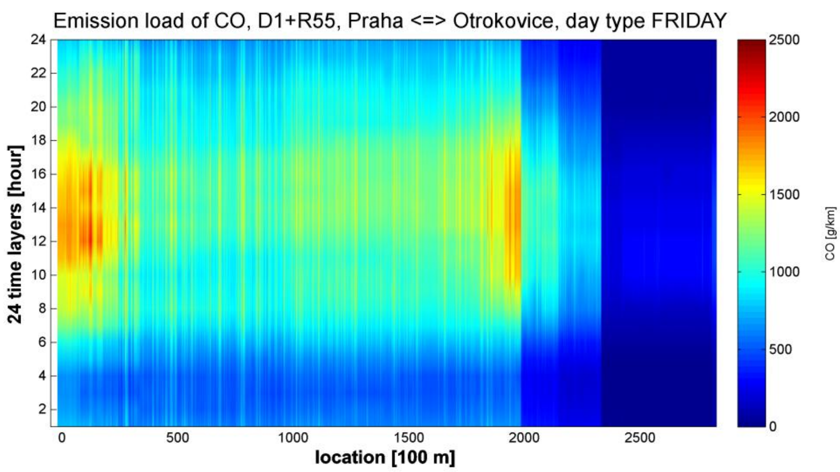


Fig. 3. Surface representation of the CO emission load model from automobiles over the 12 tons of weight and buses for Friday day type in 2009 over the track Prague - Otrokovice, D1 + R55

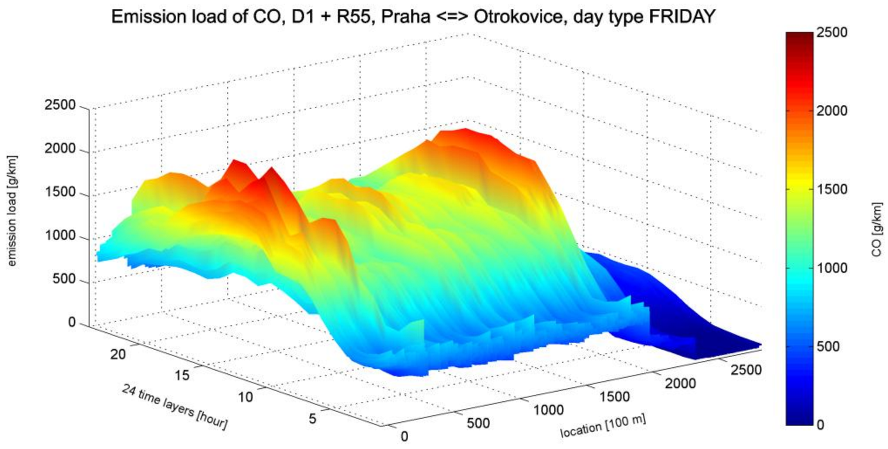


Fig. 4. Spatial representation of the CO emission load model from automobiles over the 12 tons of weight and buses for Friday day type in 2009 over the track Prague - Otrokovice, D1 + R55

### *3.2. Model Praha – Rozvadov, D5*

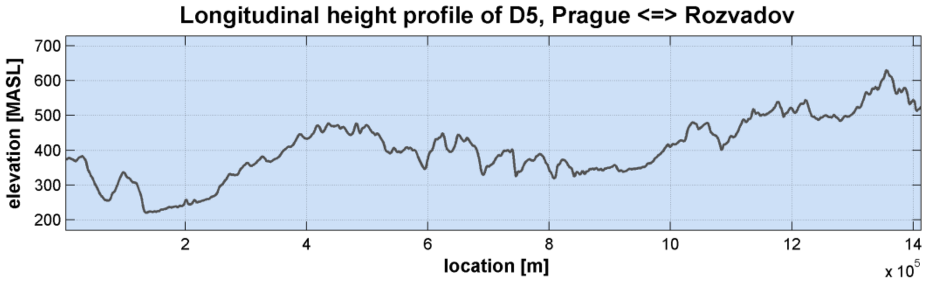


Fig. 5. Road altitude profile along the track Praha – Rozvadov, D5

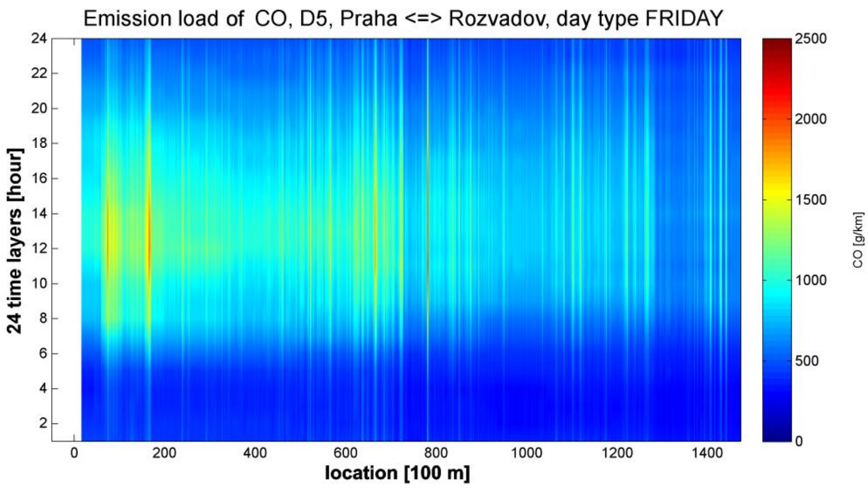


Fig. 6. Surface representation of the CO emission load model from automobiles over the 12 tons of weight and buses for Friday day type in 2009 over the track Praha – Rozvadov, D5

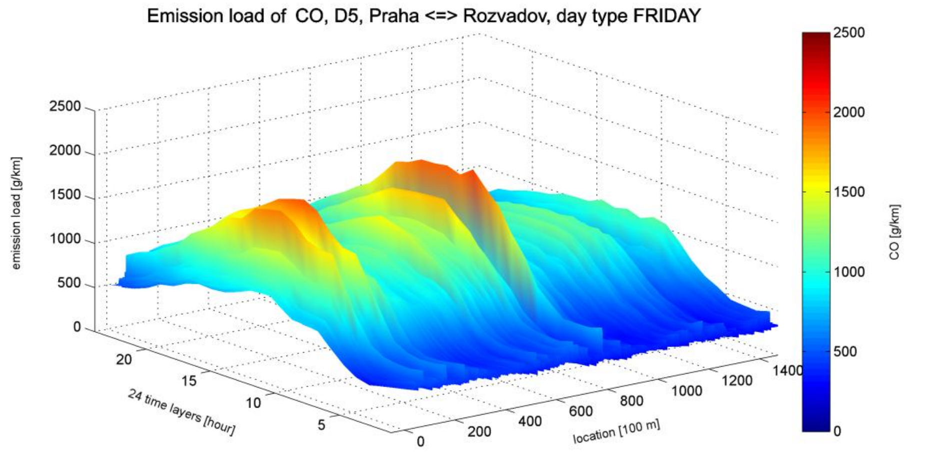


Fig. 7. Spatial representation of the CO emission load model from automobiles over the 12 tons of weight and buses for Friday day type in 2009 over the track Praha – Rozvadov, D5

## 4. REZZO 4

Furthermore, the model and its results, respectively, are compared with available application related methods of processing emission load from vehicles. Such emission models from mobile sources prepared for the Czech Republic (CR) are generated in the Register of Emissions and Sources of Air Pollution from Mobile Sources (REZZO 4) as the total annual emission sums divided by the monitored subareas of the total area of the CR. The Czech Hydrometeorological Institute (CHMI), which manages the REZZO 4 database and data processing, provided me kindly with the emission map of the Czech Republic for the year 2007 with a spatial resolution of emission values in 5x5 km2 to this comparison. Time resolution of modeled data, as already mentioned, is one year. This emission model is based on traffic counts of the year 2005.

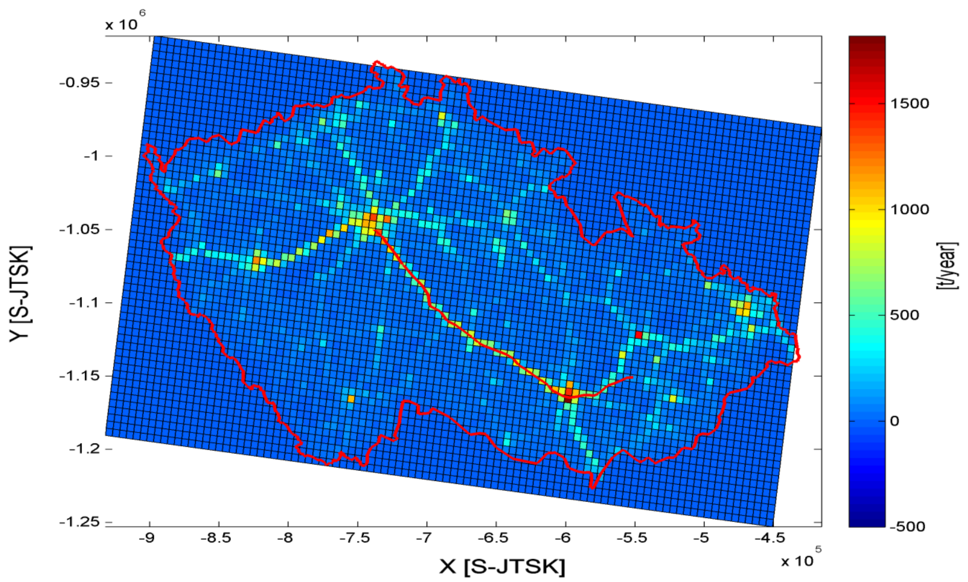


Fig. 8. Surface representation of the REZZO 4 data analysis of the complex CO emission load from mobile sources above the Czech Republic from 2007

Outputs of the PhD thesis can be used to develop the existing systems for emission modeling. In the Czech Republic it is mainly REZZO (complex Register of Emissions and Air Pollution), which is the official CHMI database used for estimates and models of the emission load. Registry creators and the responsible staff in CHMI are seriously interested in the results of this research and therefore there are high hopes, that these results will be used to improve the emission modeling in the Czech Republic.

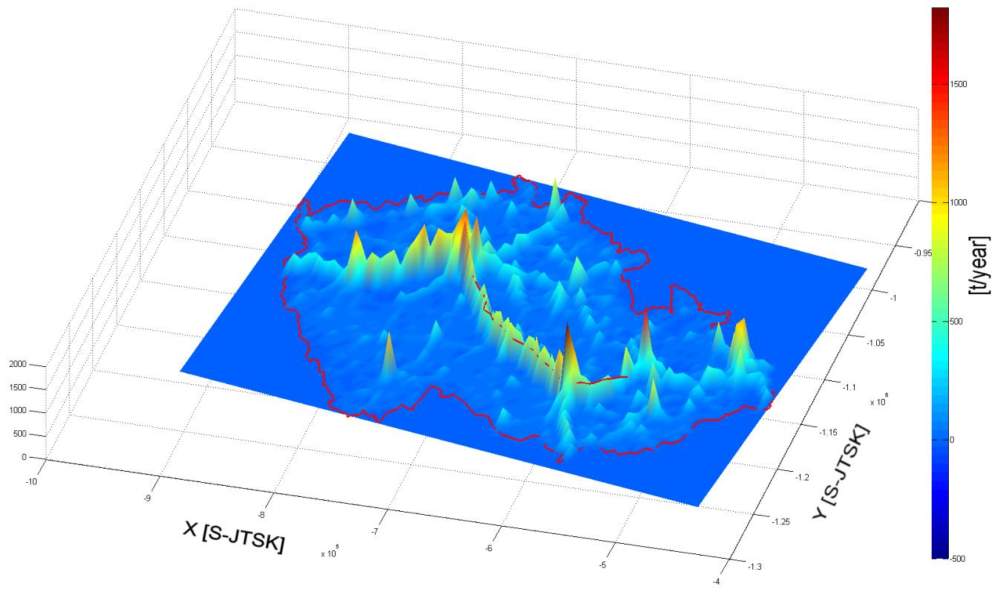


Fig. 9. Spatial representation of the REZZO 4 data analysis of the complex CO emission load from mobile sources above the Czech Republic from 2007

Direct integration into the REZZO system and connection with chemical transport models also opens the possibility of evaluating the accuracy of different versions of the emission models. This is a very complex issue that goes beyond the scope of this work and requires careful analysis of the inaccuracy of emission inventories, emission models, chemical transport models and measurement network.

## 5. Conclusion

This work on the other hand (instead of the summary disaggregation) explores the possibility of using automatically collected detailed information of the traffic. This information has been available just since the past few years, allowing for full coverage of the dynamic traffic and thus emissions from mobile sources.

The emission load from road traffic is one of the major factors affecting the air quality. The best estimate of emissions in the detailed spatial and time resolution is necessary for modeling the transport and chemical transformation of polluting substances. The current practice in emission models is the disaggregation of summary information (for example estimated mobile emissions for the whole year) using constant emission factors to individual months, days of the week and hours.

The research proposed the original model of the emission load cars with an innovative use of the data from the toll gates. The model has been implemented as a computer program and tested as a beta version on the available input data.

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# Extended Analysis of Brain Signals with Respect to Human-Vehicle Interactions

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**Abstract**

In this paper the extended analysis of the human electroencephalographic signals (EEG) in the region of alpha rythms combined with an investigation of transparency and dispersion of electromagnetic waves in near infrared region (NIRS) measured in front brain parts is presented. The existence of spindle-like (fusiform) shape appearing in the alpha band of EEG signals are discussed and verified by the set of experimental measurements. The hypothesis of possible interrelations of the EEG signals forming the so called alpha fusus with tested person psychical state and its reactions when driving the vehicle is presented.

**Keywords:**electroencephalography (EEG), alpha activity analysis, spindle-like (fusiform) shape, psychotests, iteration, multilayered iterative algoritmus (MIA), near infrared investigation

## 1. INTRODUCTION

The thalamus, a large subcortical nucleus, houses rhythmic thalamic generators (RTG) which act as terminals of nerves fibres leading from sensory organs (eye, ear, skin, muscles, smell, taste). The RTG nerve cells (neurons) are connected to to neurons in the brain cortex. On them reverberate between the RTG and the cortex very complicated sets of electric impulses. This works both in vigilance (waking) and in sleep, all through our life, known as the thalamocortical reverberation system (TCRS). In the brain an electric activity is recorded from the cranial surface (EEG). This cyclic activity appears in the frequency band generally between 1 and 30 Hz.

The so called alpha frequency (8 - 13 Hz), typical for vigilance, mostly appears in the form of undamped oscillations which immediately after few waves change into damped oscillations.

That is what gives the alpha rhythm its spindle-like (fusiform) shape. One alpha wave lasts about one tenth of a second, consistent with one cycle in the TCRS. TCRS consist of about tens of billions of neurons on which connections several hundreds of billions of impulses are propagated. These produce very complicated electromagnetic field.

We presume that in it are present not only periodic but also stochastic processes.

One alpha spindle (AL) lasts roughly one second, corresponding to reiterated exchange of impulses (information) in the TCRS. This is rather like iteration with convergence to the target solution of a task in the descending portion of the alpha spindle (ALDE). The ascending portion of the alpha spindle (ALAS) might correspond to the mechanisms of MIA (multilayered iterative algorithm) as described by A.G. Ivakhnenko [47].

In the course of learning with a supervisor (teacher), MIA, represented by an inductive neuronal network, takes on certain new neurons and neuronal layers in keeping with a particular criterion. The redundant neurons are then

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excluded to approach the task solution, i.e. from the signal point of view the convergence to global minimum (or attractor) and also from psychological point of view to problem solution or to abstraction, creation of notion, epistémé, sémém.

It appers that - using Gabor´s frequency filtration (GF), local coherence function (LCF) and Poincaré´s analysis (PA) - we have come closer to our hypothesis of a dual type of iteration: MIA in ALAS and common iteration in ALDE.

## 2. EXPERIMENTS

24 persons were examined during EEG recording and simultaneous psychotesting. For our purposes we used sections in the stages of relaxation and also during the task of summation of two-digit numbers, both with eyes closed.

The results showed quite an amount of interindividual differences. However, there was a preponderance of higher values of alpha energy in GF and lower values of coherence (LCF) in ALAS over those values in ALDE. PA demonstrated cyclic feature of alpha spindle during ALAS and ALDE during relaxation and contrary noncyclic one during psychic activity. This shows the alpha spindle asymmetry, i.e., greater and more complex recruitment of alpha in ALAS. The method may well prove useful as a supplement of tests for attention or for personality.

Thalamus is a large subcortical part of brain, from which neuronal impulses are sent to the cerebral cortex and vice versa. These synchronized electrochemical impulses keep being repeated (reverberating) in groups. Hence, once appropriately amplified, they can be recorded from the intact surface of the head (scalp) as rhythmic electric potentials in what is called electroencephalograms (EEG), [6], [20], [35]. Alpha waves (8 - 13 Hz) and beta waves (14 - 30 HZ) predominate during relaxed wakefulness (vigilance), accompanied - during mentation - by delta activity (0.5 – 3.5 Hz). The brain stem regulates arousal as well as the magnitude of the alpha rhythm as described by Moruzzi and Magoun [28] and corroborated by a number of authors such as Kandel and Schwartz [24] and the others.

The macroscopic organization of the brain is determined genetically in the prenatal period though after birth its microscopic structure continues being perfected under the impact of received information (impulses) coming from the sensory organs (eye, ear, muscles, skin, nose and tongue).

Different areas of the cerebral cortex are specialized for different brain functions such as analysis and formation of speech, target-oriented movement, reading, writing, arithmetics, abstract mentation etc. Brodmann [7] was the first to identify, with the aid of microscopic histological analysis, 52 different areas in either hemisphere.

Today, we associate each such area with specific functions according to the outcome of psychological testing carried out together with the isotope method of PET (positron emission tomography), see [27], [31]. These areas can also act as formators, i.e. centres of regulation similarly as the brainstem structures in control of vigilance and sleep, see [17], [10], [11], [12], [14].

Realized experiments have brought convincing proof of the difference between the resting state of the mind with the eyes closed and complete relaxation with, among other things, the alpha amplitude increase [15]. In terms of psychophysiology, we have yet to decide whether the "nonalpha time index" (EEG desynchronization) during habituation after eye opening is directly proportional to intelligence [19] or to arousal [21].

Apparently enough, resting alpha is not exactly sinusoidal as the ascending part of this wave is steeper than the descending part and prone to becoming more symmetrical during psychic activity [12].

Nerve cells of sensory organs send information along nerve fibres to the brain stem and from there on to the thalamus to pass impulses to other neurons. Beside sensory nuclei, the thalamus houses also motor nuclei which control muscle activity, in particular movement of the extremities, trunk, mimic muscles, respiration, speech etc. Most of the thalamic nuclei have yet another microstructure and function: groups of neurons called rhythmic thalamic generators (RTG) which generate mainly the already mentioned alpha and beta rhythms. This cyclic activity appears to be analogical to clock pulses in computers.

The human cortex is organized horizontally into 6 layers and - vertically - into columns numbering roughly one or ten million. Most of the outputs from the particular RTGs are aimed at the cortical microstructures, i.e., at the columns (echelons) totalling about 25 thousand in the cat, and approximately one or ten million in humans. Each column contains about ten thousand columns to receive specific information (SI) from sensory organs in layer 4 and, in part, in layer 6 [1] of the cortex, and non-specific information (NI) in cortical layers 1 and 2. Information from the NI coming from nonspecific brainstem structures determines the brain´s programme: wakefulness, relaxation, concentration or sleep.

Thalamus is mostly organized in nuclei. The thalamic nuclei then have two principal functions (and thirty more, [14], [15]): transmission of impulses from sensory organs to the specific areas, and sending cyclic and synchronized impulses to large non-specific association areas of the cortex.

Specific areas of the cortex are:

- for optical analysis - areas 17, 18,
- for acoustic analysis - areas 41, 42,
- for tactile analysis - areas 1, 2, 3,
- for motor control - areas 4, 8,
- for speech - areas 44, 45, 46.

Other large, so called association areas, serve the following purposes:

- for optical analysis - area 19,
- for acoustic analysis - areas 21, 22, 39, 40, for tactile control - areas 5, 7,
- for motor control - areas 6, 10 to 14,
- for speech and abstract thinking - area 47.

The main psychic (cognitive - gnostic, speech - phatic) processes appear to be facilitated mainly thanks to the cyclic activity of neuronal impulses between the thalamus and the cortex as well as to their analytical-synthetic processing inside those structures in what is called the thalamo-cortical reverberation system (TCRS).

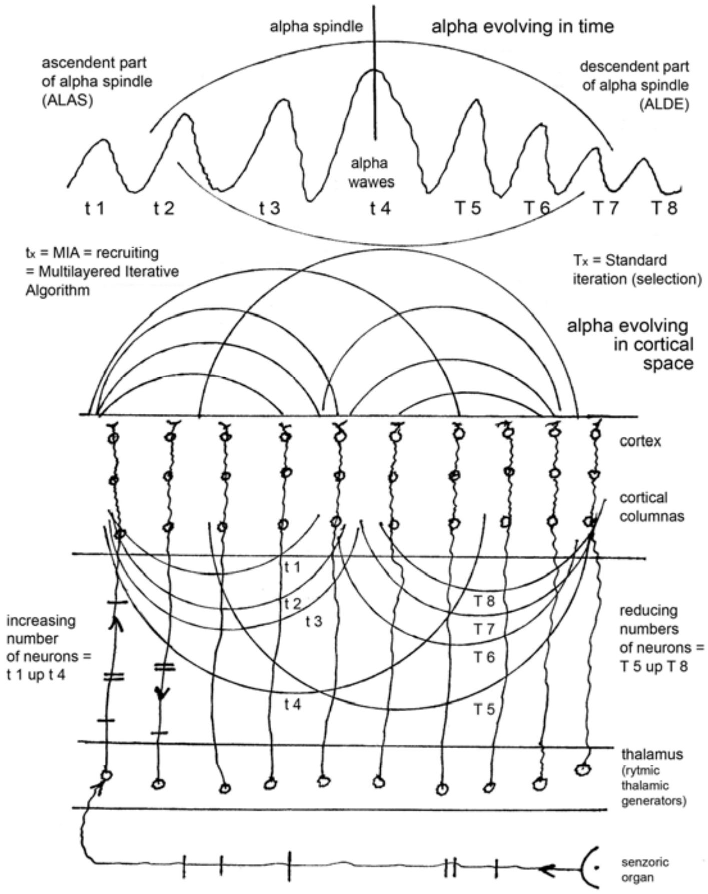


Fig. 1: The upper part carries a schematic representation of a typical fusiform shape of alpha activity with t 1 to t 4 showing the development of alpha waves of growing amplitude at times t 1 to T 4 (ascending alpha = ALAS, a build-up of the number of neurons involved in MIA iteration; T5 to T8 - alpha waves of decreasing amplitude at times T5 to T8 (descending alpha = ALDE, diminishing number of neurons involved in a selective iteration programme). Timed alpha activity is shown. The lower part shows a schematic representation of TCRS. The small circles represent neurons, with the arrows indicating the direction of impulses shown as short lines crossing the axons. The neurites or axons are fibres interconnecting thalamic and cortical neurons. The large semicircular curves represent increasing (tx) or decreasing (Tx) amounts of the neuronal population and, thereby, also the alpha activity synchronized recruitment in the cortex.

There is no doubt of the existence of the TCRS.

Its function has been recognized since the days of the discoverers [8], [4], [5[, [3] right up to our times [23]. At a given time, the sensory organs supply the thalamus with not entirely precise information of images, sounds and tactile impressions.

These messages from the outside have somewhat blurred outlines, meaning that they are fuzzy. We can be easily mistaken in case the perception is too short or if the perceived image, sound or touch is too complex. If the impression is to be eliminated, we have to take a closer look or become absorbed in the sound repeatedly. That is where the TCRS comes into play in order to, among other purposes, "defuzzify" our "fuzzified" sensory perception with its reverberation activity.

The actual perception is apparently the TCRS primary activity extending from the thalamus to the primary cortical area, and lasting about 300 ms. In terms of neuronal impulses this is a perceptogram. Abstract notions (symbols, epistemes, sememes) are manifestations of repetitive secondary activity between the thalamus and other less specific areas (TCRS) lasting about 500 ms up to a few seconds. In terms of microEEG we refer to ideograms [15].

We have experimental evidence to show that the addition of one-digit numbers in youngsters up to 15 years of age usually results in alpha acceleration by 0.5 to 1 HZ. Since alpha activity is a product of the TCRS, we believe that this system serves a "simpler" sort of mentation. The addition of two-digit numbers causes a similar change in the alpha band, moreover with a build-up of delta activity [14].

Again, since delta activity is generated by the cortex and its auxiliary systems (DACAS), using short and long association fibres and commissural connections, it represents a "more complex" sort of mentation.

The TCRS and DACAS take regular turns in their activities [11]. Walter et al. [40], Timsit et al. [38] and Howard et al.[22] have shown that delta and subdelta activities invariably underlie complex mentation, e.g., in the form of "contingent negative variation", P 300 wave of cognitive evoked potentials or "readiness" potentials.

Apart from recognizing the perceived image (sound, touch), i.e., from realizing concrete cognition, awareness of the perceived comes in quick succession.

In other words, we experience transition from concrete perception to a generalized notion or attachment of a concrete, albeit "fuzzified perceptogram" to an abstract pattern /notion) in the TCRS, i.e., to a "defuzzyfied ideogram" - resulting in abstract gnosia (cognitive functions).

It appears that for reactivity as such, i.e., for both the concrete (conditioned reflexes, dynamic stereotypes) and abstract mental process (mentation, noesis), cognition and for the generation of motor responses including speech (phatic functions), we do not need to use such a large number of neurons, as exist in the whole cortex about 100 billion).

Most of the neurons are likely to serve the purpose of remembering or filing in an archive. This, however, is a dynamic archive where the brain constantly or frequently processes the data stored there either entirely automatically or subconsciously. Primarily, however, it seems to process informations by means of associative operations, by looking for analogies and abstract patterns, thus widening the field of our knowledge and experience.

It seems that in a single process of information or mentation, our brain or rather TCRS would be unable to simultaneously and rationally employ all of the 100 billion neurons. Considering that each neuron will apparently be connected with hundreds up to thousands of other neurons and that it generates 5 up to 50 impulses per second, the whole brain operates with hundreds of billions of impulses per second. Moreover, the impulses travel in immensely complex networks and circuits.

Interneuronal impulses, while subject to binary coding, are usually organized in specific groups the code of which is till now unknown. That is why we establish at least inter-impulse interval histograms or, better still, leading cell and mass activity correlograms" according to Reinis [34]. For brevity´s sake, we use the "3f" algorithm: "firing rate, firing pattern a space firing" [15]. Indeed, all our psychic life is made up of nothing but those impulses. Though this fact suggests vulgar materialism, we accept it because so far we know of no other mechanisms of information processing in the brain.

Indeed, there seems to be a paradox: the fewer neurons participate in an actual psychic process, the greater the information power seems to be [10], [32]. The power there is understood to mean not only the process in a simple logical, combinatorial or sequential structure but also complicated mentation such as abstraction, deduction or synthesis of information.

## 3. METHOD AND EXPERIMENTAL DATA

Our main cohort of tested persons consisted of 22 healthy people, 17 men (age range 22 to 37), one 70-year-old man, one 80-year-old man) and 7 women (age range 22 to 36), and two 60-year old women. All 22 had normal EEG with basic alpha rhythm. The 70-year-old man had subclinical episodes of typical epileptic graphoelements of the spike-wave type in the EEG record, but no seizures in the past 35 years. The 80-year-old man had the pseudoneurasthenic syndrome but good logical judgment and memory, EEG showing slow alpha (8 Hz, sporadically also low-voltage theta, i.e., 4-7 Hz), while all the rest - except one - had alpha 9 Hz and faster frequency.

All persons had their EEG recorded in the standard way, i.e., with the curves picked up by 19 electrodes placed on the head in the 10-20 Jaspers anthropometric array, amplification of 100 microVolt per centimeter of amplitude deflection of the calibration curve, upper filter - 40 Hz, lower filter - 1 sec, time sampling - 128 Hz.

During 30 minutes of diurnal EEG recording, the following situations (states, conditions) were used: eyes closed (EC) and eyes open (EO), nasal (HVN) and oral (HVO) hyper-ventilation, shortened Raven test (RA) and the adding up of one- or two-digit numbers (CA) with eyes closed. Only two-digit numbers were added up for this particular study. In principle, only two states were used in EEG tests: the resting or native state and the active state. For this kind of psychic activity we also use the term mentation. To serve our purposes, we analyzed alpha activity spindles in two situations (with 8 to 18 alpha waves at a sampling rate of 128 Hz): a) at rest with the eyes closed and b) during the addition of two-digit numbers also with the eyes closed. The outcome was analyzed separately for the first half, i.e., the ascending part of the alpha spindle (ALAS), and separately for the other, descending half of the alpha spindle (ALDE). The addition of ten two-digit numbers took 30 seconds to complete, and the sums were incorrect in three young men, two elderly men and two elderly women.

To analyze each half of the alpha spindle we used spectral computations with Gabor filtration (GF) and local coherence function (LFC). We have also other sophisticated mathematical analyses ready for use such as dimensionality reduction and the like [29], [39], [37]. In some probands we also used interhemispheral coherence function (ICF), amplitude analysis (AA - isovoltage maps) and Poincaré data sequence analysis (PA). These computations were resorted to where GF and LCF failed to produce conclusive results. Only then did AA, PA and ICF deliver the expected differences between the ascendent and descendent portions of the alpha spindle as much as between the states of rest and calculation (mentation). For lack of space, we plan to present those results in another study.

## 4. RESULTS

The first group of results is presented in Tab.1.

Tab.1. Roman numerals are used to denote the probands, second column contains their pseudomonograms, the third column contains the values of alpha frequency at rest (NA), the fourth column contains the values of alpha in mentation while adding up two-digit numbers (CA). Included are also data of age and comments.

| Proband No. | Pseudomonogram | Alpha at rest (NA) | Alpha at mentation | Age | Comment |
|---|---|---|---|---|---|
| **I.** | TER | 11 Hz | 11 Hz | | |
| **II.** | SIN | 10 Hz | 11 Hz | | |
| **III** | PSN | 9.5 Hz | 10 Hz | | |
| **IV** | KRT | 10 Hz | 10.5 Hz | | |
| **V** | HLO | 10.5 Hz | 11 Hz | | |
| **VI** | STA | 10 Hz | 11 Hz | senior, 62 | |
| **VII** | HAL | 11 Hz | 11 Hz | senior, 62 | |
| **VIII** | SDA | 10.5 Hz | 11.5 Hz | | |
| **IX** | TIC | 10.5 Hz | 11 Hz | | |
| **X** | RDN | 9.5 Hz | 10.5 Hz | | somnus |
| **XI** | LPK | 10 Hz | 11 Hz | | in driving |
| **XII** | HEK | 8 Hz | 9 Hz | | in driving |
| **XIII** | SAF | 8.5 Hz | 9.5 Hz | | |
| **XIV** | VEL | 12 Hz | 13 Hz | | |
| **XV** | SLN | 11 Hz | 11.5 Hz | | somnus |
| **XVI** | MOD | 9 Hz | 10.5 Hz | | somnus |
| **XVII** | SJK | 10.5Hz | 10.5 Hz | | |
| **XVIII** | BRD | 10 Hz | 10 Hz | | |
| **XIX** | VBR | 9 HZ | 10 Hz | | meditatio 8 Hz |
| **XX** | BAK | 10.5 Hz | 11 Hz | | |
| **XXI** | SAF | 9 Hz | 10 Hz | | neurotic syndrome |
| **XXII** | FRN | 10 Hz | 10.5 Hz | senior, 70 | |
| **XXIII** | KTO | 8 Hz | 8.5 Hz | senior, 80 | |

The next Tab.2 presents an overview of all the results of all probands´ calculations. To save space, abbreviations are used for states in the columns, actual results in lines.

1. column 1 shows the amount of alpha in the power spectrum (GF) in the ascending part of the alpha spindle in native - resting - state (NA),
2. the same in the delta band, NA,

3. the amount of alpha in the descending part of the alpha spindle, NA
4. the same in the delta band, NA.
5. GF results in the ascending part of the alpha spindle during calculation, CA
6. the same for the delta band, CA,
7. GF results for the alpha spindle descending part, CA,
8. the same for the delta band, CA,
9. LCF results in the alpha spindle ascending part for alpha, NA,
10. the same for delta, NA,
11. LCF results in the alpha spindle descending part for alpha, NA,
12. the same for delta, NA,
13. LCF results for the alpha spindle ascending part for alpha, CA,
14. the same for delta, CA,
15. LCF results for the alpha spindle descending part for alpha, CA,
16. the same for delta, CA.

The data with exclamation marks show that while no major change was noted in the particular frequency band, the distribution on the cranial surface was entirely different.

Since the data were not normalized, the intraindividual results are given in relative values. Consequently, the data indicate declining or rising values for each individual separately. The results from the native EEG alpha activity represent the mean quantitative levels of the alpha or delta frequency bands. Low level is marked +, medium ++, high +++. A low level decline to a still lower one is marked -, a medium level decline is marked +, a high level decline is marked ++. A rise in the level of alpha or delta is marked with another cross, i.e., from low to higher ++, from medium to higher +++, and from high to a still higher one ++++.

Tab.2. The results of GF (columns 1- 8) and LCF (columns 9 - 16) calculations in XXIV probands. Probands I to VII are women, the last two - elderly women. Probands VII to XXIV are men, the last two elderly men. Exclamation marks in some of the results show that while the values in the alpha or delta bands remained unaltered, there were major changes of relocalization, i.e. for example, maximum alpha in ALAS was in the occipital, in ALDE in the temporal region, etc.

| | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. | 16. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **I.** | ++ | + | + | + | ++ | ++ | + | + | ++ | +++ | +++ | +++ | ++ | +++ | + | ++ |
| **II.** | ++ | + | ++ | - | ++ | + | + | - | ++ | + | ++ | +++ | ++ | + | ++ | + |
| **III** | +++ | + | +++ | + | ++ | + | ++ | + | +++ | + | +++ | + | ++ | + | +++ | + |
| **IV** | ++ | + | ++ | ++ | + | + | ++ | ++ | + | ++ | +++ | ++ | - | ++ | + | - |
| **V** | ++ | ++ | +++ | ++ | + | ++ | ++ | + | ++ | ++ | + | +++ | ++ | ++ | + | ++! |
| **VI** | +++ | + | + | + | +++ | ++ | +++ | +++ | ++++ | + | ++ | +++ | +++ | ++ | +++ | ++ |
| **VII** | +++ | + | +++! | + | +++ | + | +++! | - | +++ | + | +++ | ++ | ++ | - | ++! | + |
| **VIII** | +++ | + | ++++ | ++ | +++ | + | +++! | ++ | + | +++ | ++ | + | +++ | ++ | +++ | ++ |
| **IX** | ++ | + | + | ++ | + | + | + | ++ | +++ | + | + | + | ++ | + | ++ | - |
| **X** | ++ | + | +++ | + | + | + | +++ | - | + | +++ | +++ | ++ | +++ | ++ | ++ | +++! |
| **XI** | +++ | + | +++! | + | +++ | + | + | +++ | ++ | + | +++ | ++ | +++ | + | ++ | ++ |
| **XII** | +++ | + | ++ | ++ | +++ | + | ++ | + | +++ | + | +++ | + | +++ | ++ | +++ | + |
| **XIII** | ++ | ++ | + | + | +++ | + | ++ | ++ | +++ | ++ | +++! | ++! | ++ | + | + | ++ |
| **XIV** | +++ | +++ | ++ | +++ | ++ | +++ | +++ | ++++ | ++ | ++ | ++! | +++ | ++ | +++ | +++ | +++ |
| **XV** | ++ | ++ | + | + | + | + | ++ | ++ | +++ | ++ | +++ | + | ++ | ++ | + | +++ |
| **XVI** | ++ | +++ | +++ | ++++ | +++ | +++ | ++! | ++ | +++ | +++ | +++! | +++! | ++ | +++ | ++ | ++ |
| **XVII** | +++ | ++ | +++ | +++ | ++ | ++ | ++ | ++ | ++ | + | ++ | ++ | + | ++ | + | +++ |
| **XVIII** | +++ | ++ | ++ | + | ++ | ++ | ++ | +++ | +++ | ++ | + | ++! | +++ | ++ | +++! | +++ |
| **XIX** | +++ | ++ | +++! | + | +++ | + | +++! | + | +++ | ++ | +++ | + | +++ | ++ | ++ | + |
| **XX** | + | ++ | ++ | ++ | ++ | ++ | + | ++! | ++ | ++ | +++ | + | ++ | ++ | ++! | ++! |
| **XXI** | + | + | ++ | ++ | ++ | +++ | +++ | +++ | ++ | ++ | +++ | +++ | ++ | +++ | ++ | ++ |
| **XXII** | ++ | ++ | ++! | +++ | + | +++ | +++ | + | + | +++! | ++ | +++! | + | + | +++ | ++ |
| **XXIII** | ++ | + | + | + | +++ | + | ++ | + | ++ | + | +! | ++ | ++ | + | + | +! |
| **XXIV** | +++ | ++ | +++! | + | + | + | +! | +! | ++ | + | ++ | - | + | ++ | - | + |

The Tab.2 presents results of measured 24 probands arranged in 16 columns, thereof 8 for GA results, 8 for LCF results. Hence, eight relationships were calculated in two ways. In other words, we have here 8 relationships (x:y) listed in eight columns for 24 probands, amounting to 192 relationships. However, only the most interesting will be analyzed here, i.e., only those with a marked predominance in one variable. Thus, there are 120 instances of alpha activity asymmetry (x <y or x>y ) with the ascendent (ALAS) relative to the descendent (ALDE) portion of the alpha spindle, 68 instances of symmetry (x=y), 4 instances of relocalizations or topic predominance on the skull surface.

The differences between alpha activity at rest or during hyperventilation or cogitation in one and the same human are discernible with the naked eye. That was what made us use some mathematical methods for alpha rhythm analysis under diverse conditions in order to define its character. In our view, the EEG curve still hides a great deal of important information. It should be added, though, that emotions and affectivity, too, have an impact on the human mind, mainly rational power. Our consciousness is known to have a dual character; it is both rational and emotional. Here, for the sake of simplicity, we refer primarily to rational consciousness and mentation. So far, there is no experimental or mathematical way how to synthesize the two aspects of consciousness.

Tab. 3. Numerically expressed relations from Tab.2 (a,b) between activity in ALAS and ALDE in the resting state (NA), during calculation (CA) and between the NA and CA parts of the EEG curve in the alpha and delta bands - based on the results in columns 1 - 8 from GF in the upper part of the table, and from columns 9 - 16 from LCF in the lower part of the table. Bold numbers mean sum of men and women.

| GF: | αNA | αCA | δNA | δCA | αNA-CA | αNA-CA | δNA-CA | δNA-CA |
|---|---|---|---|---|---|---|---|---|
| columns: | 1:3 | 5:7 | 2:4 | 6:8 | 1:5 | 3:7 | 2:6 | 4:8 |
| | ♀ ♂ Σ | ♀ ♂ Σ | ♀ ♂ Σ | ♀ ♂ Σ | ♀ ♂ Σ | ♀ ♂ Σ | ♀ ♂ Σ | ♀ ♂ Σ |
| x>y | 2 7 9 | 2 6 8 | 1 6 7 | 4 4 8 | 3 8 11 | 3 6 9 | 0 4 4 | 2 5 7 |
| x<y | 1 5 6 | 2 4 6 | 1 7 8 | 2 7 9 | 0 5 5 | 1 6 7 | 2 2 4 | 1 6 7 |
| x=y | 3 1 4 | 2 3 5 | 5 4 9 | 1 4 5 | 4 4 8 | 3 5 8 | 5 11 16 | 4 6 10 |
| disl. | 1 4 5 | 1 4 5 | 0 0 0 | 0 2 2 | 0 0 0 | 1 4 5 | 0 0 0 | 0 2 2 |
| LCF: | | | | | | | | |
| columns: | 9:11 | 13:15 | 10:12 | 14:46 | 9:13 | 11:15 | 10:14 | 12:16 |
| | ♀ ♂ Σ | ♀ ♂ Σ | ♀ ♂ Σ | ♀ ♂ Σ | ♀ ♂ Σ | ♀ ♂ Σ | ♀ ♂ Σ | ♀ ♂ Σ |
| x>y | 2 2 4 | 2 7 9 | 0 6 6 | 2 6 8 | 4 6 10 | 3 11 14 | 1 4 5 | 6 4 0 |
| x<y | 2 6 8 | 3 2 5 | 4 4 8 | 1 7 8 | 0 3 3 | 1 4 5 | 1 4 5 | 0 7 7 |
| x=y | 3 9 12 | 2 8 10 | 3 7 10 | 4 4 8 | 3 8 11 | 3 2 5 | 5 9 14 | 1 6 7 |
| disl. | 0 4 4 | 1 2 3 | 0 4 4 | 1 3 4 | 0 0 0 | 1 5 6 | 0 1 1 | 1 5 6 |

As the tab. 2 and 3 indicate, the frequency spectrum (GF) show great interindividual variability with discernible differences between ALAS and ALDE in both the native and the mentation EEG curves. Power of alpha is 9 times greater in the native ALAS (column 1:3), and 8 times greater in the mentation ALAS phase (column 5:7). This is evidence of spindle asymmetry with more alpha in ALAS, though seen with the naked eye this formation appears to be a paradigm for symmetry.

Delta activity tends to be symmetrical, at rest (in column 2:4) the ALAS and ALDE values are nearly equal (7 cases to 8). A similar situation exists during mentation (column 6:8), 8 cases to 9. Likewise, the alpha band reveals considerable difference between the resting and mentation (mental activity) curves.

Comparisons between the native state and mentation in ALAS in the delta band are as follows: (column 2:6) 4 cases each and 7 cases each (column 4:8) between the native state and mentation in the ALDE phase. In other words, the situations are very well balanced, and delta does not seem to be different in the ascendent and descendent phases of the alpha spindle. Indeed, delta is 16 times identical in ALAS (column 2:6) and 10 times the same in ALDE when the resting state and mentation are compared.

Clearly enough, alpha is marked by differences, i.e., higher in ALAS than in ALDE; it's differently numerous neuronal populations on recruitment seem to suggest MIA iteration whereas only a slightly different delta shows equal quantities in both ALAS and ALDE. This is evidence of constantly equal delta energy in ALAS and in ALDE, i.e. regardless of relaxation or mentation, the TCRS keeps iterating in the delta rhythm all the time. Delta would then be consistent with routine and incessant iteration or selection of neurons. In physiological terms, this points to a constantly high activity of the associative and commissural systems.

Considerable ALAS-ALDE differences stand out when comparing EEG at rest and during mentation in the alpha band. In the ALAS phase (column 1:5) there is 11 times more alpha at rest against 5 during addition; in the ALDE phase the ratio is only 9 cases to 7. The recruitment of alpha then is greater at rest than in mentation as regards the ALAS-ALDE ratio.

There seem to be no major sex differences, but then there are only 7 women in the cohort.

In other words: the subtotals show a preponderance of alpha activity at rest in ALAS (9) over ALDE (6) (column 1 relative to column 3). In the ALAS phase, there is obviously a greater tendency toward synchronization, which is hidden to the naked eye. A similar situation exists when ALAS and ALDE are compared during mentation (column 5 in relation to column 7). In either case, however, there are 5 relocalizations of alpha activity, i.e., more than in other relations. Alpha activity predominance in ALAS suggests an increased recruitment of neurons and their impulses and, thereby, also a larger neuronal population in the ALAS phase.

The delta band (columns 2:4 and 6:8) shows a fairly balanced amount of delta between ALAS and ALDE with, however, a negligible number of dislocations. In general, delta activity is predominant in the frontal and frontotemporal regions, albeit sometimes contaminated with oculomotor artifacts.

Marked changes are in those parts of the EEG curve where higher values of alpha at rest predominate over mentation in ALAS (11) (columns 1:5). This can be put down to greater attention during mentation when, as a rule, alpha is on the decline. The number of equal values is growing in ALAS and in ALDE (8), the spindles are assuming more symmetry during mentation. There is no alpha relocalization.

In the ALDE phase, the numbers of asymmetric and symmetric spindles at rest are levelling up with those during mentation (9 a 8),(columns 3:7). There are five alpha dislocations here suggesting a major difference in the distribution of alpha in ALAS and in ALDE when the relaxed state is compared with mentation.

Delta activity in ALAS exhibits its greatly balanced amount between relaxation and mentation (16, columns 2:6). There is no delta dislocation.

Delta activity in ALDE is again very well balanced when relaxation and mentation are compared (10, columns 4:8).There are two cases of dislocation.

The bottom part of Tab.3 shows the LCF results. The GF and LCF computations are not identical but complementary. While GA shows the magnitude of energy in each particular part of the spectrum, LCF indicates mutual similarity (coherence) with the local "neighbouring" spectra.

As tables 2 a,b and 3 also suggest, the local coherence function (LCF) at rest (NA) operates conversely in the alpha band compared with alpha energy computed on the basis of GF: in ALAS - 4 to 8 cases, in ALDE - 5 to 8 cases; i.e., coherence is lower in cases of increased alpha activity. This could mean that greater coherence accompanied by lesser alpha energy would represent greater mental power with increased attention. Yet, the equivalence of the number of cases (x=y, i.e., the same amount of alpha in ALAS as in ALDE) is almost invariably greater than the reverse (x≠y), (applicable also to delta activity), as it shows little change in ALAS relative to ALDE.

In contrast, during adding up (CA) both alpha and delta show a substantially greater coherence in ALAS than in ALDE, i.e. during mental activity the similarity of the spectra is on the increase in the first half of the alpha spindle whereas in the second half it is on a very marked decline in what points to a great deal of dissimilarity between the ascendent and descendent phases of the alpha spindle.

Of considerable interest is the high delta coherence during mentation in ALAS (14 cases) compared with ALDE (none). It appears that delta has a major role to play in mental activity, indeed, even in the first half of recruitment, i.e., in the ascending part of the alpha spindle. This shows that "invisible" changes in the EEG curve are well calculable and that it makes sense to monitor those changes.

Relocalization is a characteristic feature of mainly alpha and delta during mentation with 6 cases each.

Three persons were prone to falling asleep, and on those occasions we were able to see that the alpha spindle after sleep showed more alpha energy in GF and more coherence in LCF than at rest and during relaxation at the start of the experiment. At the same time, there was a bifrontal decline of delta activity. This appeared to coincide with a decrease in oculomotor artifacts during the sleep onset, artifact being almost invariably present in wakefulness. Admittedly, the number of the probands was low, but should this finding be corroborated, it could be used for the prediction of imminent transition from relaxation to sleep.

The average alpha frequency at rest was 9.5 Hz, during mentation - 10 Hz. In 19 cases alpha accelerated during mentation by 0.5 to 1 Hz.

Apart from the resting state and psychotests, proband XX. also engaged in meditation according to Mahareshi Mahesh Yogi. As shown in optical description, his alpha was of relatively higher amplitude than in the resting state and found spreading also into the frontal region. His alpha frequency dropped from 9 to 8 Hz whereas during mentation it stood at 10 Hz. While his GF and LCF alpha increased, the analogical results in delta decreased. A similar situation without frequency analysis was described already by Anand et al. (1961) in Indian yogins. Poincaré´s analysis (PA) carried out in three probands revealed major cyclic activity at rest in both ALAS and ALDE, though this was considerably altered during mentation (CA).

As these exceptional situations pertain to too few probands, it is too early to draw any conclusions.

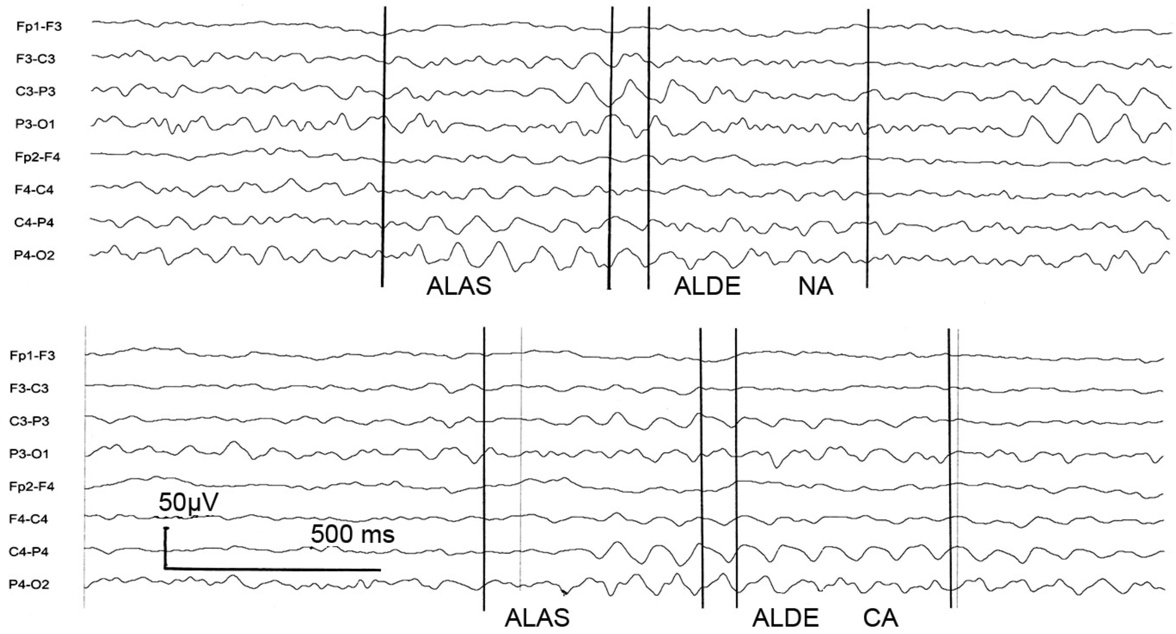


Fig.2. Example of twice eight EEG curves from the medial leads of proband XVIII. The graph, expanded in amplitude and in time, represents each time one alpha spindle divided into a first half with the amplitude increasing (ALAS) and a second half with the amplitude decreasing (ALDE). The top and bottom parts of the graphs show merely minor optical differences despite the fact that the upper 8 curves relate to the resting (native, NA) state, and that the lower 8 curves were recorded during the test, in the addition of two-digit numbers (CA). Each part (ALAS and ALDE) were analyzed separately using GF and LCF and then compared against each other or in different states.

In our previous studies we found differences in the EEG spectrum in relaxation and during psychic activity, in particular, alpha acceleration during the addition of one- and two-digit numbers. Generally speaking, the energy of alpha activity was reduced during increased attention independent of eyes open or eyes closed. In the process of mentation (Raven´s test, adding up numbers, and reading in young children) the delta band energy was rising, again regardless of whether the probands´ eyes were open or closed. Sometimes, but not always, similar changes can be seen in our present study, too. However, the duration of the previously analyzed sections used to be relatively long, 10 to 30 seconds, whereas the current time for alpha spindle analysis is only 0.5 to 1 second. Differently long intervals of the EEG curve have a significant role to play in the detection of each of the frequency bands.

The results of the present study show differences between the ascending (ALAS) and descending (ALDE) portions of the alpha spindle, mainly in the alpha band. In the resting state records, there are 15 cases of difference in the alpha band, i.e., 9 in ALAS and 6 in ALDE. During the addition test, alpha is asymmetrical 14 times, i.e., 8 times in ALAS and 6 times in ALDE. Comparing the alpha spindle at rest and in mental effort, we find 32 cases of asymmetry and 16 cases of symmetry. The delta band shows fewer differences. Our current results are, on the whole, congruent with the previous ones; for example: lower alpha during mentation than in the native resting part, or rising delta in mentation (columns 2:6 and 4:8). During relaxation and incipient sleep, the amount of alpha is on the increase and so is its coherence.

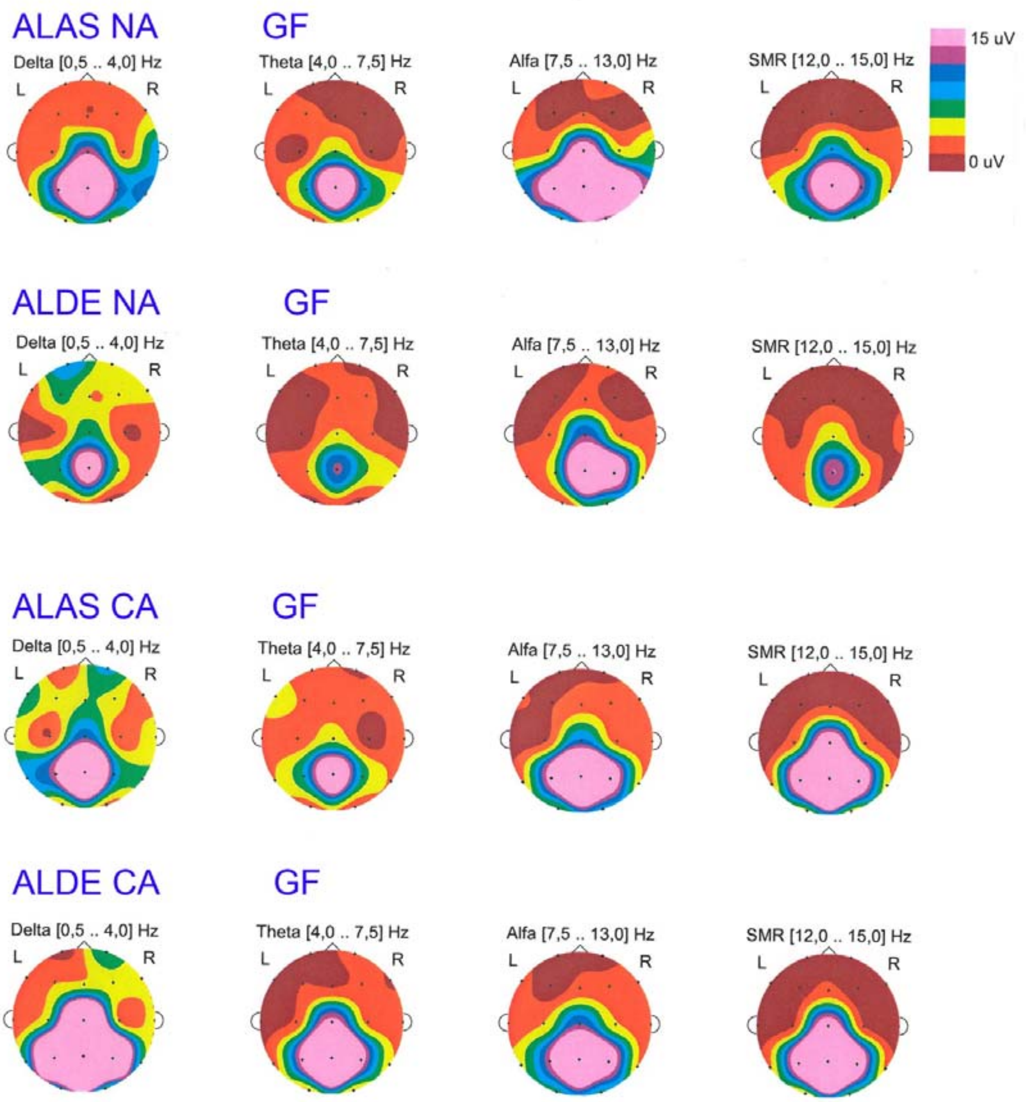


Fig.3. Four series of brain mapping (BM) diagrams of proband XVIII. from spectral GF computations in four frequency bands (delta, theta, alpha and "SMR“ or slow beta activity); on the extreme right is a scale for easier orientation from 0 to 15 µV of energy in pseudocolours or in different shades of grey. Series 1 are EEG curve computations of the native state (NA) in the ascendent part of the spindle (ALAS), series 2 - computations in the descending part (ALDE), showing decreased alpha and delta values in the ALDE phase (as well as in theta and "SMR", though these bands proved to be of lesser significance in other probands, which was why we refrained from studying them systematically). Series 3 are GA computations of EEG in the process of calculation (CA) in ALAS, and - series 4 - in the ALDE phase. Neither alpha nor "SMR" show any differences there, although there was a significant build-up of delta (and theta) activity during the arithmetic task. Comparisons show a loss of alpha in ALAS during CA as a result of increased attention; then, there is a discernible increase in delta (and theta) in ALDE during CA as a result of increased power of iteration in the TCRS and in DACAS.

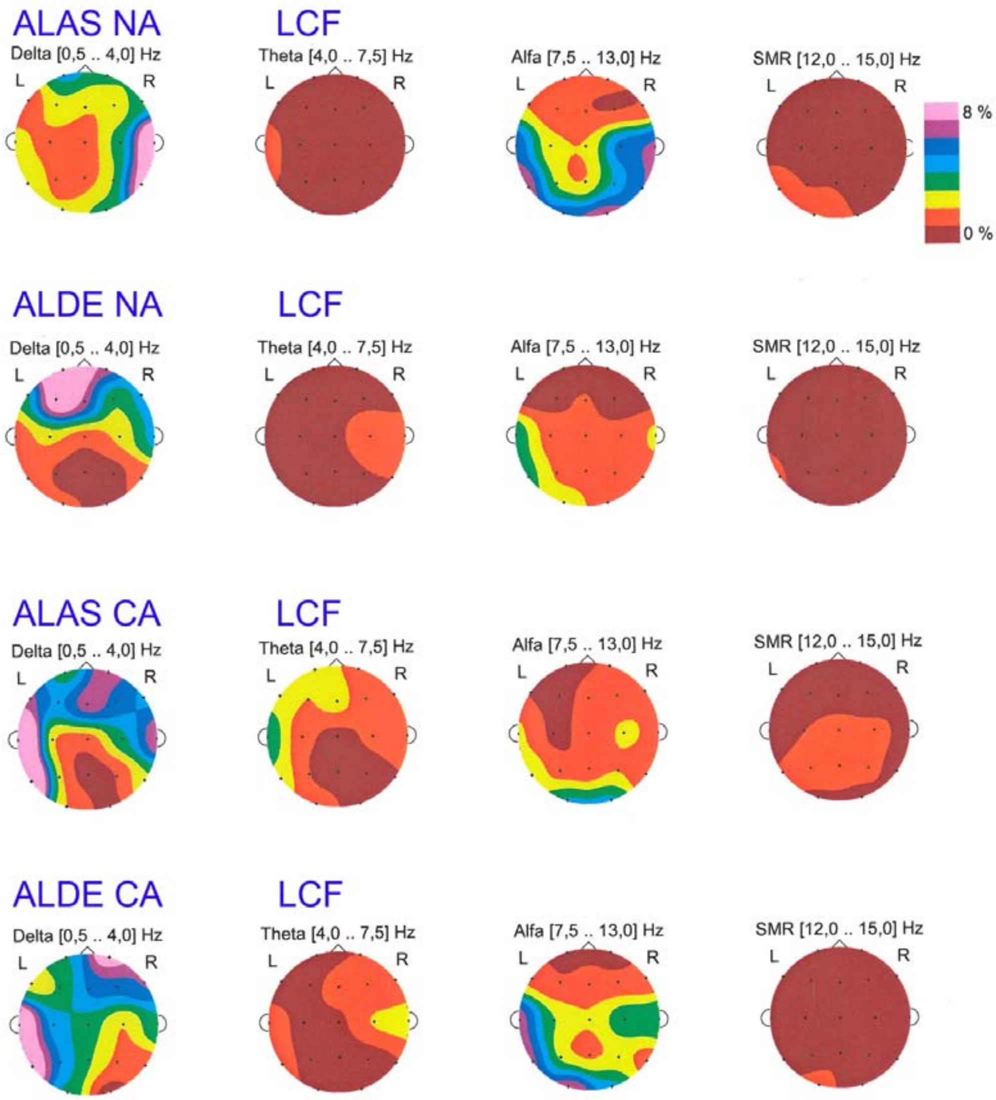


Fig.4: Another representation of four BM series (lines) of proband XVIII. made up of local coherences (LCF) in four frequency bands. On the extreme right is a scale for rating the intensity of coherence - from 0% to 8%. The first BM series shows the ascending amplitude of the alpha spindle (ALAS) at rest (NA) with a measure of focal - multifocal coherence of delta in the temporal region on the right, and coherence of similar intensity in alpha on both sides temporooccipitally. During ALDE, we can see a high degree of coherence in the left-hand frontal region, and dwindling coherence in alpha. That in itself represents a major difference between ALAS and ALDE even with the mind at rest. Series 3 and 4 illustrate coherence during calculation. ALAS shows marked delta coherence mainly in the temporal region on the left, i.e. contralateral to where it was in the resting state, with alpha coherence on the wane. In the ALDE phase, delta shows about the same coherence as in ALAS; in addition, alpha coherence has increased slightly temporooccipitally on the left. This indicates considerable differences between alpha spindles at rest and during mental effort. GF and LCF complement one another well. We can see waning coherence in the theta and "SMR" bands, thus substantiating our preference for alpha and delta activities. During mentation, there is, as a rule, increased multifocal LCF whereas in sleep LCF is evenly and diffusely localized.

More over, we have proved the Poincaré analysis of interralations in ALAS and ALDE of measured results in quiet state – NA, see Fig. 5 and also in states, when the tested persons were loaded by numeric computation – CA, see Fig.6.

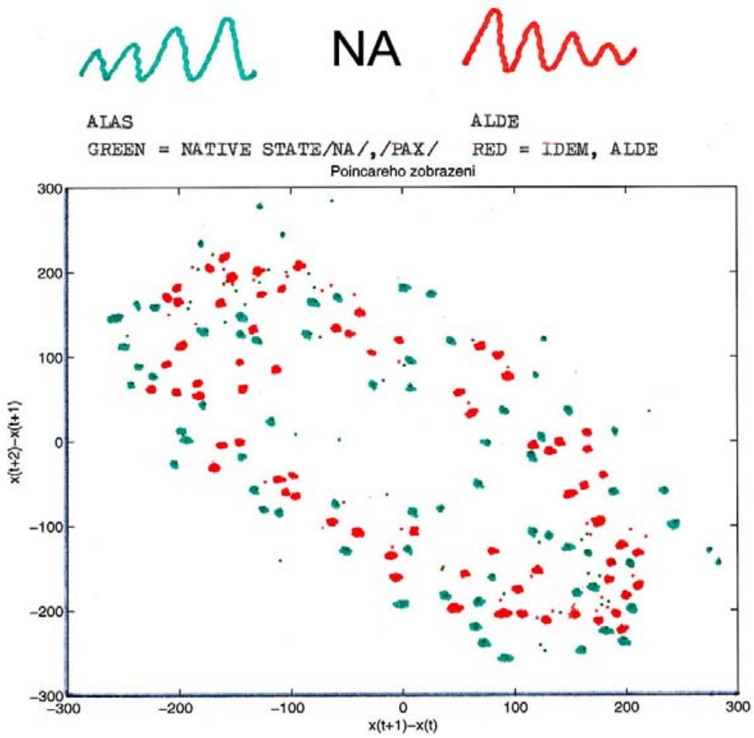


Fig.5: Poinceré analysis for quiet state: red dots mean ALDE, green dots mean ALAS

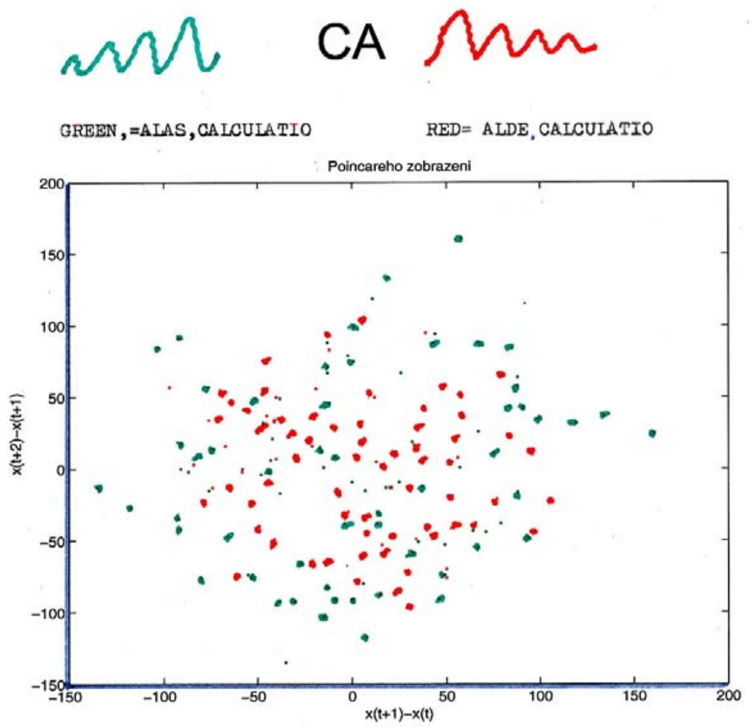


Fig.6: Poincaré analysis for state, when tested persons were loaded by calculations: red dots mean ALDE, green dots mean ALAS

Comparing of both these figures shows the significant changes of thalamo-cortical reverberation caused by psychical load nevertheless the curves looks very similar.

## 5. DISCUSSION

Much of these complex psychic operations may well unfold in periods of concentration or relaxation or sleep. There may be a certain optimum quantity of neurons, their connections, synapses and impulses in the analytical-synthetic process. Clearly, as mistakes are bound to occur in such a quantity of neuronal connections, the brain must have self-repair mechanisms to cope with errors [1]. Some of the neuronal processes may be reminiscent of mathematical operations.

The mind-boggling quantity of neurons and the complexity of neuronal networks make it inevitable to think of stochastic processes, of probability, of multivariate analyses such as the determination of factors or vectors and their rotations. Lion and Winter [26] and Saunders [34] devised and experimentally proved ways of obtaining "alpha-like" activity by appropriate filtration of generated noise. Using Wilks periodogram, we found a significant quantity of random variables in the EEG curve during vigilance, a lesser amount during an epileptic discharge, and the least amount during NONREM sleep [10]. However, the situation is too complex to warrant unanimity of official expert opinion. Thus, e.g., Reinis [33] has this to say: "To our knowledge, there are no proven neuronal systems with a documented fractal or chaotic time series." However, Freeman [18], using mathematical models proves a chao-dynamic character of impulsation in neuronal populations. Our hypothesis is based on the fact that neurons show, already in the prenatal period, a random impulsation activity, and that after birth comes a period of imprinting or impression of new neuronal "3f" algorithms into the original stochastic "arrangement". In psychological terms, this is consistent with imprinting, a process which is seen in birds only hours after hatching, and which in mammals is likely to take a long time and to be more complex. In the human young, imprinting in the form of attachment proceeds until about 3 years after birth.

We have in mind an analogy with iteration as such or MIA (multilayered iterative algorithm) processes as described by Ivakhnenko (quoted from Šnorek [36] and Novák et al. [29]). In our opinion, it is exactly reverberation in the TCRS that stands for iteration represented in the EEG curve by fusiform alpha activity with its ascendent (ALAS) and descendent (ALDE) parts. The neuronal network in ALAS operates in accordance with the MIA algorithm, while ALDE represents typical iteration, i.e. an more or less stereotype process aimed at the desired end.

The MIA (multilayered iterative algorithm) was described by Ukrainian mathematician A.G. Ivakhnenko as early as 1958. He devised a mathematical procedure, by which an artificial network of neuroids is developed using the inductive method and a teacher. This means that neither the number of neurons in hidden layers nor even the number of layers are set beforehand, but that this number keeps growing and forming in the course of learning as needed, i.e., the network keeps being built up until certain required external criteria are met. What follows then is neuronal restriction by selection. If the number of neuroids continues growing, learning becomes worse, the network is said to be overlearned. This brings the artificial network still closer to the actual development of biological, in particular, cortical structures. Genetic programmes used in artificial neural networks also follow examples from evolution [25].

The fusiformity of EEG graphoelements, alpha activity in particular, results from recruitment. This means that with every alpha wave or every cycle of impulses reverberating between the thalamus and the cortex the number of involved neurons increases [3], [4], [5]. This part of the alpha amplitude growth is discernible in the first half of the alpha spindle (ALAS). This is perhaps due to the search for the optimum size of the neuronal population. Optimum here means the number of neurons, their layers and areas needed for coping with the given task.

However, the aim of the solution for differently complex problems is differently remote, which is why the alpha spindles are differently long, as a rule, one half up to one to two seconds. The search for the "right kind of programme" culminates in the appearance of one or two alpha waves of the highest amplitude with the height of the waves declining from there on. The ALDE phase is alpha wave amplitude decreasing in the second half of the alpha spindle due to the neuronal population decline. This can be likened to the process of neuroid selection in an artificial neuronal network (ANN) as devised by Ivakhnenko. The ALDE phase also coincides with the task solution proper running on the rules of the ordinary iteration process, i.e., with the computation aimed at the desired results, in other words, at maximum cognitive approximation and cognitive success. This is where iteration takes on particularly complex forms in what is stereoiteration in an environment of stochastically operating neurons. Hence, we sometimes refer to "interation" [15].

It seems that in the ALAS phase the TCR system tries to find an algorithm for the solution of the problem while in the ALDE phase it is already working on the problem according to the algorithm found. The purpose of our computation is to find out whether or not this is actually the case. Obviously enough, most of the alpha spindles fail to find a meaningful solution of the task; on the contrary, very many such "alpha attempts" are necessary for successful cognition.

We have already in the Introduction mentioned physiological and mathematical literature suggesting how to explain the differences in alpha recruitment. The dynamism of alpha activity offers scope for a variety of explanations. Iteration is one of them, and not only simple iteration but also Ivakhnenko´s MIA. Both the division of the alpha spindle and the differences between the first and second halves of alpha recruitment seem to substantiate those hypotheses. All interindividual and intraindividual differences in the computations are due to the ubiquitous "random" component in the EEG curve. Hence, our findings are not unambiguous. Also involved are stochastic processes in their "galactic" quantities of cortical neurons and their synapses numbering hundreds of billions.

If we estimate our "alpha life" at some 60 years of duration (roughly from 10 to 70 years of age), and at about 10 hours of alpha activity daily, the time interval of one alpha spindle at approximately one second, then the 3600 alpha spindles per hour multiplied by ten hours amount to 36 000 spindles a day. This number multiplied by roughly 300 days equals 10 800 000 alpha spindles per year, and that multiplied by 60 years means 648 million alpha spindles for all our adult life. That means our disposition singled out for our education, school and professional knowledge and life experience. However, our mentation and memory capacity will be greater than that if the psychic mechanisms in operation during sleep are also brought into play. While we cannot estimate the number of "bytes" contained in an alpha spindle, we should bear in mind that not every spindle represents a successful attempt, i.e., intentionally successful iteration.

The energy level of our neuronal networks often gets stuck in a "local minimum" or is unable to find even the direction of problem solution. Consequently, our mind teems with unanswered questions both professional and everyday-life ones, not to speak of emotional problems. It is only occasionally that our iteration helps us reach the "global minimum", the point where we have come to understand the problem, where the energy function trajectory has reached the minimum, and when the resulting attractor has reached a minimum of energy in the neuronal structure, the end of neuronal selection and cognitive automation, when the optimized neuronal networks have been fixed in memory traces.

Let us emphasize the great differences between the first and the second halves of the alpha spindle also because they are not discernible to the naked eye. More differences exist between the resting and "working" spindles of alpha activity which in this case too are quite considerable interindividually. These analyses may be useful not only for the detection of brain relaxation and activity but also for the detection of some character changes. In particular, society at large would welcome prediction of potentional aggressors´ behaviour in everyday life and behind the steering wheel. All the more so, considering that the analyzed section is very short.

Complex as it is, the EEG curve appears to contain a spectral mix of regular and harmonic as well as stochastic components. An alpha spindle also contains both components, what is more, differently correlated in ALAS and in ALDE, and differently again at rest (NA) and during mentation (CA).

Going by experience, we know that many diseases exhibit changes in the frequency, form, phase and other parameters of alpha activity while still remaining within norm. Hence the difficulty in defining the difference. For instance, the milder forms of the ADHD syndrome (attention deficit-hyperactivity disease affecting up to 10% of the young population) or incipient Alzheimer dementia have no clear-cut pathognomonic changes in the EEG curve. This would also facilitate the detection of worsened concentration and imminent sleep onset, in general, attention changes prediction. That is where the above analyses could be of help. No doubt, the study calls for further mathematical programmes for more sophisticated analysis of the EEG curve, cooperation with psychologists, and more probands to be examined with new diagnostic techniques such as positron emission tomography (PET) or transcranial magnetic stimulation (TMS) and the like.

The results of this deep analysis of EEG signals seems to be supported with results of about 40 sets of measurements on healthy people on transparency and reflections of the electromagnetic rays in near infra-red region, the example of them is shown in Fig.7 (see [46] e.g.).

## 6. HYPOTHESIS AND EXPECTIS CONSEQUENCES

We formulated hypothesis of dual iteration in data processing in the thalamo-cortical reverberation system (TCRS) of the brain:

- MIA (multilayered iterative algorithm) according to A.G. Ivakhnenko,
- and
- "ordinary" iterative with convergence to the target solution in the second phase of data processing. In vigilance, the brain´s electric activity comprises primarily the alpha rhythm (8-13 Hz) of variable amplitude responsible for the fusiform spindle-like shape of those alpha waves - described as the alpha spindle.

As a rule, the general assumption is that the ascending part of the alpha spindle (ALAS) is the same as the descending part (ALDE).

Our aim was to find out whether our hypothesis of differences between the ALAS and ALDE phases is acceptable.

To that purpose, we examined 24 persons by means of EEG and simultaneous short psychotests.

We then compared ALAS and ALDE in the alpha spindle of all the probands both at rest and in a state of psychic activity (mentation) and found a preponderance of alpha in ALAS, which might correspond to a hypersynchronous recruitment of alpha and to the situation evolving in the MIA regimes. There was little change in delta which retained similar values in ALAS as much as in ALDE, probably a reflection of constantly present iteration. Interindividual differences were considerable apparently due to the role played there by psychological and stochastic processes. In our opinion, thanks to these and other sophisticated analyses and to the short EEG curve interval, the above method could be of use not only in the detection of mentation, relaxation, attention disorders and incipient sleep onset, but also for the identification of anomalous types of personality such as impulsive or even aggressive psychopaths and the like.

We can express the expectation, that the presented interrelations between the EEG alpha spindle and the tested person psychic state will be proved also by further larger set of measurements and that their existence can open the way for further improvement of many application cases, in which human subject interact with considerably complex and complicated artificial system or system alliance and in which the reliability of such interactions play crucial role for operation safety, like e.g. in railway (see [41 - 44] e.g.) or road (see [45] e.g.) transportation.

Some part of the main ideas of this paper was presented in [48].

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# Technologies of Road Traffic Surveys

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**Abstract**

The article deals with methods of traffic surveys. It describes the current state used manual methods of traffic surveys and considers the possibilities of modern technologies. Also presents partial results with their actual use. The final section is devoted to the formulation of further research, design and test of new processes, methodologies and algorithms to record the traffic situation and its evaluation by using modern technology.

**Keywords:** traffic detectors, traffic surveys, data measurement

## 1. INTRODUCTION

Traffic engineering works with large amounts of traffic data. The results of many activities depend on their quality. For example, design of new roads and reconstruction of old ones. Improve the quality, safety and traffic fluidity. Also, control, monitoring and other telematics systems cannot works without good data. Data can be retrieved by traffic surveys or by using of different traffic detectors. There are many types and technologies that differ in measured data and technical parameters. With their help, we can measure and evaluate transport data continuously.

Traffic detectors and other sensors are used in large-scale transport and telematics systems. Their task is to monitor the current state of transport and its subsequent control. The functionality and reliability of such systems is well established in practice. It is necessary to mention the disadvantages. They are mostly associated with economic demands. Expensive, is not only the actual purchase and installation of all equipment, but also build the necessary operational infrastructure to supervisory and dispatcher work and ensure their continuous operation. The systems are usable only in a limited range. Only strategically important and traffic busiest areas and sections are equipped with these systems. In practice, they are used in urban areas with high traffic volume, highways and tunnels.

Traffic surveys are one of the areas where it is not used the benefits of traffic detectors. Especially surveys in areas without telematics system that run too short. Such surveys are realized by using of the simplest methods of writing information into paper forms. These methods need a high number of well-prepared staff and contain several errors. They should not be used for long-term and continuous measurements.

There are currently developed the other methods of traffic situation monitoring. It’s mainly the use of cooperative systems, technologies of intelligent vehicles or floating car data (FCD), where information on current traffic conditions is provided without expensive infrastructure equipment. Greater use is still limited by the poor penetration of equipped vehicles in operation and little willingness to provide such data. Future developments can be seen in a switch from technology of "intelligent" infrastructure to technology of "smart" vehicles. This switch is necessary to carefully describe, prepare and verify. The use of modern technology and new methods for monitoring

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and evaluation of transport is very important for the future possibility of partial or full replacement of infrastructure systems.

## 2. Get traffic data

The easiest way to measure traffic data are different methods of transport surveys. Traffic surveys can be defined as a set of activities, which collects information about road, rail or others modes of transport [1]. Traffic surveys are used to provide data for the design or evaluation of the current traffic situation [2].

For clarity, we can classify traffic surveys by different parameters. In terms of transport mode we distinguish traffic surveys on roads, railways, air transport, water transport or the others special types of transport (cable cars) and more. Each of these types can be further divided according to areas of interest to passengers or cargo surveys. There are many other criteria for possible classification. For this text we consider primarily manual and automatic traffic surveys.

### *2.1. Manual methods of traffic surveys*

A large number of traffic surveys are using manual methods. The person monitors the traffic and notes all the necessary data to prepared forms by a pen. Role of these people is very important. There are a few problems of these methods despite the apparent simplicity. One is the required number of persons who realize the research. Their good training is necessary. The second problem is the quantity and quality of data that a person is able to note. With the increased volume of traffic this ability decreases significantly. Another problem is the high risk of human error in measurement. In case of error there is not possible to correct it retroactively.

#### *2.1.1. Quantitative surveys (traffic volume, intersections)*

Among simpler surveys include the survey of traffic volume. Workers at a specified spot record the number of passing vehicles. Every vehicle in the form represents a "line" placed in the appropriate field. Vehicles in this form are divided according to their type, direction (crossing of intersections) and the length of time (usually 5, 10 or 15 minutes). The result of measuring is the time variation of the traffic volume and the modal split. The main disadvantages of this type of survey are errors in recorded data. There is also the danger of manipulated data from the stuff. There are electronic and mechanical tools to improve the surveys quality. There are not too extended in our country. The simpler tools have also a number of disadvantages.

#### *2.1.2. Qualitative surveys (directional)*

More about traffic flow we can found out thanks to qualitative surveys. They are based on the identification of individual cars in various locations of monitored area. Based on information about time of passing vehicles we can specify additional transport parameters (such as speed and traffic density [3]). If the measuring spots are designed properly, it is possible to determine the routes of specific vehicles and expose as the proportion of transit traffic or major roads within the area. Vehicle identification is realized by recording of license plates. This method is used for different types of surveys, including measuring of vehicle speed [6]. The license plates are noted in a form for later retyped into computer for further processing. Two workers are often used in practice. One worker observes the vehicles and the other notes mark about them. It is important for data quality in case of higher traffic volume. There are also used devices for video or audio recordings. All information is recorded and after that is transcribed and evaluated. Transcribing of data is time-consuming and carries a high risk of errors. Risks of handwritten records are primarily on the incompleteness of the data and on problems with readability of letters. The transcript of the digital data is a very time-consuming and lots of errors are caused by bad pronunciation and due to traffic noise or weather conditions. These risks have been known for a long time [5] but it does not mean a greater tendency to used license plate recognition systems.

#### *2.1.3. Surveys of drivers behavior*

This type of survey records drivers’ behavior. This monitoring is so-called "near accident" [4]. Very important is quality of trained staff. They assess the traffic situation and record it the form by prescribed classifications. Rating observed phenomena can be very subjective. It is desirable that similar situations are evaluated in the same manner. Mistake of one person can greatly affect the results of the whole survey. All data are recorded into the prepared paper forms. Another method may be a recording situation on camera.

### *2.2. Automatic traffic monitoring*

The influence of human factor on the results of the surveys can be greatly reduced by using traffic detectors and other sensors. Most detectors require special conditions for their installation. It is also a main disadvantage for their short-term or one-time use. Telematics systems cannot work without them. Detectors are important in systems of traffic control in the cities areas and in systems of road line traffic control [9], in tunnels security systems, but also for automatic data measurement on busy roads [8].

The basic division of detectors depends on whether the device is intrusive or not. For permanent telematics systems can use both types of detectors. For short-term surveys are, however, excluded those that mean irreversible damage to infrastructure. Among non-intrusive technologies include following detectors.

**Laser detectors** are based on sensing the transmitted and reflected electromechanical radiation. On this basis, they can regardless of the time of day to determine the presence of vehicle, his type, speed and duration.

**Radars** detect reflected continuous or pulsed transmitted and reflected signals. They can detect the presence of vehicles, its speed or types.

**Ultrasonic** sensors detect mechanical waves reflected from passing vehicles. According to their construction can monitor the presence, height and speed of vehicles.

**Video detectors** analyze the records on the basis of "virtual loops" detect the passing vehicles and number of other information.

For the purposes of traffic surveys we can also use some intrusive technology.

**Magnetic detectors** are passive sensors that detect variations in the Earth's magnetic field caused by metal parts of passing vehicles. They can monitor the presence, type, and in case of use of multiple detectors the speed.

**Pneumatic detectors** evaluated traffic by changing the pressure signals in rubber tubes caused by passing vehicles.

## 3. The use of modern technology

It is possible to find a number of projects using different technologies for measuring traffic data. Mostly, however, is not about trying to find new opportunities for the implementation of "normal" traffic surveys. Their use is often limited by very specific requirements for placement. There is the clear trend towards the development of autonomous devices. Solar or wind energy is used by these devices. Also high quality wireless data services are available and used for sending measured data. The authors of this article have been dealing with the issue of technology. They focus on their use not only in the implementation of traffic surveys.

### *3.1. Quantitative surveys*

Currently, quantitative surveys are realized by using of manual method with “lines” in paper forms. Various electronic tools are in our country use only rarely and mechanical counters are used even less. The disadvantage of these devices is their limited use for certain types of surveys.

Our goal was the development of the tool with a wider range of use. The result is the application for cell phones, which is simply named “Counter” [11]. The application allows realizing surveys by simply pressing buttons on the phone, which represent different types of vehicles. When you press the button the number and time is remembered. Measured data are saved and available in text format for further evaluation. The advantage is more pleasant for workers. They may spend more time by watching traffic. Icons on the screen are little help for them. The application reduces the risk of cheat and falsification of measured data. Application can be easily adapted to other types of surveys. In the past, for example, was used for measuring of the time required for entry of vehicles to public garages.


Fig. 1. Counter application for cellphone

*3.2. Video (audio) recording*

The use of video cameras to record traffic for subsequent manual evaluation is an effective way to improve the quality of the measured data. Recording allows quality evaluation and control of already processed data. This significantly reduces the number of errors that are caused by poor attention and low-skilled (or motivation) of workers, unexpectedly high traffic volume or other external (climatic) conditions. Use of audio recording of license plates of vehicle is the similar. We must expect that processing of records is more time consuming than the actual length of the survey. It depends on the type of survey. Time of processing of quantitative survey is not too much longer than the time of survey. If there are monitored license plates, multiple profiles or drivers behavior, the length of the processing is several times longer. Cameras are used not only for static entry in a specific location, but also in floating cars for surveys of drivers risk behavior. Required equipment is increasingly available and these methods become more frequently used. Without automatic processing of recordings, we can talk more about useful utility than the effective tools.

*3.3. Video detection (license plate recognition)*

As mentioned earlier, in the case of directional surveys are mostly used manual methods of note of license plates (LP) into the paper forms (or manual processing of video records). It is therefore very useful to use the software for license plate recognition (LPR). Most systems allow recognition of LP in real time. For the traffic surveys purposes is better to use software that allows the processing of already saved records (off-line). The reason is the possibility of implementing the survey on any number of stations, which are equipped with only basic technology. We can use the user-friendly (but technically sufficient) camcorders with the necessary accessories. Recommended accessory is primarily a tripod, external power supply and sufficient storage capacity. Various software tools may vary in algorithms of video processing and quality of the output data. The data output format is most similar. The resulting data contain mainly information about recognized LP and its recognition time. For checking of measured data are very useful also other information about recognition quality, LP position in the image, and more.

For quality software work is necessary to have good video. Desirable is a progressive record with optimal resolution and without any motion blur. Successful LPR is mainly caused by suitable positioning of camera and quality of recording. There are number of situations which determine the quality of results. These situations should be avoided. This is mainly a problem of climatic conditions. Direct sun, shades, rain or fog can have a major impact.

Based on many directional surveys that combined different methods of implementation, we can evaluate their quality [9]. Success of LPR (software) is over 91% correctly identified vehicles. For traditional methods, it is less than 80%. Higher success reached only methods of manual data transcription from video or audio records. Success, however, was compensated by high time-consuming. Duration of manual process is 2-5 times greater than the length of the survey.

Automatic recognition of LP has also disadvantages. One of them is the missing information about the types of vehicles. Many vehicles have its LP dirty, damaged, or missing. The second problem is this type of vehicle that cannot be recognized. Very important is to check the data. By appropriate processes we can to identify and eliminate wrong data. Good results are obtained data control by using algorithms. These follow the similarity of records, missing attributes, remarkably short time gaps or noticeable change in pattern recognition. Subsequent manual control allows confirm the automatically found errors and the addition of vehicle types based on picture from the right time.

Table 1. Success of different types of directional surveys [7]

| | | proportion of detected vehicles [%] | | | |
|---|---|---|---|---|---|
| | | correct | incorrect | missing | moreover* |
| survey type | manual transcript of video record | 97,6 | 2,3 | 0,1 | 0,05 |
| | automatically recognition (SW) | 91,3 | 1,8 | 6,9 | 2,7 |
| | manual transcript of paper forms | 78,4 | 19,2 | 2,4 | 1,3 |
| | manual transcript of audio record | 92,6 | 5,5 | 1,9 | 0,1 |

* Vehicles detected as „moreover“ are not included in total.

However, control does not solve the problem of missing records. This could be solved by adding more other suitable detector. Now the issue of design of functional traffic detectors combination and fusion of heterogeneous traffic data from different sources is a key area of our further work.

### *3.4. Other types of traffic detectors*

A higher proportion of using traffic detectors in the implementation of surveys is a good way to future use of their functional combinations. Already, various technologies are successfully used. Others are often neglected, although they can also provide quality data.

Example of frequently used detector is microwave radar. As the strategic detector is usually part of the telematics systems. Detectors are also offered in a version with a battery and own data storage. This type is an ideal tool for traffic surveys. Based on the measurements it is possible to easily evaluate the daily and weekly variations of transport.

There are other technologies that can be used. Their expansion is not as great as might be expected. It is worth mentioning two technologies that belong to intrusive group of sensors. Perhaps this is the reason to distrust them. In our country are not as widespread as in Anglo-Saxon countries. It is the magnetic and pneumatic detector. Both should be affixed to the ground, but only with little or damages of road. Quality of measured data is at the same level as intrusive detectors data.

One of the activities of researchers and students of Laboratory of traffic control and modeling is testing different types of detectors and technologies. Currently we also test magnetic, pneumatic, combined or video detectors.

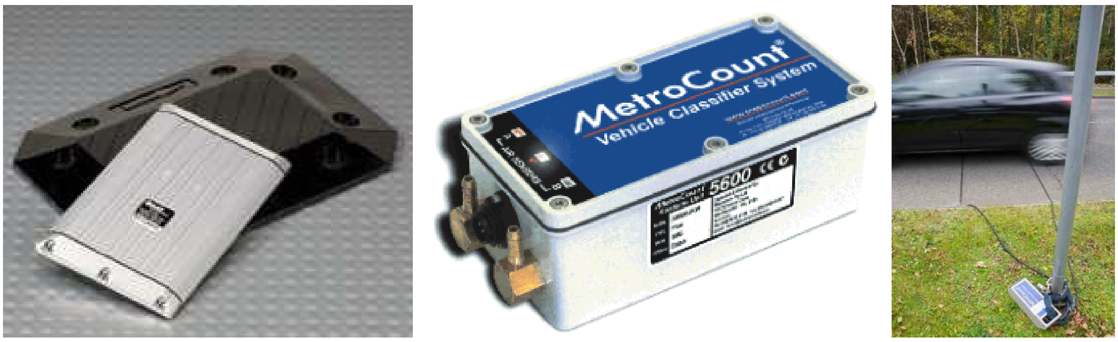


Fig. 2. (a) Magnetic [10] and (b, c) pneumatic detector [12]

## 4. Further research

One of the main motivations for further research in this area is the claim that over a wide range of modern traffic detectors, the most standard traffic surveys carried out manually (high risk of human error and low data quality) The expansion of current telematics systems to a wider range of transport infrastructure is not economically realistic. The aim is not only the possibility of replacing manual methods of surveys with automatic. The aim is also wider use of technology at traffic monitoring and control. It is desirable to use and test new methods and systems, which may include FCD data or cooperative systems.

The main objective of further work is design of new processes, methodologies and algorithms to record the traffic situation in the area and using networks of heterogeneous mobile sensors of traffic data. We assume the use of modern technologies. The requirement is a comprehensive measuring of transport parameters, increasing the quality of the measured data and the reliability. As a perspective technology for research it seems video detection in combination with the other types of intrusive and non-intrusive detectors. The bases for further action are the following assumptions: cooperation of various types of detectors; sensors networks and alliances; necessary synchronization of all actions; communication, compatibility and integrity of data outputs. The vision of the proposed methods is the direct use of technology in practice and the monitoring and evaluation of traffic conditions in real time.

## 5. Conclusion

The objective of this article is to summarize the experience with the implementation of traffic surveys and performance goals and objectives of further research activities. The proof of timelines and importance is number of research projects that are implemented in this area. Currently most significant is project "RODOS". This project is funded by Technological agency of Czech Republic. Whole name of project is the Centre for development of transport systems. Faculty of Transportation Sciences is of number of other important commercial and research subjects.

The issue is solved at many levels of school activities. Many of the goals described in this article will be filled in the doctoral thesis of its author and his supervisor [13]. Design of combination of detectors is also supported by student projects competition for year 2013. Many other sub-objectives are solved by students in their student projects and bachelor or diploma thesis. All technologies of Laboratory of traffic control and modeling is available for further research.

## Acknowledgment

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# Complex Information Systems

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**Abstract**

This paper presents original approach into information representation, transmission and processing together with their features that yield into basic principles of informatics. Models of complex systems are based on knowledge from information science [1] that has been gathered over the years in classical physics, a specialized part of which is called information physics. At present, this discipline is still in its infancy, but many discoveries have already been made [8] and some scientists have realized that without basic theories in this area, the further development of human knowledge will not be possible.
The proposed methodology represents the new ideas that come from defined mathematical assumptions like information-electrical or information-mechanical analogies. From these simple assumptions a lot of information physical principles can be derived like for example information flow, information content, information power, etc. Analogies among electrical, mechanical and information circuits seem to be efficient attempts for problems solving within systems engineering [9]. Concepts of information power [10] and significant proximity of the measure of information and knowledge could enable upgrading these analogies for solving even wider class of tasks.

**Keywords:** information, knowledge, information power, syntactic information, semantic information, quantum information

## 1. INTRODUCTION TO INFORMATION SCIENCE

Data mean a change of state, for example from 0 to 1 or from 1 to 0, where the state vector is not necessarily only digital or one-dimensional. Every such change can be described with the use of a quantity of information in bits [5]. Information theory was founded by Claude Shannon [2] and his colleagues in the 1940s and was associated with coding and data transmission, especially in the newly emerging field of radar systems, which became a component of defensive systems during the Second World War.

Syntactic (Shannon) information has been defined as the degree of probability of a given event [10] and has replied to the question: how often a message appears? For example, by telling you that the solar system would cease to exist tomorrow, I would be giving you the maximum information possible, because the probability of this phenomenon occurring is nearly equal to zero. The probability model of information so defined has been used for the designing of self-repairing codes, digital modulations and other technical applications [13]. Telecommunications specialists and radio engineers were concentrating on a probabilistic description of encoded data and on the minimizing of probability errors during data transmission. The model-theoretical work of semantic information was done by Carnap and Bar-Hiller [3]. On the other hand, semantic information asks: how often a message is true? Lotfi Zadeh [4] introduced the theory of fuzzy sets as functions that map a value, which might be a member of a set, to a number between zero and one, indicating its actual degree of membership.

Currently, a number of interesting results have been discovered in the field of quantum information science [8], taking as their basis the foundations of quantum physics and using for modeling of complex systems those principles that do not arise in classical physics, such as entanglement and quantization. In the technical literature, we read that the behavior of entangled states is very odd. Firstly, it spreads rapidly among various phenomena, where for this spreading it makes use of a property known as entanglement swapping [18]. The quantum information quantity in bits can be measured e.g. by von Neumann entropy [8] which measures the amount of uncertainty contained within the density operator taking into account also wave probabilistic features like entanglement, quantization or bosonic / fermionic quantum behavior [17].

On the basis of the information theories, a number of methods and algorithms have emerged [15] that attempt to eliminate or minimize indefiniteness and to do a better job of extracting the real, useful information from data. An excellent example is the Bayes method [6], which interprets the density of probability not as a description of a random quantity, but rather as a description of the indefiniteness of the system, i.e. how much information we have available about the monitored system. The system itself might be completely deterministic (describable without probability theory), but we may have very little available information about the system. When performing continuous measurement, we obtain more and more data, and therefore more information as well about our system, and our system begins to appear to us to be more definite. The elimination of indefiniteness therefore increases the quantity of information we have about the monitored system.

When eliminating indefiniteness, we also have to bear in mind the possibility of a change to the context of the event or phenomenon. There is plenty of testimony available to us from live witnesses, but there is none from dead ones, and this gives us an asymmetrical set of observations [7]. It brings to mind the well-known saying that history is not written by the losers.

Once indefiniteness has been eliminated, one may proceed to the interpretation of information, or in other words, to the determination of how to reconstruct the described system, or how to build a more or less perfect model of it using the information. This task already belongs to the theory of systems [9], where it is necessary to identify the state vector, individual processes of the system etc. There emerges from this a knowledge system, which is able to describe the given object appropriately.

Information systems [14] aim to support management, operation and decision making, e.g. expert system, geographical information system, enterprise system, etc. Components of computer-based information systems are hardware, software, databases, networks and procedures.

Information behavior [15] means human behavior in relation to sources and channels of information - both active and passive information-seeking and use in different contexts. Information can be treated as physical matter or physical entity, and as such can be studied using the same methods as those applied by physics to study the properties of the physical matter. That is why new field information physics is established.

If we wish to apply information theory to the natural sciences, we should begin by describing information systems using a mathematical tool similar to one by which physics is described. We would therefore use analogies between various physical systems. In every such system, there exists potential and kinetic energy, to which there are corresponding quantities of potential and flow. In electronics, for example, voltage is defined as the quantity of potential, and electric current is the quantity of flow.

Let us then introduce a unit for the current of information and call it information flow, which is measured in bits per second and describes the input or output of information per unit of time. We can analogously define a quantity of potential, which we would call information content, which determines the quantity of work per bit (in Joules per bit). Information content for information systems (IT/ICT) can be defined as the number of ‘success events’ in the system per bit of information, and one may expect that if received information is significant, in information system a sequence of ‘success events’ is activated that orders our system. This also means that in order for us to obtain any concrete information content, we would already have to have done work, such as studying, searching for documentation, preparation etc. On the other hand, it could be the other way around: the given information content might enable us to obtain a certain quantity of energy or (nowadays) funding [21].

From knowledge of information flow and information content, one can define other information physics quantities. One of the important quantities can be information power [10], defined as the product of information flow times information content. Analysis easily reveals that the unit of information power is work per second realized thanks to the received bit of information. For information systems (IT/ICT), information power is defined as the number of “success events” per second caused by the receipt of one bit of information. By introducing the quantity of information power, one can demonstrate that the impact of information is maximized if the received information flow is appropriately processed by the recipient and transformed into the best possible information content. If there is a flow of valuable information that the recipient is incapable of processing, the information power level is low. On the other hand, if the recipient is able to make good use of the information flow, but the flow does not carry needed information, the result is likewise a low level of information power.

We can take these ideas even further and introduce a phase shift between the information flow and content, thereby arriving at the definition of active and reactive information power [11]. We can imagine active information power as power caused by information, which is transformed directly into concrete physical events. Reactive information power represents our emotions, which of course do not perform any work, but which support our decision making. Worth mentioning in this context is a well-known Bible story: King Solomon proposes to have a child split in half when two women are fighting over it, but because of her emotions, the real mother would rather give up her child than let it be killed.

An interesting area of information physics is the perception of time, which we can imagine as the number of biological events taking place in our bodies with a given frequency. If the information power intake is slower than our biological clocks, we have the feeling that time is moving slowly, but if intake is faster, we have the feeling that time is being well used.

## 2. MODELS OF COMPLEX INFORMATIN SYSTEMS

On the basis of the previous definitions, we can continue with the quantities we have introduced, information flow and information content, as well as with the quantities we have derived from them, such as information power. For the sake of simplicity, let us imagine an information subsystem as an input-output information gate given on Fig.1.

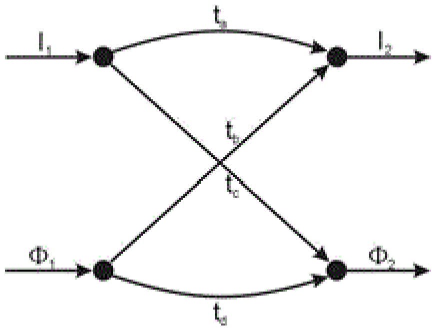


Fig. 1.– Information gate ( $\phi$ - information flow of data measured in bits per second, I - information content measured in Joule per bits)

Between the input ports, input information content is available, and input information flow enters the system. Between the output ports, it is possible to obtain output information content, and output information flow leaves the system.

We can furthermore assume that this subsystem is open and is capable of using its surroundings as a source for drawing energy. Stuart Kauffman introduced the term autonomous living agents [12], which are characterized by the ability to direct and release energy. Kauffman is also the originator of the idea that the orderliness that is characteristic of living systems is defined by a series of actions leading to the dissemination of macroscopic work.

Let us now examine the input-output information gate we have created. Input quantities can describe purely intellectual operations. Input information content includes our existing knowledge, and input information flow describes the change to the environment in which our gate operates and the tasks we want carried out (target behavior). All of the valuable, long-term information gained in this way can be used for the targeted release of energy, where at the output of the input-output gate, there may be information content on the order of millions of Joules per bit (or profits in millions of dollars). The output information flow serves as a model of the providing of such services or knowledge.

The basis of information systems is the ability to interconnect individual information subsystems, or in our case, input-output information gates. It is very easy to imagine the serial or parallel ordering of these subsystems into higher units. A very interesting model is feedback of information subsystems, because it leads to non-linear characteristics, to information systems defined at the limit of stability and other interesting properties. In this manner one may define information filters, which are able to select, remove or strengthen a particular component of information.

In the context of information physics, it is also necessary to deal with the problem of teaching, because the information subsystem called a teacher may be regarded as a source of information content. The teacher has prepared this information content for years with respect to both the content as such (optimizing the information content) and its didactic presentation (optimizing the information flow), so that the knowledge can be passed on to a subsystem known as a student. If we assume that the teacher subsystem has greater information content than the student subsystem, after their interconnection, the information flow will lead from the teacher to the student, so that the information content of the two subsystems will gradually balance out.

The students receive the information flow and increase their information content. If the students are not in a good mood, or if the information flow from the teacher is confused, the students are unable to understand the information received and to process it, so as to increase their information content. With the help of the reactive information power mentioned above, which concerns the emotional aspects of the recipient and the source, i.e. the student and the teacher, it is possible to create a situation where the students' sensitivity to the received information flow is maximized, so that they are able to process it appropriately and transform it into information content. Analogously, the teacher being in a good mood can lead to the creation of better information flow.

The individual components and subsystems of information systems can behave in different ways, and their behavior can be compared to everyday situations in our lives. A characteristic of politicians is their ability to use even a small input of information content to create a large output information flow. They have the ability to take a small amount of superficially understood content and to interpret and explain it to the broadest masses of people. On the other hand, a typical professor might spend years receiving input information flow and input information content, and within her/his field, he/she may serve as a medium for transmitting a large quantity of output information content. The professor, however, might not spread the content very far, sharing it perhaps only with a handful of enthusiastic students.

It is hard to find an appropriate system to combine the characteristics of the different information subsystems described above, but it is possible to create a group of subsystems (system alliances [16]), where these characteristics can be combined appropriately. In this way, one can model a company or a society of people who together create information output that is very effective and varied, leading to improved chances for the survival and subsequent evolution of the given group. Such approach yields into society knowledge firstly introduced by Friedrich Hayek [22].

Through an appropriate combination of its internal properties, our information alliance can react and adapt to the changing conditions of its surroundings. Survival in alliances thus defined seems more logical and natural than trying for a combination of all necessary processes within the framework of one universal information subsystem.

## 3. CONCLUSION

For many years, I have been observing how much difficulty natural sciences have with explaining the basis of life, the behavior of living beings or of society, and how such important terms as information or knowledge have gradually crept into thinking in these fields.

It is as if we were building a house. We would need material (or mass), we would need plenty of workers (or energy), but without knowledge of the plans for when and how to build, we could not erect the house. Information and knowledge are therefore the things that could enrich the natural sciences, enabling them to describe more faithfully the world around us.

In this text I tried to present basic approach to the information physics and to the complex information systems. I personally believe that the capturing of processes in the world around us with the help of information and knowledge subsystems organized into various interconnections, especially with feedback, can lead to the controlled dissemination of macroscopic work as described by Stuart Kauffman [20], and after the overcoming of certain difficulties, even to the description of the behavior of living organisms.

I am convinced that the future will see a convergence of the physical sciences, life sciences and engineering. I would even allow myself to go a bit further, to consider even convergence with the humanities, because I am convinced that the laws of behavior of human society described, for example, in sociology or political science will be able to be better understood using the tools of information physics.

From the examples given above, I see the possibility for linking the physical world with the world of information, because every information flow must have its transmission medium, which is typically a physical object (e.g. physical particles) or a certain property of such an object. The case is again similar with information content, which also must be encoded through a real, physical system. The operations defined above the information systems can then likewise be depicted in a concrete physical environment.

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# DEPARTMENT OF AIR TRANSPORT

# K621

# Actual 3D Wind Model Based on Reports from Commercial Aircraft

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**Abstract**

Exact knowledge of wind conditions is very important for aviation. Official available information (provided by Czech Hydro Meteorological Institute) is based on satellite images, on upper wind chart (provided by WAFC – London) and on numerical forecast model. But more precise, accurate and with much better resolution wind 3D model for local area airspace might be obtained by using data collected from commercial aircraft flying through our airspace. This technology is using well known principle of radar interrogation. This is new way of using aircraft derived data via mode S air traffic control radar beacons.
The following text introduces how can be very easily created current 3D wind model based on information provided by commercial aircraft via routine radar interrogation

**Keywords:** wind speed, wind direction, mode S technology, aircraft derived data,

## 1. INTRODUCTION

It is not so easy to have actual information about wind conditions for airspace users (airliners, pilots, air traffic controllers, hydro meteorological institutes …). It could be derived from wind chart provided by WAFC* – London (see figure 1 – forecast wind and temperature chart which is created from 00:00 UTC data on 31st March 2013 and this 3-hours forecast is valid for 1st April 2013 from 00:00 UTC).

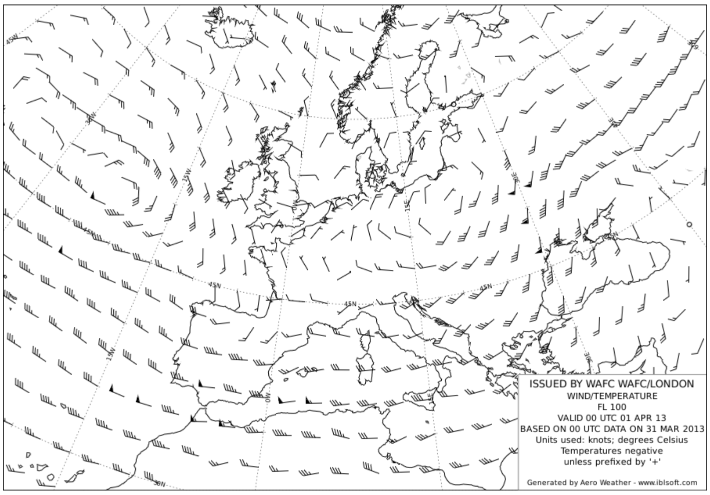



Fig. 1 Wind and temperature forecast chart for FL100 valid from 00:00 – 03:00 UTC (1st April) [3]

* WAFC – World Area Forecast Center - London

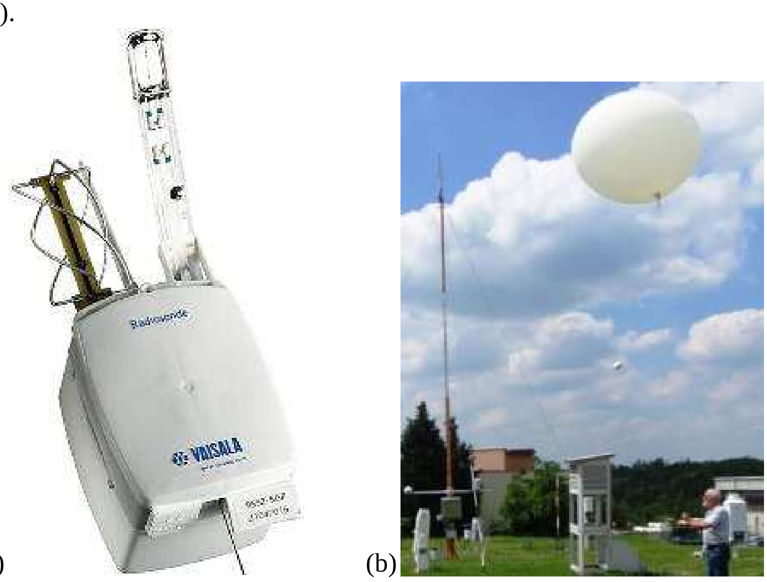
As you can see in figure 1, it is not easy to estimate current wind condition for particular position in your airsapce because the nodal points (grid) of the chart are too sparsely defined. For more efficient usage is neccesary to have thicker distribution of nodal points for particular area.

It comes out from the users (air traffic controllers) request to create more efficient and more user friendly 3D wind model. They´re very often asked by pilots for wind conditions in different flight level (higher or lower to perform the flight more efficient – in shorter time and less fuel consumption). But as it is mentioned before it is not so easy to satisfy and answer those questions.

## 2. DATA COLLECTED FOR ACTUAL WIND MODEL

### *2.1. Official CHMI [†]measurement*

The rough data for numerical weather model (base for wind chart) comes from aerological measurements of the radiosonds (see figure 2).




(a) (b)

Fig. 2 – LEFT – Radiosond used by CHMI (model RS92-SGP by Vaisala) ; RIGHT – the aerological measurement beginning (radiosond with balloon is launched)

There are 3 measurements during the day: at 00, 06 and 12 UTC from aerological station Prague – Libuš (part of the net of the World Meteorological Organization) every day. Most of radiosonds ascents through the atmosphere usually up to height of approx. 30 km. The power to climb is given by nitrogen-filled balloon and the duration of the flight is approx. 90 minutes till the balloon blasts. It means the end of measurement. Radiosonds provide data not only about wind (speed and direction) but they also measure relative humidity, temperature and atmospheric pressure.

### *2.2. Usage of commercial aircraft as radiosonds*

Now imagine the situation to change all aircraft to radiosonds. There will be suddenly data not only from 3 measurements in a day from the same position (Prague – Libuš) but data from the whole airspace which is in coverage of Mode S air traffic control radar beacons.

Almost each commercial aircraft is well equipped to measure or compute data like wind speed and direction (really well equipped aircraft are able to measure even the humidity) and of course its track angle, heading, true air speed, indicated speed, ground speed and other data. The task to solve was how to get those data to ground station but it has been solved year ago. According to the AIP CR (paragraph 1.5.1.1.1) is the carriage and operation of

[†] CHMI – Czech Hydro Meteorological Institute

Mode S transponders with EHS[‡] (see following sub-paragraph) functionality mandatory in FIR Praha for fixed-wing aircraft operation IFR flights with maximum approved take-off mass exceeding 5,7 tones or with maximum true air speed exceeding 250 knots (463 km/h). What exactly brings the previous statement in reality see the following paragraph [10].

*2.3. Enhanced surveillance and BDS registers*

Each commercial aircraft is equipped by secondary radar transponder (abbr. from transmitter responder). Transponders operated at least at level 2 in EHS maintain avionics data in 256 different 56-bit wide Binary Data Store (BDS) registers that can be loaded with information and read-out by the ground system (e.g. secondary radar). These BDS registers are also known as Ground Initiated Comm B (GICB) registers. The definition of each register could be found in [1]. Information contained in register is updated within a fixed period. Not updated registers are cleared automatically by transponder. It means there should be only current data.

Following illustration demonstrates the organization and basic data flows for the transponder registers used in ELS (yellow) and EHS (red) applications

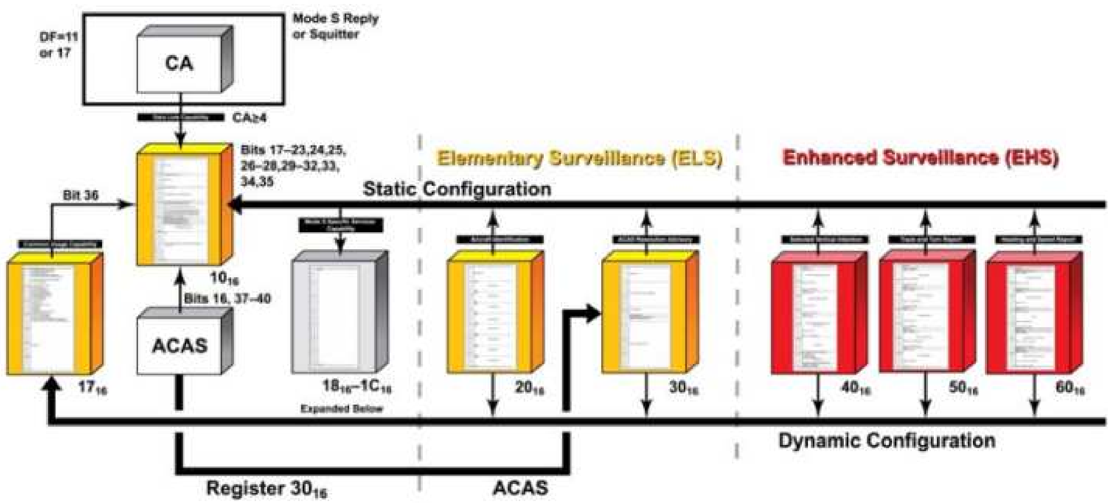


Fig. 3 – BDS register assignments [1]

Each register is identified by a two digits hexadecimal number. In relation to the text above, aircraft equipped for EHS have to provided data from registers $(40)_{16}$, $(50)_{16}$ and $(60)_{16}$.

Such data are interrogated by radar as mandatory provided information by aircraft in EHS airspace. Wind speed and wind direction could be compute based on those data (see table 1) – this algorithm is known as **wind triangle**.

***Table 1*** *– List of downlink aircraft parameters (DAP) from Mode S EHS (DAPs are comply with the EASA AMC 20-12) [2]*
*Note: highlighted data are used for wind speed and direction computation.*

| BDS register | Basic DAP set |
|---|---|
| BDS 4,0 | Selected Altitude |
| BDS 5,0 | Roll Angle |
| | Track Angle Rate |
| | **True Track Angle (TRK)** |
| | **Ground Speed (GSP)** |
| BDS 6,0 | **Magnetic Heading (MGH)** |
| | Indicated Air Speed (IAS)/ Mach no. |
| | Vertical Rate |
| | **True Air Speed (TAS)** |

*2.4. Enhanced surveillance and BDS registers*

‡ EHS – Enhanced Surveillance

Transponders contain even two registers managing the meteorological data. $(44)_{16}$ called “routine meteorological reports” and $(45)_{16}$ called “hazardous meteorological data”. But to gain these registers is quite difficult because not every transponder is automatically configured to provide these registers and it requires also special configuration of ground sensors (radars) to interrogate these registers. Two radars have been configured (Praha, Buchtův Kopec) on demand of this research since May 2010 in the Czech Republic. It was found out that only 1/4 of aircraft provides data from register $(44)_{16}$ from which can be explicitly decode the value of wind speed and wind direction computed by aircraft avionic.

## 3. PRINCIPLE OF THE WIND TRIANGLE

Because each aircraft accomplishes the conditions listed in AIP CR (paragraph 1.5.1.1.1) has to be EHS equipped, it brings enormous amount of basic data (ground speed, true air speed, magnetic heading and true track angle) to compute wind conditions from each position where we received the reports from aircraft. Radar beacons are set to interrogate mandatory register $(50)_{16}$ and $(60)_{16}$ every second rotation. It means, reception of data for wind computation is obtained about every 10 seconds from each aircraft. Graphical representation of the wind estimation is depicted in the figure 4.

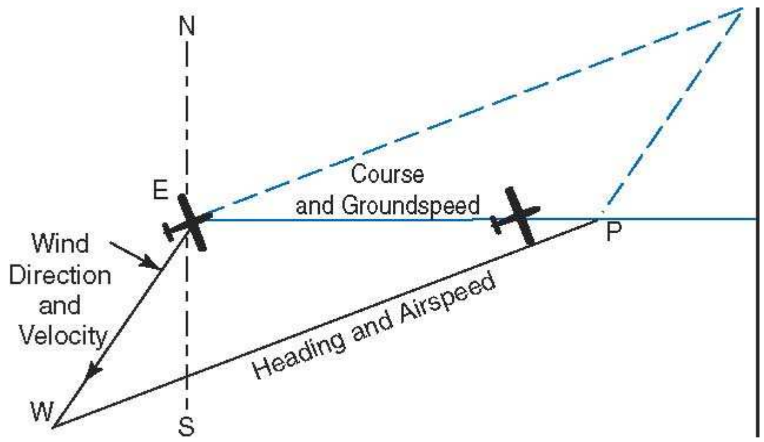



Fig. 4 Principle of the wind triangle

If a flight is proceeding on a course to the east, with a wind blowing from the northeast, the airplane must be headed somewhat to the north of east to counteract drift. This can be represented by a diagram as shown in figure 4 above.

By using following equations for wind speed (1), resp. (1a) and (1b) and wind direction (2) can be computed the values very easily.

$$WS = \sqrt{Vx^2 + Vy^2} \quad (1)$$

$$Vx = (-TAS * \sin(MGH + DEC)) + (GSP * \sin(TRK)) \quad (1a)$$

$$Vy = (-TAS * \cos(MGH + DEC)) + (GSP * \cos(TRK)) \quad (1b)$$

$$WD = (270 - arctan2(Vy, Vx)) mod\ 360 \quad (2)$$

Legend:

- TAS – true air speed
- MGH – magnetic heading
- GSP – ground speed
- TRK – track angle
- WS – wind speed
- WD – wind direction
- Mod – modulo division
- DEC – magnetic declination[§]

Note: function *arctan2(Vy,Vx)* converts rectangular coordinates (*Vx,Vy*) to polar coordinates (*ro*, *theta*) and returns *theta*.

## 4. DATA VALIDATION / COMPARISON

After completion of the first step which means data collection (track angle, magnetic heading, ground speed and true airspeed) and computation of wind speed and direction we can move to the next one which is the results verification.

There are several ways how to check the computed values by ground station:

- Comparison of computed wind data with wind speed and wind direction provided by the same aircraft in meteorological BDS registers $(44)_{16}$.
- Comparison of computed data with output from aerological measurement based on radiosonds.
- Comparison with wind conditions depicted in the WAFC forecast wind chart for EUR region for particular time period (for wind chart see figure 1)

## 5. ERRORS IN MEASUREMENT AND COMPUTATION

### *5.1. Magnetic declination*

In the end of the third paragraphs, there are basic equations for the computation wind speed and direction from the 4 basic values (magnetic heading (MGH), track angle (TRK), ground (GSP) and true air speed (TAS)). The results showed that wind speed and especially direction measured by aircraft is slightly different from the values of wind speed and direction computed by ground station.

Accurate values of TAS and MGH are essential for accurate wind computation. At low speeds, errors in TAS and MGH can lead to large errors in wind direction [5].

For more precise computation we take into account variable value of magnetic declination for different position of aircraft defined by coordinates. The magnetic declination for the Czech Republic varies from 2°30´E in eastern part up to 4°30´E in western part – using International Geomagnetic Reference Field Model for (epoch 2010 – 2015) see figure 5.

When using varying value of declination instead of one constant value for all observations in relation to the current position of the aircraft, the computed values of wind conditions were more precise (approximately about 30%).

[§] Magnetic declination - sometimes called magnetic variation, is the angle between magnetic north and true north. Declination is considered positive east of true north and negative when west. [4]

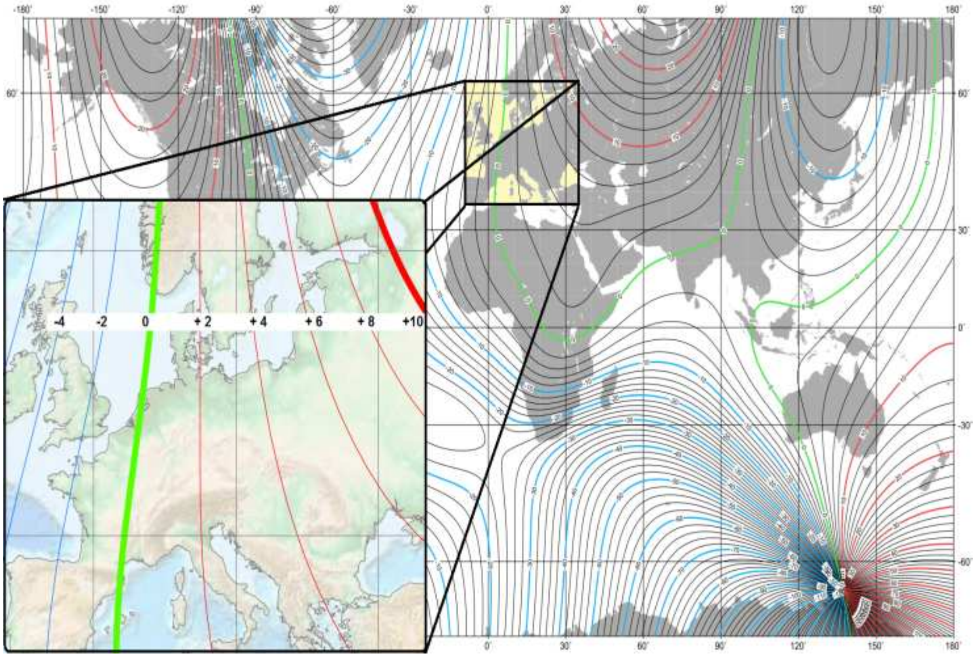


Fig. 5 US/UK World Magnetic Mode, Main Field Declination, [6]

*5.2. Aircraft maneuvers*

During more precise studying of the results was detected that maneuvering (climbing, descending, turning or even combination of these maneuvers) can cause big inaccuracy in measured data (TRK, MGH). At high pitch or roll angles, wind vector errors (which are proportional to true airspeed) can be significant.

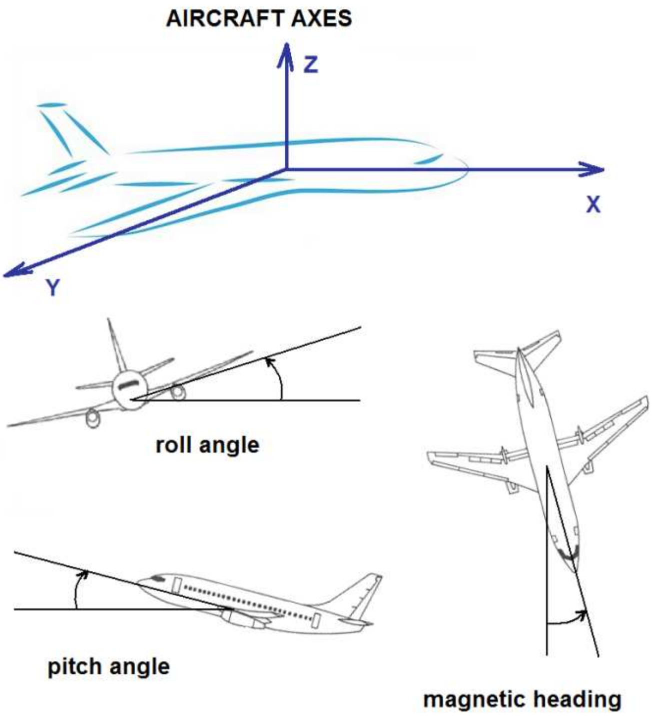


Fig. 6 Aircraft reference axes and manoeuvres

Although full resolution of the wind vectors requires measurements of aircraft pitch, roll and yaw too, in normal level flight could be these angles very small and can be neglected. However, errors during maneuvers can be significant, so the data should be excluded when the roll and pitch angle is above a certain threshold. In [7] is proofed that with 5° pitch and 10° roll might be expected wind vector error about 2 knots (1 m/s). This is valid statement for airspeed about 150 knots. If the airspeed is increased twice (approx. 300 knots) the wind vector error doubles to 4 knots (2m/s).

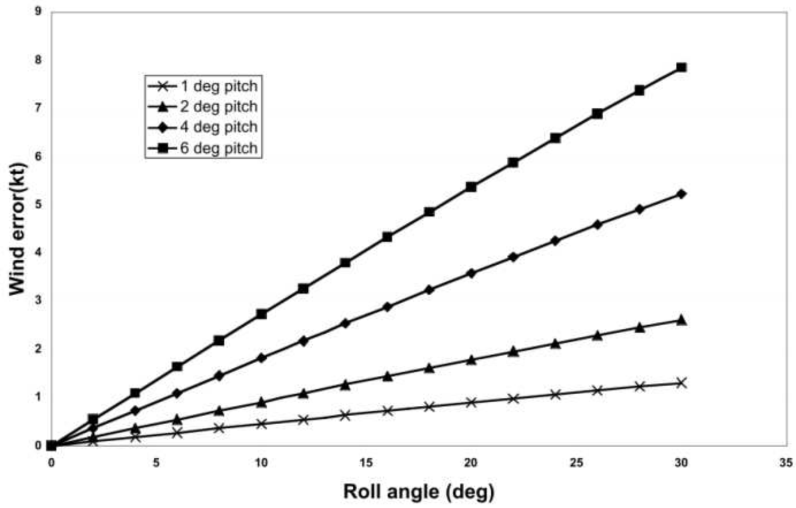



Figure 7 – Effect of pitch angle on wind speed

At low wind speeds, error in wind directions can be large. Considering all the above error sources and combining wind speed and direction errors as vector error, it is suggested in [7] a typical uncertainty of 4 – 6 knots (2 – 3 m/s).

To create 3D wind model, there are sufficient amount of observations only from horizontal parts of the flight. The input data requirement can be therefore reduced to true airspeed, ground speed, magnetic heading (corrected by declination) and track angle.

## 6. COMPUTED WIND DATA FROM TRK, MGH, GSP AND TAS; COMPARISON WITH AIRCRAFT METEOROLOGICAL BDS REGISTERS

In the tables and graphs below, there are summarized preliminary outputs of comparison of computed wind speed and direction (computed from track angle, magnetic heading, ground and airspeed) with wind speed and direction provided in meteorological BDS register $(44)_{16}$ containing wind data computed by aircraft avionics.
First of all should be shown the basic overview: what is the number (on average) of aircraft providing BDS $(44)_{16}$ plus EHS data and number of aircraft providing EHS data only – see table 2.

*Table 2 – Average number of aircraft provided data (per day)*

| BDS registers | Number of Aircraft |
|---|---|
| $(44)_{16}$, $[(50)_{16}$, $(60)_{16}]$ = EHS | **357** |
| $[(50)_{16}$, $(60)_{16}]$ = EHS | **4364** |
| Total count of aircraft within radar coverage | **4490** |

The differences between computed wind data by ground station and data computed by aircraft avionics could be found in the table 3 followed by diagrams which illustrates the results.

*Table 3 – Differences between wind speed and direction computed by aircraft and grand station (numbers in table are count of observations (average per day, 10/2012 – 03/2013))*

| Wind Speed | | | | | Wind Direction | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| UTC | <0;5) | <5;10) | <10;15) | ≥15 | UTC | <0;5) | <5;10) | <10;15) | <15;20) | <20;25) |
| 0 | | | | | 0 | | | | | |
| 1 | | | | | 1 | | | | | |
| 2 | | | | | 2 | | | | | |
| 3 | | | | | 3 | | | | | |
| 4 | 10 | | | | 4 | 8 | 2 | | | |
| 5 | 1246 | 250 | | | 5 | 521 | 325 | 171 | 144 | 119 |
| 6 | 3857 | 3 | | | 6 | 1963 | 990 | 404 | 182 | 77 |
| 7 | 4018 | 224 | | | 7 | 2391 | 885 | 412 | 135 | 106 |
| 8 | 4834 | 438 | | | 8 | 3267 | 1128 | 441 | 173 | 89 |
| 9 | 5889 | 43 | | | 9 | 3476 | 1458 | 403 | 208 | 147 |
| 10 | 3459 | | | | 10 | 2131 | 826 | 220 | 135 | 58 |
| 11 | 5806 | 12 | | | 11 | 3967 | 942 | 311 | 307 | 190 |
| 12 | 6881 | 68 | 1 | | 12 | 3654 | 1578 | 707 | 499 | 142 |
| 13 | 3762 | | | | 13 | 2495 | 867 | 234 | 79 | 35 |
| 14 | 5319 | 25 | | | 14 | 3272 | 904 | 282 | 236 | 195 |
| 15 | 4055 | 31 | | | 15 | 2490 | 925 | 207 | 126 | 141 |
| 16 | 4514 | 47 | | | 16 | 2361 | 915 | 209 | 136 | 204 |
| 17 | 4648 | 65 | | | 17 | 1983 | 621 | 476 | 569 | 380 |
| 18 | 5404 | 52 | | | 18 | 6077 | 1117 | 279 | 233 | 212 |
| 19 | 1991 | 20 | | | 19 | 1366 | 486 | 81 | 40 | 17 |
| 20 | 2393 | 5 | | | 20 | 1836 | 439 | 68 | 19 | 8 |
| 21 | 2368 | 1 | | | 21 | 1758 | 437 | 116 | 36 | 10 |
| 22 | 72 | | | | 22 | 35 | 15 | 5 | 3 | 5 |
| 23 | 98 | | | | 23 | 86 | 12 | | | |

The charts below (figure 8 and figure 9) are based on data from table 3. Values in table legends on right sight are in knots.

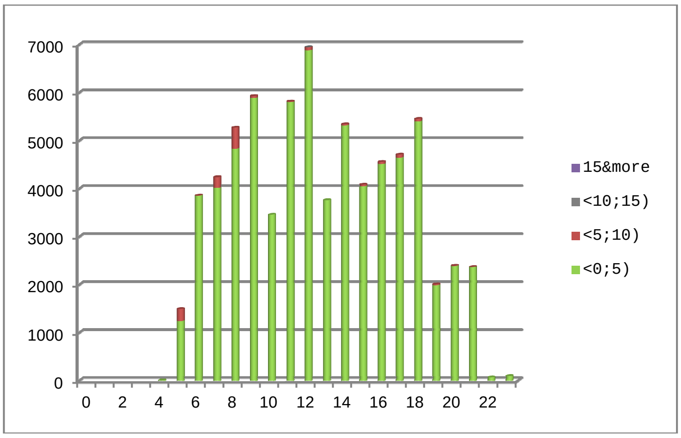



Figure 8 – Differences between computed wind speed and wind speed provided by aircraft (axis x – time in UTC, axis y – number of observations)

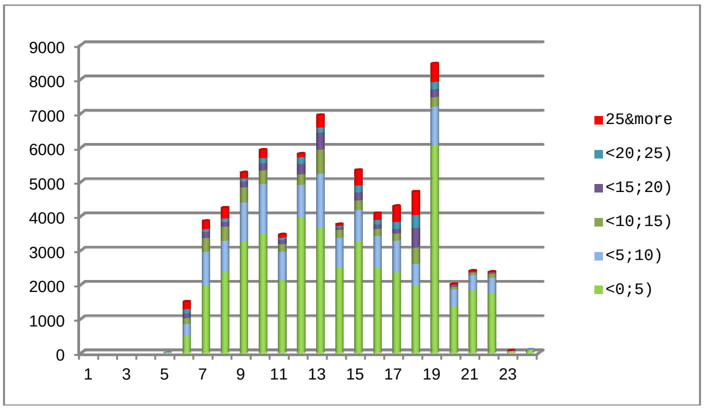



Figure 9 – Differences between ground station computed wind conditions and wind conditions provided by aircraft (axis x – time in UTC, axis y – number of observations)

In figure 10 below, there are 2 pie charts of above presented data (upper chart – wind speed differences, lower chart – wind direction differences)
.

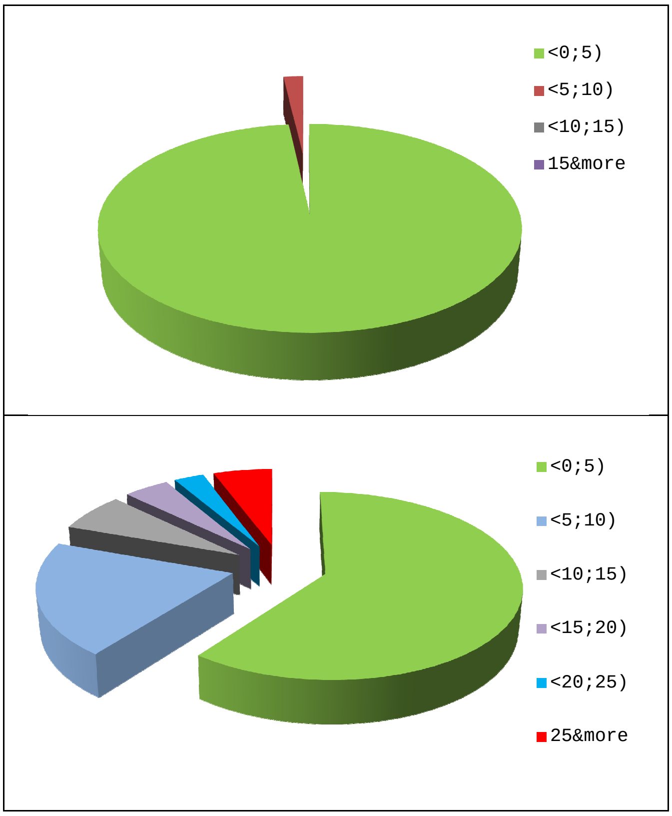



Figure 10 – Pie charts of differences between computed data by ground and aircraft station (based on average data from table 3), values in legends are in knots

It should be also mentioned what is the total count of observations. On average, there are 71 thousand of observations where the reference meteorological BDS register $(44)_{16}$ is provided for validation. When taking into account only registers with data for computation of wind triangle, there are more than 1.3 million observations per day (from the airspace within the range of used radar beacons – see figure 11).

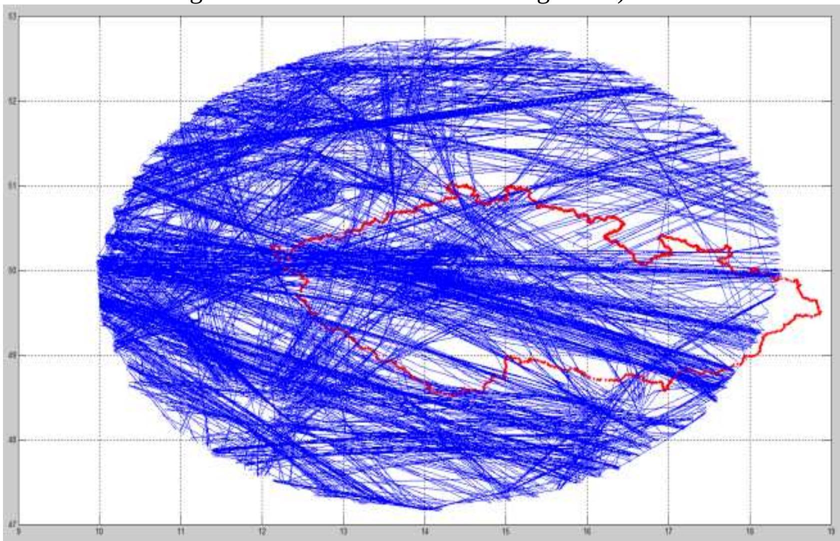


Figure 11 – Trajectories of aircraft provided EHS registers, time period: 27-03-2013 00:00 – 08:00 UTC, (axis x – longitude, axis y – latitude, values in degrees)

## 7. CONCLUSION

It was proofed that data are mostly valid but not 100% correct. There are several main reasons causing the error (described in paragraph 5). Nevertheless, it can be said that the Mode S observations are valuable source of information for meteorology, when the observations are calibrated and smoothed. Some smoothing algorithms which could be used are presented in [7]. Other recommendations and validation algorithms (especially for wind triangle) could be found in [8].

As could be seen in figure 10 (lower part), system is working in 80% accuracy (differences up to 10 degrees) in wind direction. Calculation of wind speed is correct in more the 95 %. It must be said that this result include also the error observations when the aircraft perform any maneuver (climbing, descending, pitching, rolling or yawing or even combination of those). By excluding of these error observations could the accuracy of computation attacks limit of 95% or even more in wind direction as well as in wind speed.

In the beginning of this research (2011) was the goal to create 3D wind model based only on data provided in meteorological register $(44)_{16}$. Unfortunately this register is not mandatory for aircraft to report. When taking only register $(44)_{16}$ into account, there are time periods of data lack during the day (mostly during the night, 01 – 04 UTC). By using data (track angle, magnetic heading, ground speed and true airspeed) from mandatorily reported registers $(50)_{16}$ and $(60)_{16,}$ we obtain in an order of magnitude more data to compute current wind speed and direction in atmosphere. Data from meteorological register $(44)_{16}$ are used mostly presently for validation and debugging the smoothing algorithm.

This is the function way how to get current wind model in atmosphere which is based on wind triangle from basic data provided by commercial aircraft flying through airspace. Thanks to sharing of actual weather (wind) conditions can profit many end users – pilots and passengers (shorter flight duration when flying in more affable wind conditions), air traffic controllers (more comfort when providing air traffic control service), flight data processing systems (more precise computation of time over reporting points), airliners (no delay, fuel saving, less consumption) and living environment as well (less production of harmful substances and pollution to the air).

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# BDS Registers as the Source of Data Supporting Air Traffic Controllers

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**Abstract**

ATM systems can use thanks to the Mode S technology new source of information which can simplify work of air traffic controllers and reinforce the safety in any case. Following paragraphs introduce currently used data obtained via Mode S technology and show its implementation and usage in ATM systems in the Czech Republic. It will also adumbrate further data that might be used and it will propose the way of its usage in ATM system.

**Keywords:** Mode S Technology, BDS register, Aircraft Derived Data (ADD), ATM system, Downlink Aircraft Parameters (DAPs)

## 1. INTRODUCTION

Trajectory prediction (esp. the computation of estimated time over the route significant point), data for numerical weather forecast models, easy accessible information about current weather situation, essential information for air traffic controllers and many other domains can be enhanced by integration of data from source called the BDS registers (the components of modern aircraft transponder). Based on the co-operation of properly configured mode S ATC radar beacons (to interrogate specific data), accordingly adjusted aircraft transponders (ability to provide requested information) and last but not least the implementation of the new algorithms using aircraft derived data, we can gain very modern help tool from which can profit everyone who is adherent to aviation. E.g. air traffic controllers might use it during radar vectoring and provisioning of ATC service, passengers and airliners could profit from it implicitly when their flights are on time on arrival and finally everybody of us acknowledges milder environmental impact. The aircraft derived data (abbr. ADD) from the BDS registers have been using in the ATM systems for almost 2 years in the Czech Republic. Following text will outline basic commonly used data and it will sketch the new vision of using weather data as well. It introduces the research of the capability mode S technology in the Czech airspace.

### *1.1. Local implementation in the Czech republic*

More than one year is the Czech airspace under Mode S radar coverage. This technology brings new dimension of data that could be used for more efficient air traffic control service provision. Not only altitude, SSR code and eventually ground speed computed by ground station is now available almost for each aircraft for air traffic controllers within controlled airspace. The information is obtained from the particular BDS registers of transponders operating in Mode S – EHS (enhanced surveillance*). The data is commonly called as Aircraft Derived Data (ADD).

Provision of ADD is not a new idea, but recent technological progress makes it a more realistic proposition, especially since most modern aircraft have much more accurate information than the ground system concerning their actual status and its projection to the future.

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* Two forms of Mode S surveillance are implemented in Europe: Elementary and Enhanced.

## 2. AIRCRAFT DERIVED DATA (ADD) AND BDS REGISTERS

ADD is transmitted from the aircraft to the ground station. These data may be displayed to the air traffic controllers or used for further processing in ATM system functions. The main differences between ADD and conventional surveillance techniques (such as radar) are:

- ADD are measured (or computed) by the aircraft sensors (avionics); radar data are measured by the ground radar station (e.g. ground speed, speed vector prediction)
- Much more data available from ADD than from radar (ground station, e.g. tracker)

Where are ADD stored in aircraft and how are they sent to the ground station? Each commercial aircraft is equipped by secondary radar transponder (abbr. from transmitter responder). Transponders operated at least at level 2 in EHS maintain avionics data in 256 different 56-bit wide Binary Data Store (BDS) registers that can be loaded with information (ADD) and read-out by the ground system (e.g. secondary radar). These BDS registers are also known as Ground Initiated Comm B (GICB) registers. The definition of each register could be found in [1]. Information contained in register is updated within a fixed period. Not updated registers are cleared automatically by transponder. It means there should be only current data.

In the table 1 is shown the example of BDS register $(50)_{16}$ which is called "Track and Turn report" and BDS register $(60)_{16}$ which is called "Heading and Speed Report". Table´s columns TRK, MGH, GSP and TAS contain decoded values. For illustration, register $(50)_{16}$ contains following binary coded values of:

- Roll Angle (RLA)
- True Track Angle (TRK)
- Ground Speed (GSP)
- Track Angle Rate (TAR)
- True Airspeed (TAS)

Register $(60)_{16}$ contains binary coded values of:

- Magnetic Heading (MGH)
- Indicated Airspeed (IAS)
- Mach Number (MN)
- Barometrical Altitude Rate (BAR)
- Inertial Vertical Velocity (IVV)

The values from the above mentioned registers are called as Downlink Aircraft (or Access) Parameters (DAPs).

Table 1 Example of BDS registers $(50)_{16}$ and $(60)_{16}$ in hexadecimal form and its decoded values (TRK and MGH in degrees, GSP and TAS in knots)

| BDS $(50)_{16}$ | BDS $(60)_{16}$ | TRK | MGH | GSP | TAS |
|---|---|---|---|---|---|
| 80 52 F3 3E<br>80 04 EE 50 | 97 1A 6F 34<br>60 0F FF 60 | 66.27 | 64.86 | 257.22 | 244.87 |
| FF D4 2F 3D<br>FF F4 EF 50 | A0 CA 41 34<br>FF CF FF 60 | 94.04 | 92.10 | 254.13 | 245.90 |
| FF DC F5 34<br>60 0C D9 50 | E7 69 F3 2F<br>20 0C 01 60 | 291.44 | 290.74 | 215.04 | 223.26 |
| FF D0 A7 39<br>7F FC E1 50 | 83 EA 1F 30<br>FF F7 FF 60 | 14.58 | 10.89 | 235.62 | 231.5 |
| FF FD 2F 37<br>60 04 E8 50 | E9 09 FD 32<br>3F EF FF 60 | 296.54 | 295.31 | 227.38 | 238.70 |
| FF D4 43 3B<br>E0 04 DE 50 | A1 B9 EB 2F<br>BF F4 00 60 | 95,80 | 245,9044 | 94,74 | 228,41 |
| FF 5C 57 2D<br>BF FC D6 50 | E1 09 D7 2E<br>3F 37 E4 60 | 277,56 | 187,25 | 272,81 | 220,18 |
| 80 3E 3F 31<br>3F FC DE 50 | EE 69 E9 30<br>60 04 01 60 | 320,45 | 201,66 | 310,42 | 228,41 |
| FF FC 35 2E<br>A0 04 D7 50 | E0 49 DB 2E<br>BF 17 E6 60 | 274,57 | 191,37 | 270,70 | 221,21 |
| FF 93 13 3D<br>E0 04 D5 50 | 96 FA 33 2D<br>A0 DC 1B 60 | 69,08 | 254,13 | 64,51 | 219,15 |
| 80 5C 69 31<br>60 04 E8 50 | E1 BA 45 32<br>20 0C 00 60 | 279,14 | 202,69 | 274,74 | 238,70 |
| FF 97 CD 38<br>FF FC E3 50 | BF 3A 11 30<br>E0 4C 01 60 | 175,43 | 233,55 | 177,71 | 233,55 |
| 80 7D 67 32<br>60 0C E3 50 | E8 3A 01 31<br>B F7 FE F60 | 301,46 | 206,80 | 293,02 | 233,55 |

## 3. REPESENATION OF ADD (DAPs) IN CONTROLLERS WORKING STATION (CWS)

### *3.1. Basic label in radar target*

Every controlled aircraft is depicted on controller´s radar screen as radar target (see figure 1). In figure one is shown basic label where are available only basic information for the controllers:

- Aircraft ID (DLH6LP),
- Flight Level (330 = altitude 33000 feet),
- Ground Speed (44 = 440 knots) – computed by ground tracker
- Vertical manoeuvre (symbol "=" means maintaining level in this case)

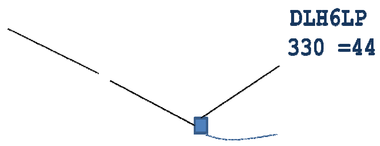


Fig. 1 Radar target on CWS with basic label

All above described information are usually depicted in each ATM system cooperating with secondary surveillance radar. By using Mode S technology can be obtained and depicted much more relevant information for each flight. (See paragraph extended label in radar target).

### *3.2. Extended label in radar target*

Other relevant information for the particular flight could be shown to air traffic controllers by clicking on the basic radar target label. By this action is depicted so called extended label (see figure 2).

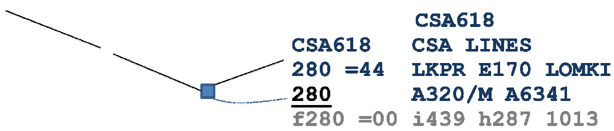


Fig. 2 Extended label of radar target

In this depiction is now available information not only about aircraft identification, flight level and ground speed (computed by local ground tracker) but also such information as Mode S ID (CSA618), radiotelegraphy callsign (CSA LINES), departure aerodrome (LKPR – Praha, Vaclav Havel), exit flight level from ACC sector / entry flight level to Prague TMA (E170), entry point to Prague TMA (LOMKI), type of aircraft and wake turbulence category (A320/M), SSR code (A6341) and finally the DAPs – downlink aircraft parameters are shown in the very last line of label.

All above described information (excluding DAPs) are shown in first, second, third and fourth line of label in figure 2. Information is based on cooperation of flight data processing system (FDPS) and radar processing system (RDP) and is obtained from database and flight plan.

The very last line of the label contains the information obtained via Mode S technology (most of them from BDS registers $(40)_{16}$, $(50)_{16}$, $(60)_{16}$. For the first view, the meaning could seem to be not so clear to common reader but for air traffic controllers it is very useful and clear information. Based on these data, system can detect misunderstandings between pilots and controllers when "catching read-backs".

### *3.3. Downlink Aircraft / Access Parameters (DAPs)*

In the figure 3 below, there is the view of DAP label line in depth (extract from figure 2).

**f280 =00 i439 h287 1013**

Figure 3 DAP label line

The following text will describe in brief the meaning of above shown numbers and symbols from radar label.

- **f280** – Final State Selected
  This is the value of altitudes which is set by the pilot in the cockpit of aircraft
- **=00** – Barometrical Vertical Rate
  This is the value of vertical speed provided by aircraft avionics (in other words – rate of climb/descent)
- **i439** – Indicated Airspeed (IAS)
  This is the value of indicated airspeed
- **h287** – Magnetic Heading (MGH)
- **1013** – Barometrical Pressure Setting
  This is the value of pressure set on aircraft altimeter (QNH[†]). In this situation the value is 1013, because aircraft is at altitude 28000 feet, flying above transition altitudes where the pressure has to be set to standard atmosphere pressure (1013).

### *3.4. Origin of data*

All data presented in radar labels (as shown in figure 2, resp. figure 3) are downloaded from the plane to the ground station. In rectangle in figure 4, there are shown the parts from which are the data downloaded.

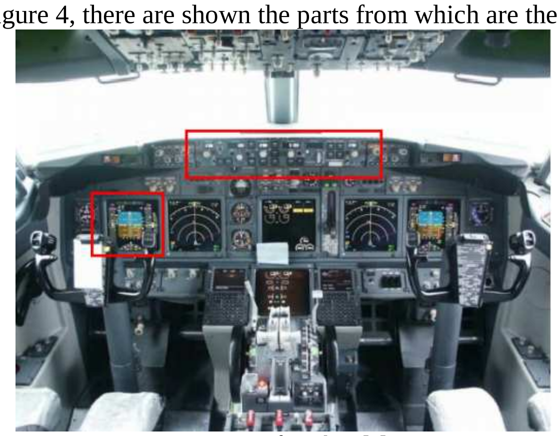

Fig 4 Aircraft cockpit [9],
pilot´s AP/FP Mode Control Panel (detail in figure 5),
pilot´s primary flight display - PFD (detail in figure 6)

The pilot selects the altitude cleared by air traffic controller in the following panel (see figure 5). This selected altitude is presented on the pilot´s PFD and downlinked to the ground station where are the data presented to air traffic controllers on the surveillance/radar screen.


Fig. 5 Altitude window and altitude selector [9]

Magnetic heading (MGH) and indicated airspeed (IAS) are “measured/computed” by the aircraft. In other words, there is no pilot interaction for deriving the data. IAS and MGH are presented on the pilot´s PFD and downlinked to the ground station as well.

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[†] The pressure 'reduced' to mean sea level, assuming ISA temperature profile from the station/airfield to MSL. An altimeter set to the airfield QNH reads the elevation of the airfield when on the ground.

Fig. 6 Pilot´s primary flight display (PFD) [9]

*3.5. Warning based on DAPs*

The first and the last described item are very important for the safety and the system produce visual warning when any discrepancy occurs. For instance the pilot set wrong flight level which was given by controller. The ATC system is able to recognize the difference between given cleared flight level (CFL) and flight level set in PFD by the pilot in the aircraft (thanks to Mode S technology) – see figure 7.

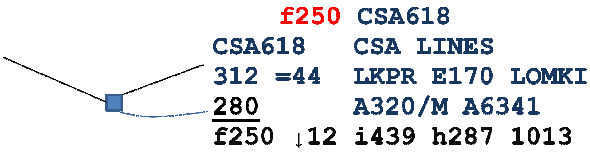

Fig. 7 Radar label – depiction of wrong setting of cleared flight level

In this situation is aircraft passing flight level 312 and descending to FL280 (cleared FL given by controller – it is controller's input via radar label to the ATC system used for SFLW (selected flight level warning) algorithm. The pilot in aitrcraft set wrongly FL250 to descent (it can be seen in DAP value) with rate 1200 ft per minute. SFLW algorithm detected difference between controller´s (FL280) and pilot´s (FL250 = routine information derived to algorithm from mode C) input and generated the warning (red text "f250" in the very first label line). Warning is not depicted if the values (CFL and Selected FL) are equal.

Other very important warning is related to the QNH setting in the cockpit. Especially during approach phase of the flight is the correct setting of QNH very important. If the pilot set QNH value which is different from the QNH provided in the latest METAR[‡]. The controllers are visually warned in the label of affected aircraft radar target (see figure 5).


[‡] METAR is a format for reporting weather information

Fig. 8 **Wrong QNH setting warning**

In figure 8, there is shown cutout from surveillance/radar screen with the aircraft (Cessna 525, registration YUBUU) during the approach phase to Karlovy Vary airport when approaching final approach fix at altitude 4500 feet with ground speed 180 knots. Because in this altitude it is below transition level, the altimeter should be set to aerodrome pressure (local QNH). System identified discrepancy between the set QNH onboard and the latest QNH in ATM system (extracted from METAR). By using extended label can be the value checked and the controller can give a notice to the pilot about wrong setting.

In the Czech republic (ANS CZ) and in Hungary (Hungarocontrol), there is implemented so called function "resolution advisory". In other words, in situation when TCAS[§] is given resolution advisory to the pilot, this information is depicted on the controllers radar screen as well (see figure 9).

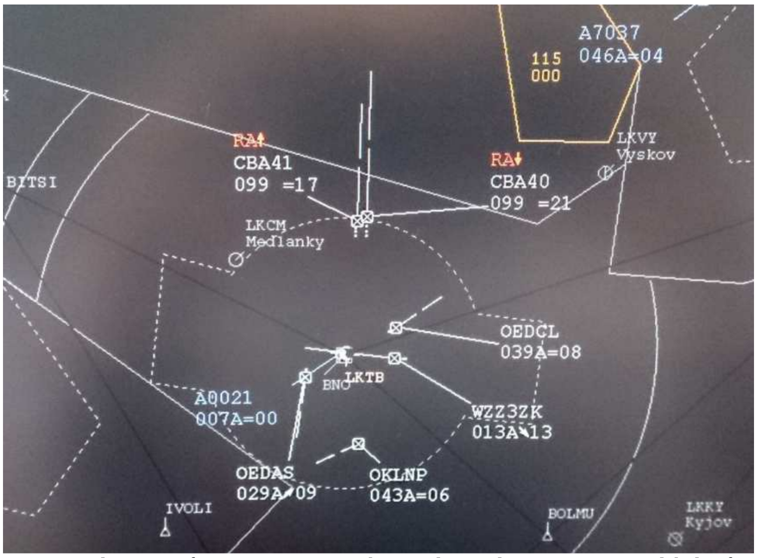


Fig 9 Radar screen from 13 May 2013 where is depicted "RA" warning in labels of inspection flights CALIBRA40 and CALIBRA41 during testing new primary radar installed in LKTB. (Both aircraft are closer to each other than prescribed separation minima (5, resp. 3 NM horizontally and 1000ft vertically)

## 4. BENEFITS FROM ADD

ADD quality depends on aircraft equipage but it tends generally to be more up to date and accurate than information extracted from flight plans and other ground data stores. ADD fits nicely in the context of the operational concept for ATM that was endorsed and adopted by the ICAO member states at the 11th Air Navigation Conference in Montreal, 2003.

Operational benefits from ADD are foreseen in the following areas:

- Safety;
- Strategic and tactical planning, through MSP and MTCD;
- Arrival management;
- Flight time spent in holding patterns;
- Optimization of airport resources;
- Collaborative decision making i.e. prioritisation;
- Fleet management.

Safety nets should benefit from ADD because of the more accurate tracking and short term trajectory prediction resulting in lower false alert rates and improved conflict warning times for the air traffic controllers.

Arrival management should benefit from ADD through the improved reliability and performance of conformance monitoring and the increased accuracy of ETA[**] estimates.

Efficient real time fleet management is a key to successful airline operations. The critical requirement is to maximise the usage of the aircraft in combination with minimum time on the ground. Fleet management not only needs accurate ETA but would also benefit from more accurate and frequent weather reports (ADD can be used to collect weather data in order to improve meteorological forecasts for ATM).[8]

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[§] TCAS = Traffic Collision Avoidance System

[**] ETA = Estimated Time of Arrival

Currently used ADD in ATM systems in the Czech republic are very important step from innovation through Mode S technology. The main benefits currently used ADD are listed below [9]:

- Selected altitude (often called as cleared flight level (CFL)):
  - Provides the pilots altitude intent
  - Confirms if the pilot follows the clearance
  - Could be used as safety nets (see paragraph 4.4)
  - Objective to use this SAP: **reduction of level bust**
- Indicated airspeed (IAS):
  - Provides actual indicated speed of the aircraft (for air traffic controllers is usually available only ground speed computed by ground tracker)
  - Objective to use this DAP: **reduction of RT** (not necessary to ask the pilot for IAS when speed control applied)
- Magnetic heading (MGH):
  - Provides actual magnetic heading of the aircraft
  - Objective to use this DAP: **reduction of RT** (not necessary to ask the pilot for MGH during vectoring)

## 5. FURTHER USE OF ADD

In many EUROCONTROL documents can be found that ADD are generally useful not only for direct using by controllers (DAP) but other relevant information from BDS registers could be used for ATM system support functions. Such tools as Medium Term Conflict Detection (MTCD), Short Term Conflict Alerts (STCA), Arrival Manager (AMAN), Minimum Safe Altitude Warning (MSAW), Area Proximity Warning (APW) and others could eliminate its false warning by using ADD. [8]. Almost none of proposed enhancements of these functions have been implemented so far. Evaluation of effect of ADD on e.g. more precision trajectory prediction is described in [2].

In year 2011 has been tested due to research purposes BDS registers $(44)_{16}$ and $(45)_{16}$ in the Czech Republic. The first listed register contains meteorological data (wind speed and direction, temperature, humidity, pressure) and the other one contains dangerous meteorological phenomenon such as wind shear, turbulence, microburst, icing and wake turbulence. The results are presented in [7].

Knowledge of current wind condition in the atmosphere is also very important for controllers when providing ATC service (esp. during radar vectoring). But also for pilots (resp. airliners) it is very useful to know wind condition in the vicinity of aircraft (to fly some levels above or below to perform the flight more economical – in better wind conditions). Controllers are very often asked by pilots for wind conditions in different levels. But they´re not able to provide the relevant answer for that request nowadays. By using ADD (esp. data from register $(44)_{16.}$ could be created actual 3D wind model and in some way presented to air traffic controllers in information system for controllers. Of course there is weather information but wind data are based only from 3-hours weather forecast and there are only few nodal reporting points with wind conditions from the whole FIR Praha.

The other ways, how to use wind data for controllers, is its showing in radar label. Some proposals are presented in [4].

It was even tested to use meteorological data collected from the aircraft (wind speed, direction) for numerical weather forecast model. The biggest problem was that the model was not capable to incept such amount of data which were spread irregularly in the airspace and in very fluctuant density. That caused very unstable outputs. Although already existing weather prediction models are not capable effectively cope with such kind of data, it is possible to create actual wind 3D model (resp. 4D model taking time in account) based on data which are downloaded from the aircraft (for more details see [10]).

It was mentioned in the introduction that ADD can positively influence the trajectory prediction (TP). Current trajectory predictors estimate the future path of a flight on the basis of intent information (obtained from the flight plan), an aircraft performance model, forecasts of meteorological conditions, and ATC constraints (specified by the controller). ADD is a potential additional source of input data to the TP function.

Major sources of trajectory prediction uncertainty are [8]:

- Weather forecast uncertainties;
- Turn dynamics;
- Aircraft performance modeling fidelity (simplifications, omissions and uncertainty in the mathematical models used to estimate the trajectory);
- Erroneous assumptions on aircraft characteristics, which may vary dynamically (for example aircraft weight) but are usually assigned values derived from flight plan data;
- Tracking and flight mode errors;
- Pilot and controller intent uncertainties.

## 6. CONCLUSION

There is no doubt of the improvement in the ATM system and safety in general which was achieved due to the use of the ADDs (resp. DAPs). Using of BDS registers as the important ATM data source brings huge potential for further research and development. ADD should be beneficial not only to the ATCO but also to airline operations, and airport organization. ADD is a contributor in the air transport cooperative case, which should enable increased predictability for the whole system and hence allow for safe and cost efficient operations.

Therefore, the introduction and use of ADD should be an opportunity to improve and strengthen the cooperative case between air and ground.

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# LPV for "Every" Aerodrome

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**Abstract**

This article focuses on research to extend usage of EGNOS and Galileo. This type of navigation is crucial for expansion of flight procedures without the need for terrestrial radio navigation equipment for general aviation. This transition or change of focus on GA is also described in the article with the main point – safety analysis. The level of risk will be assessed based on data from existing approach systems and it will create comparison with proposed changes in the system.

**Keywords:** LPV, RNP APCH, Aerodrome, SBAS, Safety, Safety Study

## 1. INTRODUCTION

At present, the development of aviation is almost stopped. Current systems and technologies are constantly improved, but the time when these upgrades will no longer be cost-effective is approaching. That's why Europe moving towards a new principle of air traffic control with all that goes with it for several years. This direction is called SESAR - Single European Sky ATM Research. Unfortunately, SESAR focuses mainly on "big" aviation which begins to stagnate. This can be seen from medium-term report forecast of air traffic processed by EUROCONTROL. This study shows standard air traffic growth of approximately 10% per year (see Fig 1), but it does not cover, or cannot cover, some fluctuations in the world economy that from time to time "returns" aviation a few years back. An important point of SESAR is the focus on space technologies, thus primarily on satellite navigation.

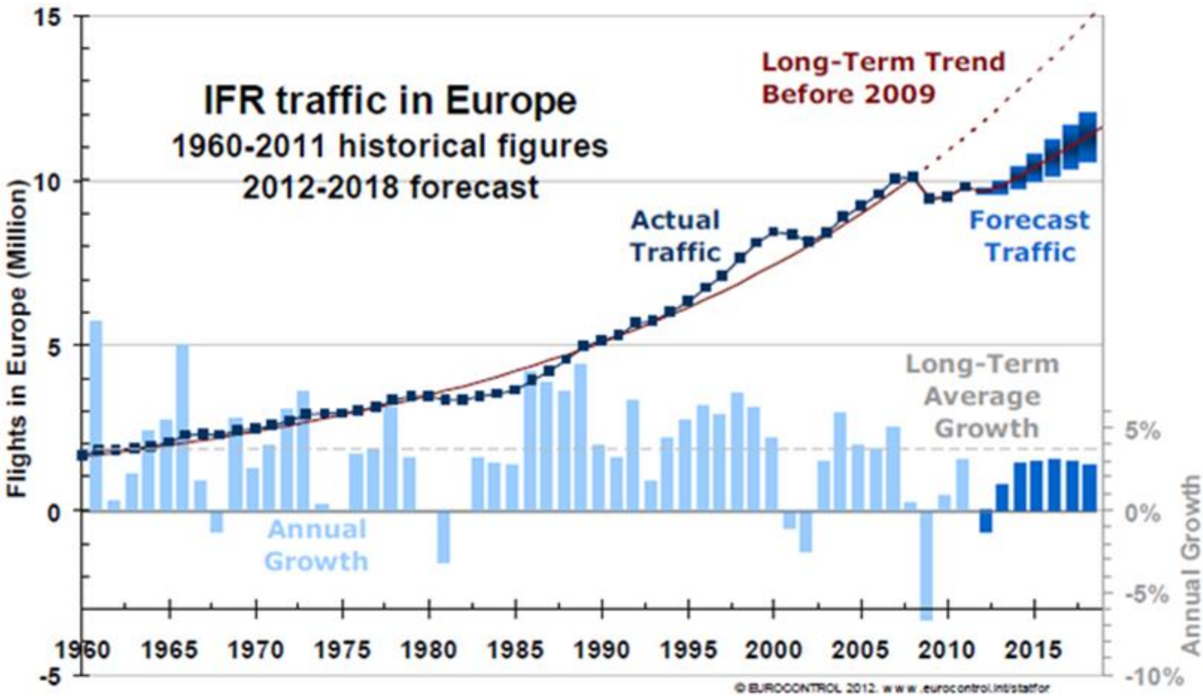


Fig. 1. Eurocontrol IFR Traffic Forecast [9]

## 2. CATEGORIZATION AND CLASSIFICATION

Due to the steady development of "big" aviation and saturated European market, "big" aviation does not seems appropriate to attempt to give impulse for startup further development. Also, air carriers with airliners have one specific feature, which is lack of interest about systems that they are using if the systems work. This problem can be mainly felt in Europe with the aim of creating a European satellite navigation system GALILEO. The air carriers do not care whether they are using GPS, GLONASS, COMPAS, or GALILEO. And for today GPS and ILS is sufficient. So this is not the right way.

Therefore the right airspace user to stimulate is general aviation (GA). For more precise focus, we divide GA into small and big, where big GA can be aerodromes as Hradec Králové, České Budějovice with the operation of private business jets. Small aviation is represented by aerodromes with grass runways e.g. Klatovy or Šumperk with typical aircrafts Cessna 182, or Zlín Z43.

It is also important to perceive certain structure specialization, which we find in aviation. Four important categories could be defined, which are themselves closely related. These include GNSS, CNS / ATM, Safety and Security. The relationship is shown in Figure 2.

$$\frac{\left[\underline{GNSS}\ \text{as enabling technology} \rightarrow \underline{CNS/ATM}\right]\underline{Safety}}{\underline{Security}}$$

Fig. 2. Four parts for providing air traffic

Essentially, the basic idea is that GNSS alone can never exist, because it is included in bigger picture. GNSS is enabling technology for CNS and ATM. This transition must be safe and must ensure an adequate level of safety. Also, every part has to be supervised in terms of security.

But this analysis of GNSS background is not enough as the main issue still not appeared. Is GNSS required for general aviation? The simple answer is yes, especially during approach. The reasons are basically the interests of all stakeholders: pilots, aircraft operators, aerodromes, avionics manufacturers. Every pilot to whom we spoke said: I would like to fly it. It is obvious, because most of them fly for fun and they want to try a new technique and a new approach. Our conclusions are consistent with the findings of EUROCONTROL and their study about this topic. The only major difference is that our results come from testimonies of pilots in the Czech Republic and EUROCONTROL's from testimonies of pilots across the whole Europe. The important conclusion is the same - for pilots, there are two obstacles, the price of avionics and the lack of approaches. (see Figure 3)

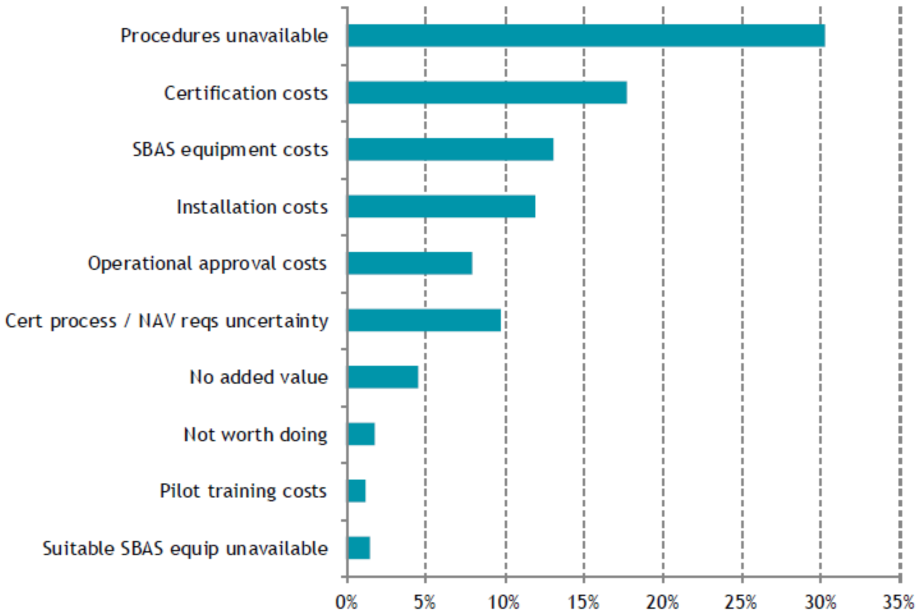


Fig. 3. – Obstacles in usage of SBAS/EGNOS [8]

When focusing on the other two groups, aerodrome operators and avionics manufacturers, the situation is much easier. Avionics manufacturers want to sell new toys, because there is money, and therefore they support the introduction of new approaches. Very similar is the case with aerodrome operators, who also want to earn more money. Their main source of income is the fees charged for the plane. So if they will be able to satisfy more aircrafts (pilots), if they will be more attractive, there is a possibility to earn more money. The last point that is missing is therefore only the implementation of approach based on GNSS / EGNOS on VFR aerodromes (Figure 4).

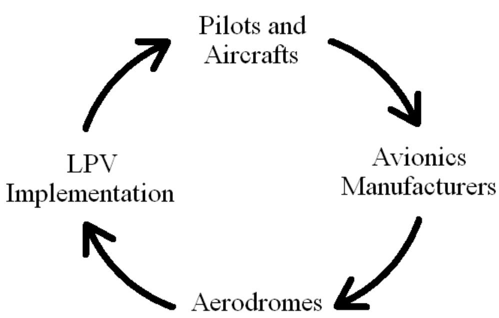


Fig. 4. – Approach implementation cycle

## 3. CHALLENGE

**The Challenge is to change Aviation as we know it today.**

Division of the IFR and VFR is obsolete and does not allow flexibility for responding new requirements from airspace users and air traffic. This change can be made from several directions; all of them have as the main denominator expanded use of EGNOS, followed by GALILEO support. The major obstacle is also identified - Safety.

## 4. EXPANDING THE USE OF GNSS IN EUROPE AND THE CR

As mentioned above, the increased use of GNSS in Europe must lead to IFR approaches at VFR aerodromes.

### *4.1. Part 1 – Airspace*

These procedures are already implemented in some countries and approaches are in use. These are countries such as Germany with an activated class F airspace, United Kingdom with class G, or Norway with Traffic Information Zone (TIZ) and class G*. For Czech Republic the first step must include allowing IFR traffic into airspace around uncontrolled aerodromes, namely ATZs. Inspiration for this implementation can be taken from the above mentioned countries, but conditions in the Czech Republic are slightly different. Our findings therefore suggest that the best solution is combination class F airspace and TIZ. TIZ with proposed dimensions is on Figure 5.

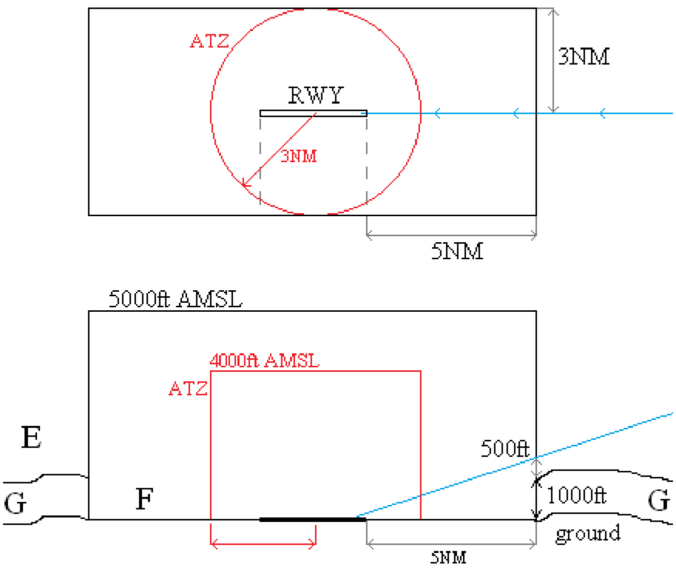


Fig. 5. – TIZ for Czech Republic

Our proposal of TIZ for Czech Republic has one weakness which does not concern functionality or feasibility. It is an attitude of authorities involved in aviation. One is the European Commission with its current effort to implement Standardized European Rules of the Air (SERA), which should be applied in all European countries. EC does not want solution of IFR operations at uncontrolled aerodromes with class F airspace in these rules, so our proposal gets crack thanks to this. The second subject is the highest organization in the aviation - ICAO, which, like the EC, understands the use of class F only as a temporary solution. However, it is possible to apply this model to the Czech environment, because European legislation does not cover small aerodromes.

### *4.2. Part 2 - The cost for aerodrome*

Airspace solution is nothing compared to the costs which need to be spend by aerodromes to build IFR infrastructure according to Annex 14. However, it is generally known that small aerodromes do not have the finances to build this infrastructure, since they even cannot meet the requirements given to them in terms of security, e.g. compulsory fencing. The solution of this issue could be help of the State, or the European Union, but it will be perceived as a distortion of the market. Therefore, there is one organization remaining, ICAO, which exists for aviation. The legislation needs only a few minor changes. But the main thing is still the safety analysis.

## 5. SAFETY STUDY

In Aviation Safety is everything. If some procedure is safe, there is no reason why don't use it. Also in aviation are a few important rules related to safety. These are:

- Standards must be followed
- Standards are here to ensure quality
- In aviation quality is safety

From these three points it is a clear that the use of GNSS depends only on safety issues. Therefore, it is possible to create a simplified equation of safety of approach:

$$Safety\ level\ of\ approach = safety\ of\ technology + procedure + aircraft + aerodrome \quad (1)$$

This equation is very important for any further development in aviation.

### *5.1. Procedure for safety assessment of approach*

The introduction of new procedure into operation in today's legislation conditions requires the implementation of safety studies. In our case, that means the comparison of the modified approach to others, which are commonly used today. The study is based on analysis of accidents and incidents that have occurred when using existing systems for IFR approach, on potential risks models and on a simulation of the modified approach procedure.

For the safety analysis of the existing types of approach were chosen NDB approach, VOR / DME approach and ILS approach. The analytical procedure begins with data collection about accidents and incidents from the past (Figure 6). It is also important to choose an appropriate period of time to ensure sufficient information value thus obtained knowledge. Through analysis of the obtained data it is possible to determine the frequency and severity of events affecting the safety that occurred during the operation. Then it is possible to determine the total amount of risk that exists for each type of approach and hence the level of safety of the approach.

For safety assessment of the modified approach is needed to analyse all procedures, actions and conditions that will be implemented for the approach. It is necessary to model all the processes used during the approach and then identify all the critical ones. We analysed these critical processes and from the results created scenarios of critical events. For this can be used, for example FTA analysis, which allows the determination of all emergency scenarios, that may occur during operation. All these crisis scenarios are now subjected to further investigation and we will determine the frequency and severity of potential consequences of the realization of these scenarios. These values can be further modified by the safety coefficients, which will cover the uncertainty caused by the simulation because the data cannot be abstracted from real operation.

From these studies it is possible to determine whether our type of approach is on the same level of safety or whether it has the characteristics of higher level of safety than existing types of approaches. This comparison will be made on basis of extracted alphanumeric assessment of consequences of risk, i.e. by comparing the risks of each type of approach.

If the study shows that the modified procedures of this approach are at the same respectively better level of safety, nothing should obstruct the introduction into service. During the use of this type of approach it will be possible still performing safety assessment thanks to data obtained from real operation and to take various corrective measures. Safety evaluation of the operation is being conducted by safety indicators that are obtained during the initial assessment based on process modelling.

The following figure shows a simplified model which underlies the process of safety study. Analytically toughest phase will be the safety evaluation of the modified approach due to lack of data from actual operations and because of that the analysis will be based on modelling and simulation. After this analysis the comparing of the modified approach with each already commonly used types of approach will be conducted. If the modified approach will show better safety characteristics than any commonly used approach today, it can be implemented into operation without change. If the value of the safety will be below, it is necessary to look again at the procedures, characteristics, etc. of this approach and make adjustments, which will lead to lower the risks and the complete evaluation process will be repeated.

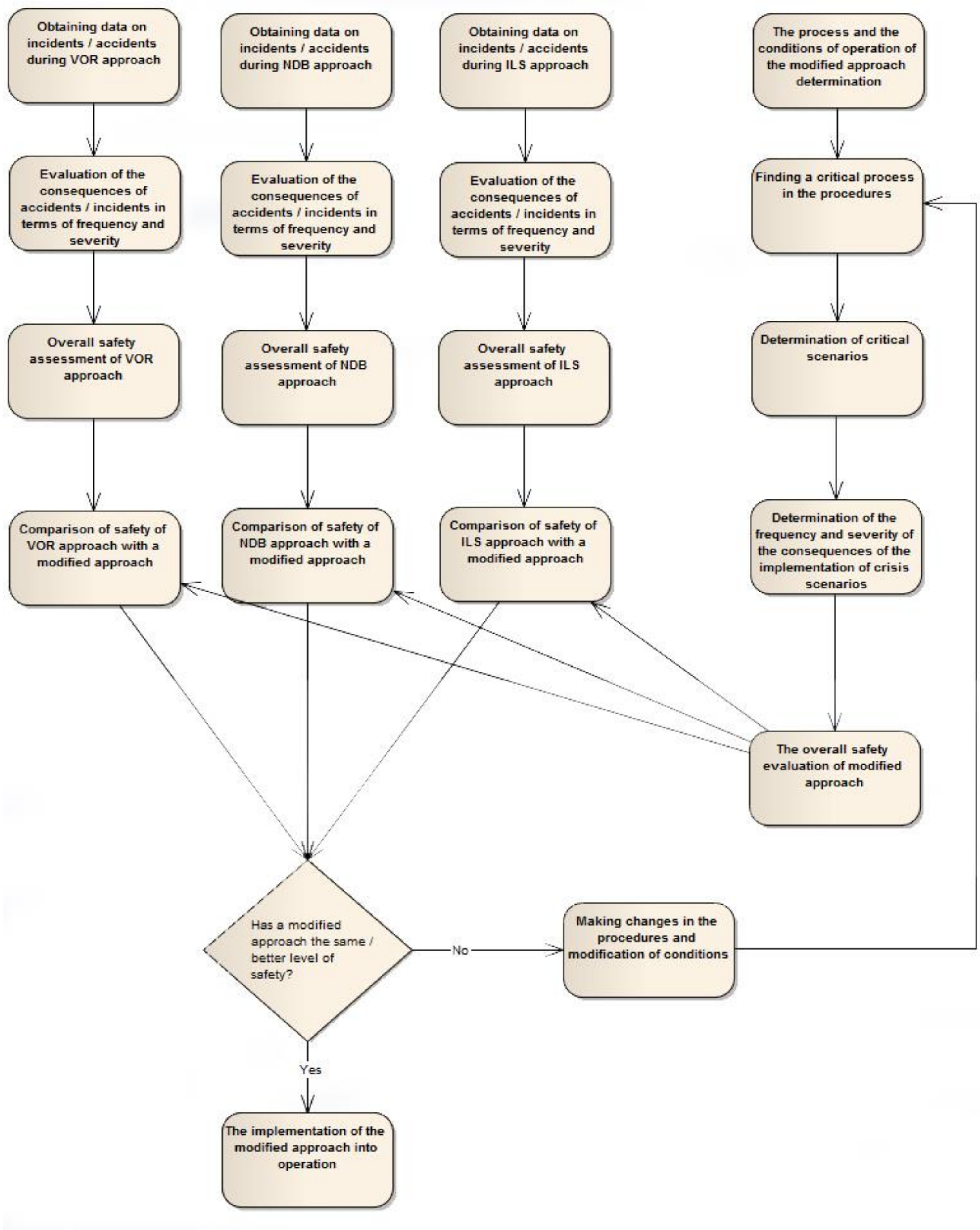


Fig. 6. – Model of Safety Evaluation of Approach

## 6. MODIFICATION OF APPROACH PROCEDURE

If we are focusing on approach procedure, we will notice that in current time the quality of approach is measured by minimum decision altitude or minimum descent altitude (see table 1).

Table 1. DA a MDA for each type of approach

| Approach | ILS Cat I | VOR/DME | VOR | NDB | LLZ | APV/SBAS |
|---|---|---|---|---|---|---|
| DA (MDA) (ft) | 200 | 250 | 300 | 300 | 250 | 250 |

To increase the use of GNSS (EGNOS and Galileo), the minimum decision height is irrelevant. General aviation can now use most aerodromes (84 out of 92 in the Czech Republic, a fraction of all 4600 in Europe) at VMC conditions only. For this reason, there is plenty of room for the implementation of an instrument approach, which could have a decision height about 400-500 feet and allow aerodromes operation even in poor weather conditions. According to safety level of approach equation (1), on the right side there is safety of the procedure and safety of the aerodrome. Therefore, it must be possible to exchange a few hundred feet from the decision height for reduction of the aerodrome infrastructure. Or use precise technology for approach while maintaining the decision height and again exchange it for a reduction in infrastructure.

Therefore, it must be possible to design a precision approach with a decision height of 500 ft for VFR aerodrome with very limited infrastructure and get certification.

$$ILS\ Cat\ I + compatible\ aerodrome = LPV500 + compatible\ aerodrome \quad (2)$$

$$ILS\ Cat\ I + Annex\ 14\ Airport\ Infrastructure = LPV500 + Airport\ Infrastructure for\ this\ approach \quad (3)$$

In this consideration hide huge savings for aerodrome operators and very well spend public funds. Their consuming to develop and operate new satellite navigation system GALILEO will have therefore another great reason in the entire aviation and not only in one part. Investing in infrastructure also strengths the economy in European Union.

## 7. CONCLUSION

In this paper, we showed the direction how to increase the use of European global satellite navigation systems in aviation. This increase goes toward new users of GNSS, general aviation, which is group many times bigger than big civil aviation, whether by the number of aircraft or aerodromes. Although the base is very large, it is necessary to note the overall small amounts of money, in which the GA moves. Subsidized some areas of the economy by the government appears to be inadequate, so there is a need to get finance into aviation another way – via satellite systems.

Extending the use of EGNOS, or the GNSS depends only on the safety issues. Therefore, it is necessary to use new methods for comprehensive evaluation of the safety of systems, technologies and procedures that create a basis for the overall change of aviation. The best method of safety analysis through risk assessment is described in this article.

## ACKNOWLEDGEMENTS

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# Evaluation of passenger flow through Ostrava airport

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**Abstract**

This article is focused on evaluation of passenger flow through Ostrava Airport. It describes the history and the present situation of the passenger air transport on the Leos Janacek Ostrava international airport. This article is based on author's diploma thesis.

**Keywords:** Ostrava, airport, passenger, line, tariff, survey

## 1. Introduction

Modern people of today usually travel. Actually people are travelling more than in the past years. Just a few years ago people cannot travel so much because of the political system in former Czechoslovakia. And before that there were technical reasons, because all possibilities of travelling were so slow, that almost all today's destinations were too far away from the origin.

Nowadays there are many options how to travel. For short routes we usually choose some kind of land transportation. But if we want to get further, we usually fly by airplane. Some destinations are accessible by more than one transport mode and that means we can compare and choose the best.

## 2. History of airports in Ostravian region

In this chapter I will analyze the historical circumstances which affect airports today's situation.

### *2.1. Before the Mošnov Airport*

Pioneer of flying in this region was A. Wachalowski from Vienna who made his first flight over Ostrava in 1910. Two years later the Žurovci brothers made their first flight using "First Moravian aeroplane" of their own construction. [1]

The first real airport was nearby the Bohuslavice village, opened in October 1928. It was used by Masaryk Aviation League and also for first regular scheduled flights between Ostrava (Bohuslavice) and Prague. The first flight of this service took to the air on July 1st, 1935. The service was provided by four and eight-seater airplanes. However, this service was the swansong to this airport. In the late September 1935 passenger flights were cancelled, with only three months of service.

Another airstrip was located in Přívoz district, on meadows west of Ferdinand Northern Railway station complex (today's Ostrava hlavní nádraží). But this airstrip was soon abandoned, when a new airfield in the Hrabůvka district has been opened.

The airfield in Bohuslavice was quite far away from Ostrava City and there was a need for a closer site. The ideal location was found in Hrabůvka district, where the new airport was opened on March 21st, 1936 with the final inspection performed only in October 1938, so this is why the regular scheduled flights between Ostrava and Prague were not re-initiated before the start of World War II. In the post-war era this airfield was nationalized and became part of Czechoslovakian domestic air transport infrastructure. First flights destination since July 1946 was Prague soon followed by other destinations like Zlín, Olomouc, Brno and Piešťany. In 1951 Košice service was added. The airfield was categorized still as temporary, because of its small size and proximity of several obstacles. The Czechoslovak Airlines left the airfield in 1959. Nowadays the area of former airfield is site of housing estate. [2]

*2.2. . Airport Ostrava - Mošnov*

This airport is located ca. 20 km southwest from Ostrava city. The founder and first operator of today's airport was German Air Force Luftwaffe that constructed an airstrip in 1939. The regeneration of this site started in 1955 and the airport was opened in October 1958, by landing of the TU-104 jet airplane. This airport was both the passenger terminal and the military air base and this combination lasted until 1993. Since that year the airport is only civilian. [3]

The airport has one runway in direction 04/22; its dimensions are 3500 m x 63 m. The airport's facilities were modified and expanded as the meaning of this airport grew in time. For example in 1970's the new air traffic control tower was built. However more significant development started after the year 1989. Since then new departure hall was built (current arrival hall) and during the years 2005 and 2006 the new departure terminal was built. Nowadays the airport is very modern and dignified gateway to the world. The important fact in history of the airport was its renaming in 2004 from Ostrava international airport to Leos Janacek international airport.

Every airport should be in a state of permanent development, because every airport that does not develop stagnates and stagnation demonstrates problem. Leos Janacek Ostrava airport (LLJ) has some projects to build as well, for example the Security Centre, which will contain premises for police, customs, fire fighting services and air traffic control tower. Another oncoming project is the rail link directly to the proximity of the terminal.

## 3. Operational analysis of the airport

*3.1. Development of passenger movements 2000 - 2012*

The last 12 years of the airport operation is the era of increasing number of passengers, the peak (in year 2008) followed by decline and start of increase again (since 2011).

The situation clearly shows Fig. 1. [4, 5, 6, 7]

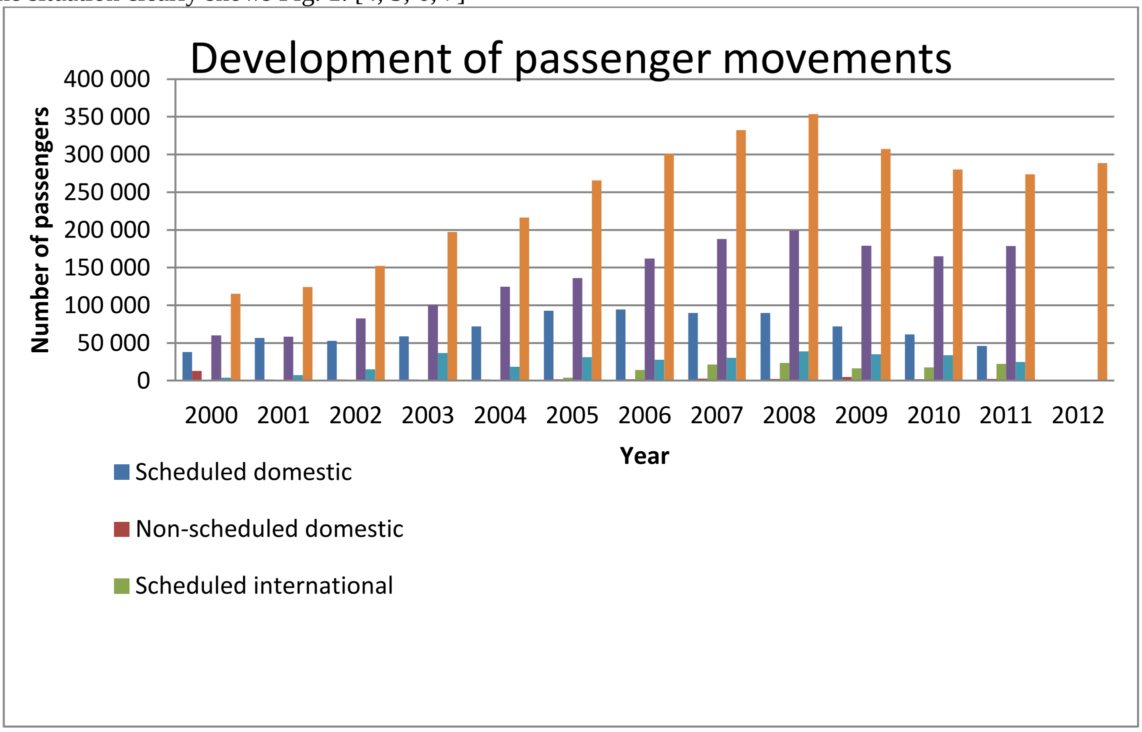


Fig. 1. Graph of passengers handled between 2000 and 2012

Data for graph on Figure 1 are taken from annual reports; year 2012 data come from an airport director interview (Mr Pavel Schneider).

*3.2. Current scheduled flights*

There are four direct destinations from Leos Janacek Ostrava airport for this year.

- Prague – operated by Czech Airlines
- Vienna – operated by Danube Wings
- Paris – Roissy Charles de Gaulle – operated by SmartWings
- London – Stansted – operated by Ryanair [8]

This clearly shows that on Ostrava airport is one line operated by a traditional carrier – Czech Airlines. This spoke line goes to Prague where Vaclav Havel Ruzyně Airport is used like a hub. The recent development shows us, that importance of Prague airport will be more significant in subsequent years, especially after partial takeover of CSA by Korean Air. The recovery of long haul fleet at CSA and concerning their interest on the Far East Countries (CSA wants to use their new Airbus A330 for flight to Incheon Airport (ICN)). The line to ICN is going to be served in code share with Korean Air and Korean Air. [13]

Line to Vienna is depreciated because it is not operated in code-share with the most important user of Vienna airport – Austrian Airlines. That means tickets on this flight cannot be booked as a transfer and this line cannot be effectively used like a spoke for a hub. Nowadays this connection is temporarily suspended [12].

Lines to Paris and London are operated by low-cost carriers, and are meant as point-to-point. Flight of SmartWings Company can be found in global distribution systems. On the other hand tickets for Ryanair flights ale sold exclusively through their web.

The prices for all these flights are quite cheap comparing to the recent history prices. There are also some special sale prices offered by Czech Airlines and using them you can buy a cheap transfer ticket to some European destinations. For example Flight on the route Ostrava – Prague – Milan (OSR – PRG – MXP) and back can be purchased for 2995 CZK.

*3.3. Current non-scheduled flights*

The airport is mostly used for holiday travelling as shown on Fig. 1. For these purposes there are many connections mostly to European, North Africa (Tunisia, Egypt) and near east (Turkey, Israel).

*3.4. Current seasonal scheduled flights*

Many people want to arrange their vacation by themselves, and Leos Janacek Ostrava airport offers many seasonal scheduled flights, which are flown to the common holiday destinations. Tickets to these flights can be purchased using global distribution systems. All these flights are operated by SmartWings.

The destinations are:

- Burgas, Bulgaria
- Heraklion, Greece
- Thassos, Greece
- Lamezia Terme, Italy
- Larnaca, Cyprus
- Mallorca, Spain
- Rhodos, Greece
- Split, Croatia [8]

*3.5. Competition between rail and air transport*

The flights to Prague and to Vienna are typical short-haul flights, where the travelling time is one hour or less. On these routes the land transport can be competitive. Especially the connection between Ostrava and Prague by train is high quality, frequent (during peak hours up to 4 connections per 30 minutes), fast and cheaper than by airplane. Currently the cheapest train tickets (one way) from Ostrava – Svinov train station to Praha hlavní nádraží cost less than 100 CZK. [9] This is something that a plane cannot compete with. Also the travelling time is comparable, because train goes from city centre to straight to city centre, while the airports are usually outside the city, which makes travelling by air less convenient.

Trains competes to airplanes also at the line to Vienna, but there is much smaller offer of connections (one night fast train and two daily Euro City trains), [10] the trains here loses also their advantage of getting straight to the city centre, because Vienna Main Station is repaired and the trains must stop at Wien Meidling station, which is not exactly the city centre. Another problem here is, that even that this route is shorter that the route Ostrava – Prague, the trains here go more slowly and the travelling time is higher. Fact, that this route is international brings another systematic delay caused by insufficient interoperability of the various rail operators. This problem will be generally solved by implementing the European Rail Traffic Management System (ERTMS). Last but not least the prices are much higher, even using the first class coach and buying a seat reservation the costs are higher than an airline ticket purchase. 111.6 EUR for return ticket via train vs. 108 EUR via airplane. [11]

## 4. Analysis of results of passenger survey

During the period from February to April this year was made a special passenger survey focused on their satisfaction with Leos Janacek Airport and on their needs and wishes about scheduled flights from Ostrava.

The survey was made by a special questionnaire which was situated in departure hall where every passenger could fill it out and provide the valuable feedback. During the above mentioned period only 5 passengers filled the form. Questionnaire consisted of set of closed and open questions, the answers can help the airport what to focus on.

To obtain more results I decided to use an active questioning. This three weekends interviewing involved passengers of Friday Prague flights, Saturday Hurghada flights and Sunday Marsa Alam flights. Active questioning helped me to obtain 45more filled out questionnaires.

The survey took place during the winter timetable, so there were no low-cost passengers and also no seasonal flights passengers.

### *4.1. Distribution of passengers*

First questions were about the purpose of the journey and the final destination. I would like to mention here, that nobody, who flew to Prague, ended his journey in Prague, for all questioned passengers Prague was only a transfer hub.

Most passengers on the Prague flight flew because of the business, only one young man was on a private journey. On the other hand all questioned passengers of charter flights to Egypt were on the way to holiday.

The survey subsequently shows that most people are purchasing tickets at a travel agency. This is probably caused by the fact that the respondents were mostly the customers of travel agencies, where they bought package holiday which includes also the airline ticket. On the other hand the respondents were the businessmen, who buy their tickets via travel agencies and not for example via the internet.

Other results show that usual holiday passenger usually fly only for a holiday and that means only to the typical holiday destinations like the summer resorts nearby the Mediterranean Sea.

On the other hand the respondents from flight to Prague usually fly worldwide or at least to many European destinations. Also passengers from Prague’s flight fly much more frequently than the ones from the flights to Egypt.

Another question was “How often do you fly from Ostrava Leos Janacek Airport?” This question has shown us that holiday travellers are much more loyal than business passengers. That’s also reasonable, because most people travelling to Egypt were locals while the most of passengers from flights to Prague were foreigners. The nationalities of the passengers were mostly European, but there were also some Korean passengers, relating to massive Korean investment in Moravian-Silesian region (e.g. Hyundai Motor factory in Nošovice).

Next question was about the usual travelling class. The vast majority chose economy. Charter services in Czech Republic usually offers only seats in economy class, but on the scheduled flight to Prague there is also an option to buy a ticket to business class. However even here dominates the economy class (80% Economy vs. 20% Business).

Questionnaire contained also a question on preferences of traditional or low-cost carriers. For people who fly only on holidays, there was a special option “Charter”. The answers on this question were affected by the fact, that a survey took place during winter season, when no low-cost operations had been on schedule. However 22% of respondents chose low-cost carriers. This result clearly shows, that people want cheap flights and concept of cheap no frills travelling even though that there is no offer. For completion: 48% chose Charter and 28% chose Traditional.

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Next question connected to the previous one asked “What in your opinion should be the adequate price for intra-European flight economy return ticket e.g. Ostrava – Paris or Ostrava – London?” This question was open, but for better evaluation I made some intervals and the most common answer was inside the interval from 1 to 2000 CZK. (32%) second was interval 2001 – 5000 CZK (28%). These results confirm the conclusion of previous question.

Good news for passengers and for airport too, is that you can fly from Ostrava for such prices. And thanks to the special offer at Czech Airlines (as mentioned at III.B) not only to the direct destinations.

This is related to the next question „Which direct destinations would you like to fly to from Ostrava?” Surprisingly most people responded that none. On the other hand majority of respondents were people travelling only charter flights, and the offer of scheduled flights is not so important for them.

Last questions of the questionnaire referred to nationality and residence of the respondents. Vast majority of passengers were Czech (75%) and 86% of them were from Moravian-Silesian region. This illustrates that Leos Janacek airport serves the people of the region. On the other hand airport should make some steps to spread its range and try to attract people also from different regions and countries (e.g. Poland).

I made also a closer look only to passengers on flights to Prague and there was a different situation. Czech nationality was not major. Results were rather equal; no nationality reached more than 20%.

### 5. Conclusion

The airport experienced inconsistent years recently. I hope that in near future the situation will stabilise and airport will achieve a growth of passenger handled. The survey supports the idea that most people want to fly cheap and that no frills low-cost carriers are good choice for the future of the airport. The low-cost services are presented at the airport for a second year and I believe that new connections can be opened in subsequent years.

Leos Janacek Ostrava airport is not a reasonable airport for a long haul flights, however there is a significant demand for connection to Korea, but it is easy to get to Korea with only one transfer at Prague. Also the connection between CSA and Korean Air is going to strengthen in subsequent years, what makes connection to Prague much more useful. So the idea that management of the airport concentrates on flights to big European hubs is meaningful and demand for cheap flying can be covered by low-cost carriers.

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# Human Factors Role in the Air Traffic Control Occurrences

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**Abstract**

Flight safety together with demands on effective and well-ordered air traffic flow is an essential requirement of modern society. Flight safety depends on proper human and machine operations. The paper is focused on the impact of objective and subjective aspects on human factors in the Air Traffic Control environment. Special interest is paid to the influence of day-time and season period, character of air traffic, aircraft movement phase, meteorological conditions, Moon-phases, flight-release conditions and air traffic intensity in particular airspace. Data of 981 air traffic occurrences records were gathered during the period 2000 - 2012 in Czech Republic, Great Britain, Canada and United States, respectively.

**Keywords:** Flight safety, human factors, air traffic controller, incident, accident, separation minima infringement, day-time, season, air traffic, workload, Moon-phase

## 1. INTRODUCTION

Human Factors have been defined briefly as "fitting the task to the man" (Grandjean 1981), and "designing for human use (Sanders and McCormick, 1992), and more lengthily as "aiming to design appliances, technical systems, and tasks in such a way as to improve human safety, health, comfort and performance" (Dul and Weerdmaster, 1993). An implicit fourth and operationally interesting, definition (one with which controllers might concur) is "give us the tools and we will finish the job" (Oborne, 1992). Clearly Human Factors is about the giving the human operator an efficient working environment and tools which take account of human strengths and limitations, but it is also about selecting the most suitable operators and giving them the required skills. In this way Human Factors seeks to optimize Human Performance and thus system performance, but not to the detriment of the health (physical and psychological) of the humans in the system. Human Factors can therefore be said to be "work-focused", though it is also demands of "healthy" work.

Human Factors has its roots in applied psychology, but with substantial inputs over the years from fields as diverse medicine (e.g. to understand psychological effects on human of work systems), physics (e.g. to understand perception), engineering and design. In fact people who are working in Human Factors themselves come from a range of backgrounds such as psychology and engineering, and it is considered a hybrid discipline.

In contrast to the embracing of automation by a range of other industries, Air Traffic Management (ATM) in practice at the time remained very human focused with relatively little automation support. Nevertheless, with the evolution of computer-based systems the Human Machine Interface (HMI) became an item of central interest to the ATM community, as it was seen as desirable to replace older radar screens with systems that could super-impose

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more information for the controller, to enable more efficient performance. Legibility and contrast, font size and design, were subsequently the subject of research for quite some time. In parallel, the controllers' workload evolved as a central issue for successful system design, arguing that appropriate design of the human-machine interface could help to reduce operators' workload, thus contributing to overall safety and efficiency. The aim was to increase "capacity" (volume of traffic) in response to more public demand and accessibility to flight-based travel. It became obvious to many that Human Factors could be a key enabler to increase capacity and hence growth of the industry as a whole. The human element in the ATM systems, still the key element, should therefore receive support in order to improve performance.

The Air Traffic Control Officers (ATCOs) play crucial role in the Air Traffic Control, which is considered as the most visible and flexible part of Air Traffic Management (ATM) system. The ATM comprises The ATM comprises of airborne and ground-based functions (air traffic services, airspace management and air traffic flow management) to ensure the safe and efficient movement of aircraft during all phases of flight operations. Despite the all automated processes and tools for ATCO decision-making support of the airspace and air traffic control, together with problem solving will remain in hands of controllers. No one system is 100% reliable and accurate and no one can replace all human-provided actions. All decisions made by controller are influenced by considerable number of factors. Their impact on each person varies individually and usually there is impossible to distinguish, which factor had the most significant impact on flight safety and which was less important. On the other hand, the research of the Human Factors and Human Performance is very complex and takes a lot of time in the future because the issue is not closed issue. Despite advances in technology, ATM is still critically dependent on the day-to-day performance of highly skilled front-line personnel, such as controllers, engineers, supervisors and other operational staff. Operational personnel safely and efficiently handle millions of flights, and effective human performance at the front line makes this happen. [1]

## 2. Method

The study is based on wide retrospective analysis of the air traffic occurrences where controllers were involved (ATC Involved Occurrences). For the unity of data interpretation and classification the author of this paper asked for the assistance in this matter the majority of European and overseas investigation institutions and Air Navigation Services Providers (ANSPs). Several organizations had not been interested in and some denied providing the data because of their sensitivity. Thanks to positive approach of five asked bodies there was possible to summarize and analyze 981 accidents and incidents between 2000 – 2012 in the Czech Republic (Air Navigation Services of the Czech Republic, Armed Forces of the Czech Republic), Great Britain (Civil Aviation Authority), Canada (Royal Canadian Air Force) and United States of America (National Transportation Safety Board). The data are extracted outputs from the national databases in individual format and content. The Czech ANSP (civil) data were collected directly from their internal database. The records are mostly complex and contain all time-location information, occurrence description, controller's workload, weather information and occurrence category. Other data (especially from the USA and Canada) were received as written reports containing almost the same details without incident category. This classification was assessed based on its description (distances between the aircraft, their heading, consequences) according to EAM 2 / GUI 3 Mapping Between the EUROCONTROL Severity Classification Scheme & the ICAO Airprox Severity Scheme. Some databases contain information concerning time on duty, time after break and controllers age.

Initial normality data test was successfully checked (data have normal distribution). For statistics constructions was used IBM SPSS Statistics Base, ver. 21 software. Tested data were linearly correlated, summarized and analyzed.

## 3. ATC involved occurrences

### *3.1. Scope of the research*

The research was focused on the Air Traffic Control (ATC) involved occurrences led to the accidents or incidents in the Air Traffic. The level of ATC involvement was considered as a main contribution (cause) of ATCOs or secondary role (factor) in the occurrence. The occurrences were divided in to nine categories; each category was "qualitatively" described as a severity risk according to ESSAR2 – Reporting and Assessment of Safety Occurrences in ATM. The study covers Accidents, Serious, Major and Significant Incidents (Category A, B, C). Incidents without impact on flight safety (Category E) were included only in part and the Not determined (Category D) incidents were omitted. [2]. This number covered whole spectrum of flights, i.e. commercial (scheduled and non-scheduled), general aviation, military, instructional and special flight (e.g. aero-medical, sightseeing, positioning etc.). Analyzed factors were day-time and season, air traffic type, aircraft movement phase, meteorological conditions, Moon-phases, flight-release conditions, air traffic intensity in particular airspace. The numbers of occurrences by types are presented in the Table 1 and by categories in the Table 2.

Table 1 – Occurrences Types

| Occurrence Type | Frequency | Percent |
|---|---|---|
| Separation Minima Infringement | 629 | 64,1 |
| Controlled Flight Into Terrain | 43 | 4,4 |
| Mid-Air Collision | 27 | 2,8 |
| Ground Collision | 30 | 3,1 |
| Airspace Infringement | 101 | 10,3 |
| Another Aircraft Interference | 21 | 2,1 |
| Runway Incursion | 100 | 10,2 |
| Aircraft Mis-Identification | 23 | 2,3 |
| Mis-Communication | 1 | 0,7 |
| **Total** | **981** | **100,0** |

Table 2 – Occurrences Categories

| Occurrence Category | Frequency | Percent |
|---|---|---|
| Serious Incident | 319 | 32,5 |
| Major Incident | 195 | 19,9 |
| Significant Incident | 301 | 30,7 |
| Not Safety Effect | 68 | 6,9 |
| Accident | 98 | 10,0 |
| **Total** | **981** | **100,0** |

The accident ratio (Controlled Flight Into Terrain (CFIT), Mid-Air Collision (MAC) and Ground Collision (GCOL) is 10.3 %. All of them occurred in the USA; 75 people died, 6 people were seriously and 3 people easily injured.

## 4. The role of individual factors

### *4.1. Season, day and day-time*

The density of air traffic does not remain constant during year and varies with the season. The typical year distribution of air traffic can be characterized as continuous increase in first seven months (January – July) and continuous decrease in the next period of the year. The peak of the air traffic sets in summer and is connected with holidays and travelling of significant number of population. Fig. 1 shows distribution of incidents and accidents during the year. The highest number of accidents and incidents does not fall on summer months, when the density of air traffic is highest, but coincides with spring months. In other words: The higher number of aircraft in the airspace automatically does not imply higher number of accidents nor incidents. The number of aircraft is not the single and isolated factor. It relates with their clustering, i.e. with the density of air traffic in individual parts of the airspace – the sectors. This factor has more representative value concerning the workload of ATCO.

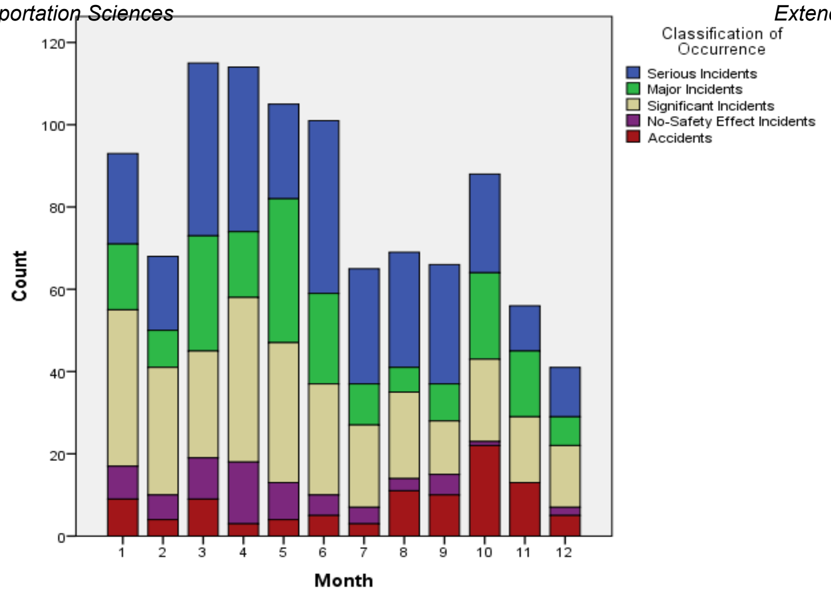



Fig. 1. Accidents/incidents Season Distribution

Other important factor was the distribution of air traffic during the week. The amount of air traffic on Mondays, on Tuesdays and on Wednesdays is almost the same and reaches slightly to 14 % of all-week amount. Sharp climb of air traffic is typical for Thursdays (nearly 15 %) and this trend is followed by other increase above 15 % on Fridays. Saturdays are characterized by descend of air traffic and Sundays (13.5 %) on the contrary by increase above first three week-days. [3]

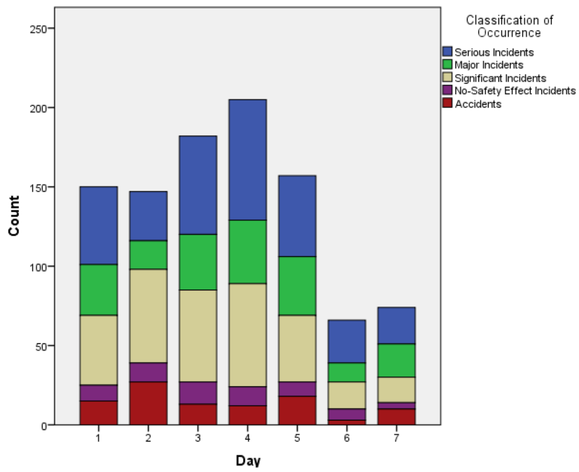



Fig. 2. Accidents/incidents Week Distribution

The occurrences´ week distribution was in line to the air traffic amount. The peak of all incident categories was observed on Thursdays, when the air traffic increase is typical; the lowest numbers were documented during weekends. On the other hand accidents during Thursdays are rare.

Furthermore there was analysed the impact of various hours of a day on the appearance of incidents and accidents. Of course, the amount of the air traffic during a day is variable and its typical distribution is characterized by the peak between 08:00 – 12:00 local time [1]. This is followed by the highest number of incidents in all severity categories with the exception of accidents. Fig. 3 documents that the significant amount of worst occurrences, such as accidents, falls on the period 04:00 - 07:59 hours. At this time there is not the air traffic peak but its sharp increase after minimal traffic between midnight and 03:59 leads to big number of accidents as well as the highest number of serious incidents (Category A) in comparison with the rest of periods of a day.

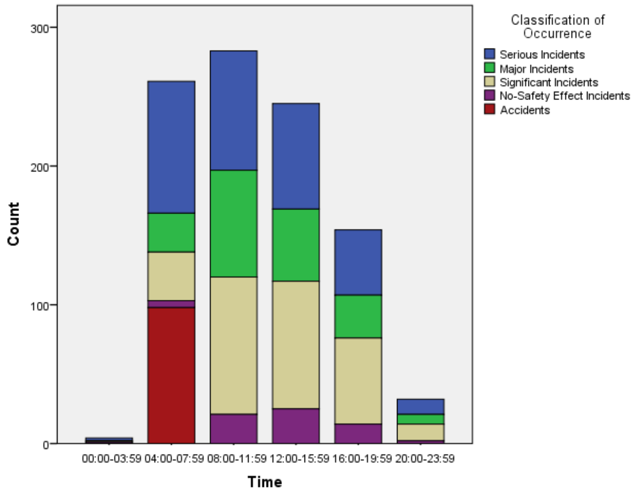
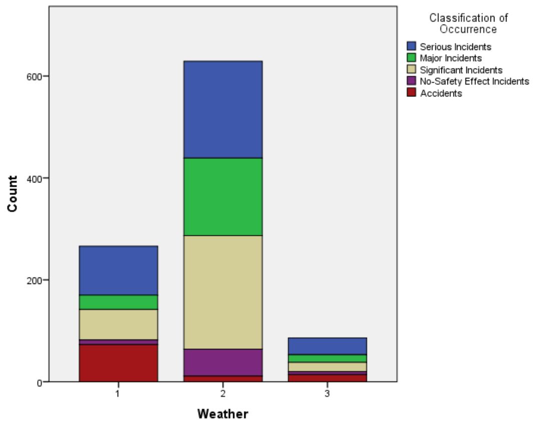



Fig. 3. Accidents/incidents Day-time Distribution

### *4.2. Weather and flight rules*

Weather plays in the aviation very important role. Adverse meteorological conditions can influence not only planned aircrafts route (vertical and horizontal) but their unexpected changes can lead to dangerous situation in flight. The basic weather characteristics are visibility, clouds ceiling, sky coverage by the clouds, wind direction and speed, temperature and significant weather phenomena (storm, rain, snow...). The accidents/incidents reports were very often reluctant to specify all weather details. When the weather contributed to the occurrence there is mentioned but in other cases the information concerning weather conditions is absent. Therefore, the meteorological significant information were interpreted in three main groups (1 – weather was ideal, i.e. visibility more than 7 km, ceiling above 5 km, clouds coverage to 2/8, no significant wind), 2 – weather had not any impact on the occurrence but was not ideal, i.e. visibility 4 – 7 km, ceiling 3 – 5 km, clouds coverage 3/8 – 5/8, no significant wind, 3 – weather had significant impact on the occurrence and was observed at least on dangerous meteorological condition (strong wind, low visibility or ceiling etc.). Correlation between the weather and occurrences categories was significant at 0.01 level.

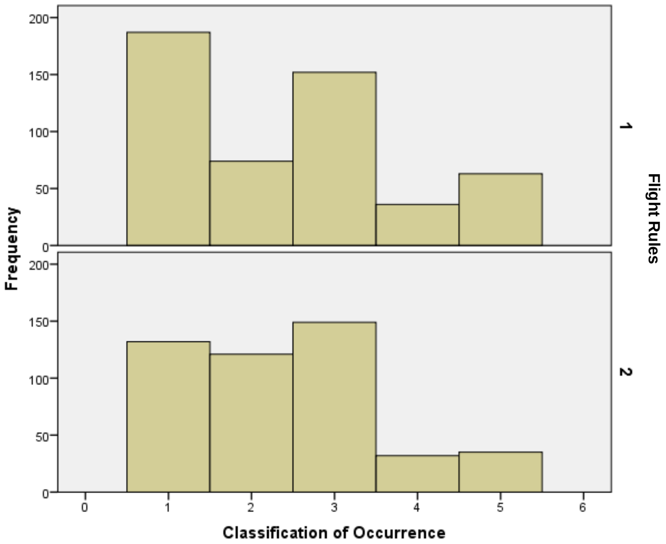
Absolute maximum of occurrences was documented in meteorological conditions described as “normal weather”. Absolute minimum of all occurrences was reported during adverse weather. On the contrary, the highest number of accidents was observed when the weather was ideal, i.e. without dangerous meteorological phenomena. These data are interesting because it is probable that controllers in ideal weather are reluctant to admit the possibility of safety problems. On the other hand, during adverse meteorological conditions they (and air-crews as well) are more able to take into account the severity of the situation and the number of incidents is significantly decreasing.




Legend:
1 – “ideal” weather
2 – normal weather
3 – adverse weather

Fig. 4. Accidents/Incidents Distribution in the Weather Categories

Parallel to weather there is another factor affecting the flight – flight rules (visual – VFR (1) or instrumental – IFR (2)). Histogram at Fig. 6 represents accidents/incidents occurring in conjunction with the flight rules. There is obvious that flight rules have not any significant impact on the occurrence arising nor their category. It turned out, that types of flight were also analyzed and none special type proof significance for occurrences rising as well.

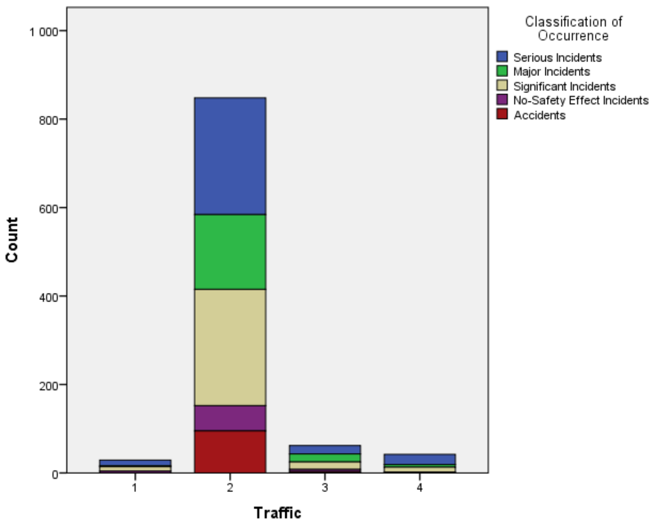



Legend:
1 – Visual Flight Rules (VFR)
2 – Instrumental Flight Rules (IFR)

Fig. 5. Occurrences in VFR/IFR Flights

*4.3. Controllers workload*

Workload is an important focus because errors can be induced if mental task demands exceed the capabilities of the human operators. In turn, the consequences of these errors might be critical and detrimental to safety. Workload might simply be defined as the demand placed on the human operator. This definition, however, is overly limiting because it only includes the requirements generated by external sources (e.g. task difficulty). In order to address workload completely, it is also necessary to consider demands generated internally that compete for an operator's resources. Therefore, an appropriate human factors definition of workload is: Workload is the demand placed on an operator's mental resources used for attention, perception, reasonable decision-making and action. [4].




RULESLegend:
1 – light traffic
2 – normal trafic (close to light)
3 – normal traffic (close to heavy)
4 – heavy traffic

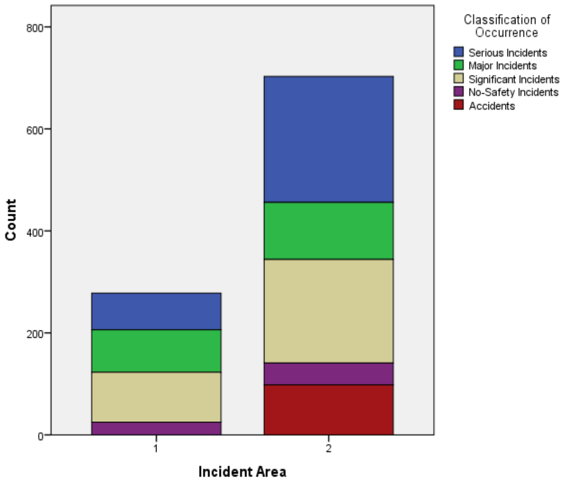
Fig. 6. Occurrences Distribution by Air Traffic Level

The operator´s workload is subjective sensation (impression) and has not any accurate measures. According to occurrences reports was ATCOs workload level assessed as the level of the air traffic controlled by them (1 – low workload, 4 – the highest workload). Task demands are not a single factor that can affect the effort required by a task. The time on task for a given task demand will also affect the performance as well as the workload of the operator. The workload increases as a function of time, even if the task load is stable. After a variable threshold of time, resources are exhausted and an increase in workload and breakdown in performance are likely to occur. The operator gives up or "sheds" the least significant parts of the task in order to make workload more manageable. [4].

There are two extremes, very light traffic (low workload) and very intensive traffic (high workload). These extremes are connected with very low number of occurrences; number of accidents is practically zero. Logically, serious incidents are the most frequent occurrences during high workload of the controllers. The alarming information is frequency of accidents and incidents of all categories in positive conditions – workload/traffic felt as normal closer to low. The reason is in unintended lowering of controllers' awareness and their feeling that "anything could not happen" in these good conditions.

### *4.4. Location of the occurrences*

The aim of this paragraph is to describe how the location contributes to the accidents/incidents frequency. The occurrences were classified as airport- and en-route accidents/incidents. The correlation between the occurrence category and their location is significant at the 0.05 level. Fig.7 shows the proportion between the airports' and en-route occurrences. This situation was anticipated because the air traffic is more concentrated in the vicinity and on airports (i.e. take-offs, landings, taxi) in shorter period of time.

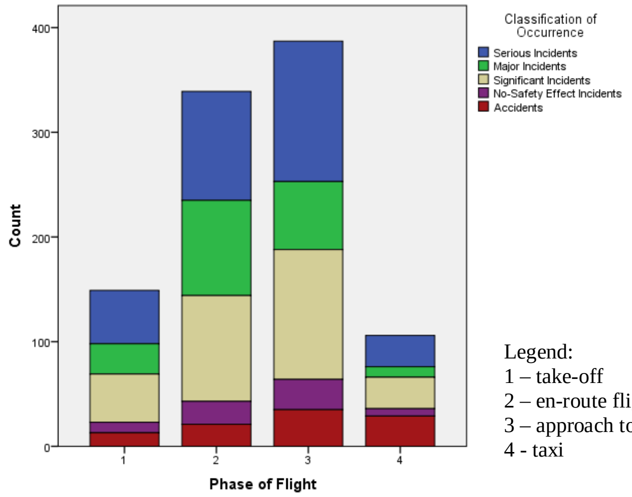



Legend:
1 – En-route
2 – Airports

Fig. 7. Airports- and En-route Occurrences

### *4.5. Phase of flight*

As mentioned above, airports are locations with higher frequency of occurrences. It is reflected in the phase of flights involved in accidents or incidents. Most occurrences are connected with aircraft´s approach and descent for landing. Those phases of the flight are from controllers' perspective the most challenging due to number of aircraft, their different headings, altitudes, vortex-categories and speeds. The right aircraft sequencing for this maneuver is crucial and the probability of controllers' or pilots' error rises. The safest phase of aircraft movement is taxiing. Despite this assumption occurrences connected with mentioned phase of flight (especially ground collisions and runway/taxiway incursions) are more frequent, than en-route contingencies, yet their consequences being not severe.

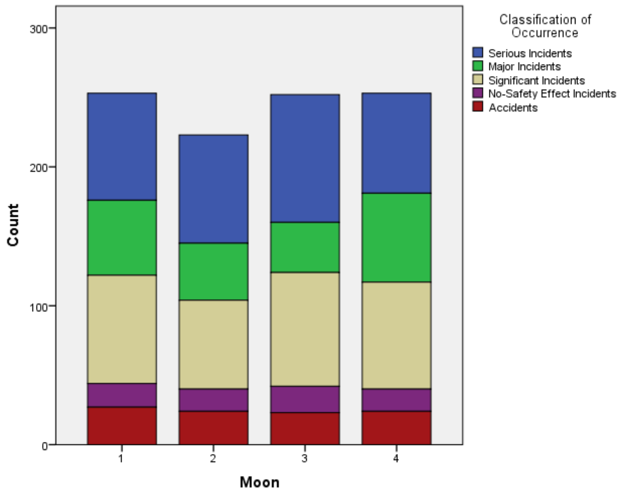



Legend:
1 – take-off
2 – en-route flight
3 – approach to landing
4 - taxi

Fig. 8. Occurrences in Particular Phases of Flight

*4.6. Moon-phases*

Several researchers tried to put through the Moon phases with human and animal behaviour (accidents, crime and suicides) and on the animals (Zimecki, 2006). According to their studies the number of accidents occurring during the full-moon day was lowest, the highest occurring two days before the full moon. Accidents were more frequent during the waxing than during the waning phase, but no significant differences were noted when the lunar month was divided into the four intervals of the lunar cycle. [5]. In the air traffic control involved occurrences this fact was not confirmed. There was no any correlation between the Moon-phases and occurrences (r = -0.009).




Legend:
1 – waxing
2 – full moon
3 – waning
4 – new moon

Fig. 9. Moon-phases Impact on Occurrence Distribution

## 5. Conclusion

The air traffic density on particular days of the week and particular periods of time (peaks and saddles) affected the frequency of occurrences. The majority of occurrences were observed at airports and in their vicinity during final approach and landing. This phase of flight is the most challenging for controllers as for pilots. Airports' traffic contributes to the occurring of accidents and incidents. The period of year had no impact on incidents' occurring. Higher workload did not implicate higher amount of incidents, most of them appeared during normal operational workload. Proper arousal (i.e. no under- or overload) is vital to fulfil all ATCOs tasks at requested quality. Flight rules had no significant impact on accidents or incidents occurrence; the distribution was identical for VFR as for IFR. Moon-cycle had no relation to the controllers' errors rate.

## Acknowledgements

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# DEPARTMENT OF FORENSIC EXPERTS IN TRANSPORTATION

# K622

Faculty of Transportation Sciences CTU in Prague has permission for forensic activities from the 22nd July 2002. The range of forensic permission was established for transportation technology and communication, logistics in transportation technology and communication, transportation engineering and communication, traffic infrastructure, management and economics in transportation technology and communication, automatization in transportation technology and communication, transportation systems and technology and engineering informatics. From the10th January 2005 was current range of Faculty forensic permission extended to urban traffic with specialization in traffic accidents causations. On the 15th November 2006 Department of Forensic Experts in Transportation became a self-sustaining department in frame of CTU in Prague, Faculty of Transportation Sciences. Faculty of Transportation Sciences is asked exclusively from Court and Police to elaborate expert's audit opinions or these, which are necessary to be verified using specific research approach.

# Accident Locations on the Expressway R46

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**Abstract**

The aim of the paper is to introduce the reader a pilot research project – shortened analysis of cause and process of traffic accident on expressway R46, generally by using backward analysis of accident process. The main objective of this project is to obtain overall classification of technical circumstances of accident causes in a part of the expressway and to evaluate potential connection between parameters of the road, driving speed, possible dazzle, atmospheric influence etc. The last part of the project is focused on the design of safety measures, which should result into an overall increase of traffic safety.

**Keywords:** expressway R46, accident rate, shortened analysis of traffic accidents, road parameters, light dazzle, road safety measures.

## 1. INTRODUCTION

The evaluated section of the R46 road (km 0.0 "intersection with D1" – KM 39.0 "Olomouc Slavonín", is part of the international motorway E462 Brno – Olomouc – Český Těšín – Krakow. Construction of the road was initiated by decision of the Czechoslovakian government no. 286 from 10. 4. 1963 within the conception of long term development of civil road network.

Table 1. Design parameters of R 46

| Section | Design parameters |
|---|---|
| Vyškov – Drysice | R 22,5/100 |
| Drysice – Želeč | S 22,0/100 |
| Želeč, obalovna | S 22,5/100 |
| Želeč – hranice okr.Prostějov | S 21,5/100 |
| okres Olomouc | S 20,5/100 |

In 2010 the Police of Czech Republic (PCR) investigated 75 522 traffic accidents (further abbreviated as TA) in total (countrywide). There were 695 fatal accidents (753 persons died), 2 462 accidents lead to serious injury (2 823 persons seriously injured), 16 519 lead to light wounds (21 610 persons lightly wounded) and 55 846 of cases resulted into property damage only, coming to a total cost of 4924.95 million CZK (246 million USD).

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On the observed road section (fig. 1), which is approximately 3,3 % of the total length of all highways and motorways in Czech Republic, PCR investigated 170 accidents in 2010. Where 163 of cases were located in rural areas, 6 in urban and at one traffic accident the location was not further specified (parking area). During these accidents 1 person was killed, 4 seriously injured, 40 lightly injured and 248 participants of traffic accidents were not injured at all. In total 266 vehicles were involved in accidents, with damage costs exceeding 27 million CZK (1.33 million USD). Based on the statistical indicator, the accident rate on the expressway R46 was not above the average accident rate in comparison to similar roads of the same category.

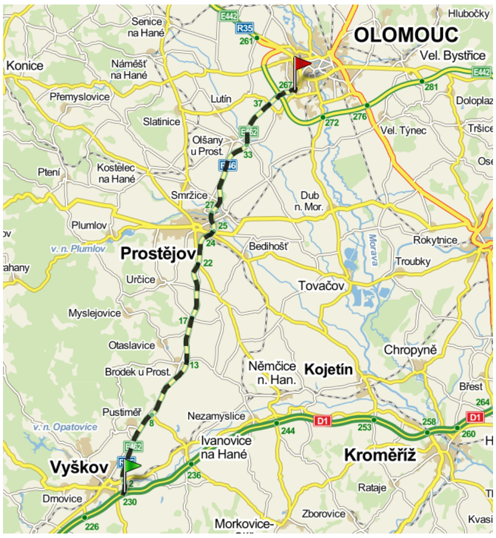


Fig. 1. Map of the analyzed section of motorway R46

## 2. Shortened Analysis of Traffic Accidents

During the shortened analysis of traffic accidents, the methodology of backward analysis of accident process is generally used, which consists of four main stages:

- post-crash analysis,
- crash analysis,
- pre-crash analysis,
- determination of the reaction time.

This methodology allowed an evaluation of traffic accident causes in connection with parameters of the road, driving speeds, potential dazzle or atmospheric influence. Consequently, in accordance with the application of safety measures, the evaluation allowed achieving a significant decrease of accident rate and discovered dangerous elements, either general or specific for particular places. The evaluation was based on obtained classification of technical circumstances of traffic accidents origin on the road section.

The origin and the process of the accident can be analysed using the road geometric characteristics, documented marks, post-crash positions of the vehicles and the deformation of the vehicles. The research team also had the statements of the drivers and the witnesses at their disposal.

## 3. Accident Datasheet

All accessible and relevant information was sorted into accident datasheets which were created and numbered for every accident. In total 170 traffic datasheets were created for the year 2010 and consecutively analysed. The accident datasheet is divided into four sub-sections: basic information about an accident, description of vehicle damage, description of the traffic accident from PCR protocol with photo documentation and analyses of accident together with proposed safety measures (resulting from analyses) (fig. 2).

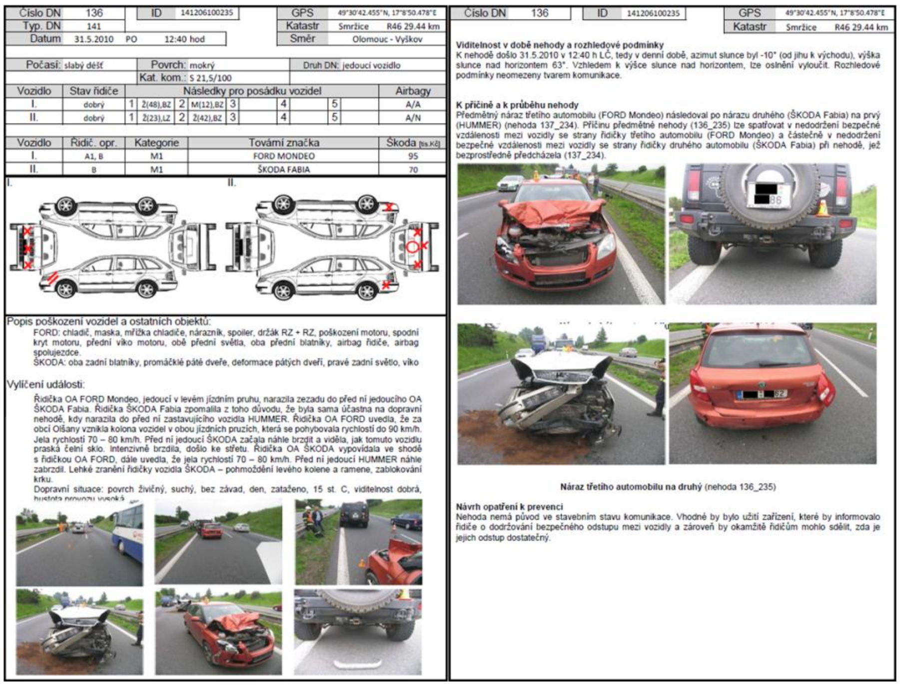

Fig. 2. Accident datasheet for the accident analysis

### *3.1. Basic information about the accident*

The heading of the datasheet (fig. 3) contains the reference number of the accident (number of TA - DN), typology of the accident, PCR files number (ID), date and time of the accident. Furthermore, the GPS coordinates of the exact location of the traffic accident are included, along with the stationing and direction of the road. The information about weather conditions, road surface and the type of the accident is given below. The physical condition of the driver for every vehicle involved in the accident is described in the datasheet (good, fatigue/fall asleep, under influence of alcohol, sudden physical indisposition, driver died before the accident, other adverse state), the number of occupants of the vehicle and corresponding ID (1 – driver; 2 – front passenger seat; 3, 4, 5 – back seats without distinguishing), his or her sex (male, female), age and severity of the injury (without any wound, light injury, severe injury, fatality), presence of airbags in the vehicle and information about their activation (N – car was not equipped with airbags, A/N – equipped, but airbags were not activated, A/A – equipped and airbags were activated). Furthermore the datasheet contains the type of driving licence of the driver. Information about the car include details relating to the vehicle category (passenger car – M1, truck – N3, bus – M3, motorcycle – L), model and estimated damage by PCR in thousands of CZK.

| | | | | | |
|---|---|---|---|---|---|
| Číslo DN | 136 | ID | 141206100235 | GPS | 49°30'42.455"N, 17°8'50.478"E |
| Typ. DN | 141 | | | Katastr | Smržice R46 29.44 km |
| Datum | 31.5.2010 PO 12:40 hod | | | Směr | Olomouc - Vyškov |
| Počasí: slabý déšť | | Povrch: mokrý | | Druh DN: jedoucí vozidlo | |
| | | Kat. kom.: S 21,5/100 | | | |

| Vozidlo | Stav řidiče | | Následky pro posádku vozidel | | | | | | | | Airbagy |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I. | dobrý | 1 | Ž(48),BZ | 2 | M(12),BZ | 3 | | 4 | | 5 | A/A |
| II. | dobrý | 1 | Ž(23),LZ | 2 | Ž(42),BZ | 3 | | 4 | | 5 | A/N |

| Vozidlo | Řidič. opr. | Kategorie | Tovární značka | Škoda [tis.Kč] |
|---|---|---|---|---|
| I. | A1, B | M1 | FORD MONDEO | 95 |
| II. | B | M1 | ŠKODA FABIA | 70 |

Fig. 3. Datasheet – basic information about the accident

### *3.2. Description of vehicle damage*

In this section of the datasheet there is the description of the vehicle damage stated in police documentation for every vehicle. Damage of vehicles is indicated within the datasheet using the help of pictograms, defining the place and extent of the damage on the chassis of the vehicle (tab. 2).

Table 2. Graphical illustration of damage on the vehicle

| Pictogram | Description |
|---|---|
| × | Destroyed parts of the vehicle |
| // | Scratches on the chassis parts |
| ○ | Slight deformation of the chassis |

### *3.3. Description of the traffic incident from PCR protocol with photo documentation*

This section contains description of the accident based on the police documentation, the traffic situation at a given place and time. In addition, selected photographs taken by PCR at the time of examination of traffic accident are included (fig. 4). Photographs capture the post-crash situation.


Vylíčení události:
Řidička OA FORD Mondeo, jedoucí v levém jízdním pruhu, narazila zezadu do před ní jedoucího OA ŠKODA Fabia. Řidička ŠKODA Fabia zpomalila z toho důvodu, že byla sama účastna na dopravní nehodě, kdy narazila do před ní zastavujícího vozidla HUMMER. Řidička OA FORD uvedla, že za obcí Olšany vznikla kolona vozidel v obou jízdních pruzích, která se pohybovala rychlostí do 90 km/h. Jela rychlostí 70 – 80 km/h. Před ní jedoucí ŠKODA začala náhle brzdit a viděla, jak tomuto vozidlu praská čelní sklo. Intenzivně brzdila, došlo ke střetu. Řidička OA ŠKODA vypovídala ve shodě s řidičkou OA FORD, dále uvedla, že jela rychlostí 70 – 80 km/h. Před ní jedoucí HUMMER náhle zabrzdil. Lehké zranění řidičky vozidla ŠKODA – pohmoždění levého kolene a ramene, zablokování krku.
Dopravní situace: povrch živičný, suchý, bez závad, den, zataženo, 15 st. C, viditelnost dobrá, hustota provozu vysoká.

Fig. 4. The accident datasheet (description of the traffic accident)

### *3.4. Analysis of the traffic accident*

The last section of the datasheet is divided into several parts. The first part is focused on a potential dazzle of the driver by sunlight in every accident. The height and position of the sun at the time of the accident is described. Using these facts together with weather conditions and road orientation, the possibility of sunlight dazzle is then evaluated. Furthermore, it is specified if the road could influence the traffic accident of sight barriers.

In the second part, the place of the traffic accident, especially the particular section of the road which was prior to final position of the vehicles, is described. This is the initial place of origin of the accident. Further information is provided, e.g. about traffic signs, slope, curves radiuses, road nonskid quality or potential unevenness of the road. This is followed with an analysis of the accident and all relevant circumstances, which sums up and describes the process and main causes of the accident from a forensic expert point of view.

Third part of this section introduces potential safety measures leading to prevention, which should be taken as preliminary concept, formulated from side of traffic accident forensic expert.

## 4. Individual Scenarios of the Traffic Accident

To experts are known facts, which are proven by real accidents (such as risk of aquaplaning in the beginning of left-handed curves), which is necessary to implement into prevention awareness.

The location of the accidents led to determination of the repeated causes specific for the certain sections of the road. In total 10 accident scenarios were established:

- Scenario no. 1 – Speeding (30 x TA)
- Scenario no. 2 – Rear-end collision of two vehicles (5 x TA)
- Scenario no. 3 – Lane breakaway from R46 on exit ramp (5 x TA)
- Scenario no. 4 – Lane breakaway from R46 caused by steering manoeuvre (19 x TA)
- Scenario no. 5 – Skid (38 x TA)
- Scenario no. 6 – Accident with animals (20 x TA)
- Scenario no. 7 – Distracted driving (17 x TA)
- Scenario no. 8 – Technical issue (19 x TA)
- Scenario no. 9 – Condition of the driver (13 x TA)
- Scenario no. 10 – Other (4 x TA)

## 5. Identification of High Risk Locations

The accumulation of traffic accidents is connected with multi-level exits, although the main factor on the whole R46 (not only around exits) is the speed limit with regards to the design speed of the road. The absence of connection and turning lanes together with poor technical conditions of the road surface are also a danger.

Road layout => traffic density => sight possibilities => speed of the vehicle defines time that the driver has for solving a sudden traffic situation (e.g. TA no. 67 and 149). Time space computations shows that drivers had the chance to solve a critical situation without collision in 55 % of cases (the cause of the accident was just the misjudgment of the driver). In 26 % of cases, the driver had the chance to solve the situation without collision by making immediate, fast and precise decisions (without the delay caused by solving of the situation). Experiences show that differences between an actual accident and traffic conflict lie within tenths of seconds (corresponding to meters or tens of meters of trajectory).

From analysing the findings we can determine four locations where the improvement of current state is desirable (fig. 5).

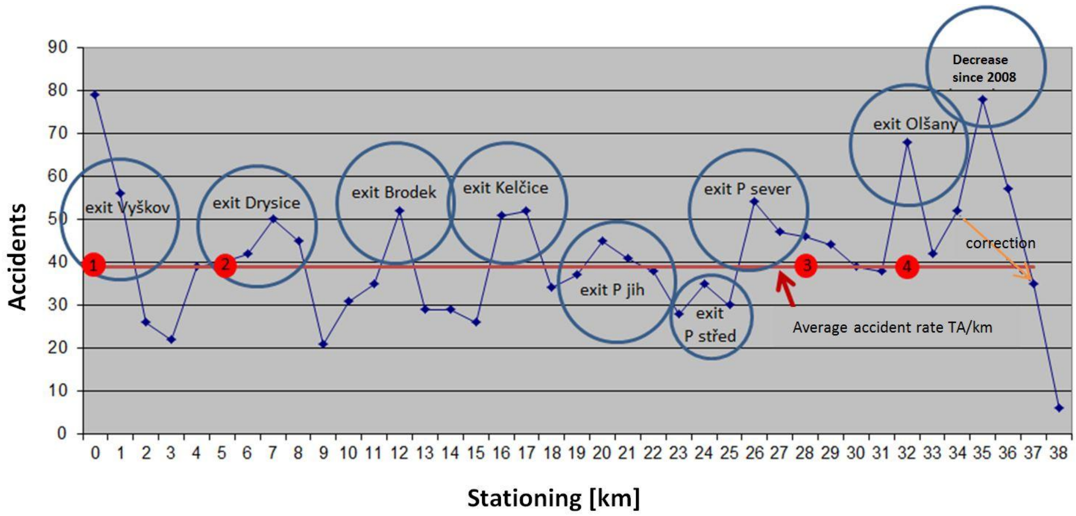


Fig. 5. Accident rate on evaluated section in the years from 2005 to 2010

### *5.1. Location 1 – direction Olomouc - Vyškov, stationing km 0.8; TA no. 2, 4 and 5*

Drivers are most likely caught off guard by the location of the exit in the direction of Vyškov (fig. 6). Consequently, they try to turn from the traffic lane, which results in lane breakaway into a ditch, where concrete front of exit-ramp is situated. Probable explanation could be a psychological problem: the driver sees the exit – turns into turning lane – follows the signs on the bridge and suddenly realizes that the exit to Vyškov is in fact situated before the bridge. The braking marks on the road also confirm the problematic placing of the exit and this type of the accidental movements of the vehicles.

Fig. 6. High risk location 1– sight limited by vegetation

The concrete pillar of the bridge is protected by steel crash barrier from the side (fig. 7), but is not protected from the front (e.g. with impact damper) => the potentially dangerous spot is highlighted by the red circle in fig. 7 (e.g. TA no. 2).


Fig. 7. High risk location 1– missing protection of concrete construction of the bridge

*5.2. Location 2 – direction Olomouc - Vyškov, stationing km 5.1; TA no. 24, 25, 26 and 27*

Traffic accidents in this location occur repeatedly during winter time. The problem lies in significant differences between the maintenance of the road in direct lanes, turning lane leading towards gas station and area near gas station (fig. 8 and 9).

Fig. 8. High risk location 2 – the gas station and winter maintenance

Fig. 9. High risk location 2 – concrete bases of traffic sign above the terrain

### *5.3. Location 3 – direction Olomouc - Vyškov, stationing km 28.3; TA no. 125, 126 and 127*

The initial parameters and course of the accidents were the same for all analysed incidents. In the beginning of a left-hand curve on a rainy day the car begins to skid and crashes on the right side of the road. The main cause can be seen in insufficient drainage of the road, which leads to aquaplaning (fig. 10).

Fig. 10. High risk location 3 – detail of condition of the road surface

### *5.4. Location 4 – direction Vyškov - Olomouc, stationing km 32; TA no. 150, 152, 153 and 154*

The initial parameters and course of the accidents were the same for all analysed incidents. In the beginning of a left- hand curve on a rainy day the car begins to skid and crashes. Traffic accidents are most likely connected with new road surface. Excellent nonskid quality under wet conditions is stated in given official technical status report on road quality (measurement 2009). From analysis of accident rates for this specific location in the years 2005 to 2010, a quadruple increase of accident rate (fig 11) can be seen.

Fig. 11. High risk location 4 – detail of condition of the road surface with crashed vehicle

### *5.5. Problem 5 – snowdrifts/snow barriers*

- Area of airport Vyškov, stationing km 9 and area Drysice – antenna, stationing km 26.5 Prostějov north.

From photo documentation of TA no. 13, 15, 19, 20 and 46 and from protocols of TA no. 11 and 119 it can be stated, that during the winter period there are snowdrifts on the road, alternatively snow barriers can arise. Snow barriers, especially at centre guard-rail, can have negative effects on their retaining function (fig. 12).

Fig. 12. Problem 5 – winter condition

### *5.6. Problem 6 – concrete canalization shafts/concrete elements*

- TA no.: 4, 22, 26, 27 and 88

Fig. 13. Problem 6 – detail of concrete canalization shaft

The research team was analysing only photo documentation of traffic accidents, therefore they have no further information about another locations where concrete objects could be above terrain level (fig. 13).

### *5.7. Problem 7 – driving in the opposite direction TA no. 116/2010*

In all the evaluated accidents there was one accident where a driver entered the R46 road in the wrong direction. In TA no. 116/2010 the driver entered the expressway in the wrong direction after leaving the gas station at the Prostějov-south exit, where she had been asking for the directions. The accident happened during the night.

### *5.8. Probem 8 – insufficient width of the shoulder*

Vehicles which pull over after breaking down or after accidents, partly reach into the traffic lane and cause traffic situations leading to an accident (TA no. 9, 67, 82, 128, 149, 151 and 155) (fig. 14).

Fig. 14. Problem 8 – Vehicle pulled aside still significantly covers the main traffic lane

## 6. Conclusion and Recommendation of Safety Measures

Analyses have shown that the majority of traffic accidents were caused by the drivers, and that the road itself was the cause for traffic accidents in 26% of cases. Drivers probably do not realize that driving at a high speed decreases their crucial time for solving critical traffic situations. Nevertheless we consider the permission of 130 km/h speed limit on a road with a design speed 100 km/h being problematic. Apart from the actual speed limits, another accident prone element is the difference in speeds between vehicles, especially on locations where there are multi-level intersections without connection lanes. Automobiles on entrance ramps of the intersection have to stop or slow down significantly and then accelerate to the speed of the main traffic flow. All this happens while in the right lane trucks drive with an average speed of 85 km/h and in the left faster lane vehicles drive with a speed of 130 km/h.

A specific problem and potential accident element of the observed section of the expressway R46 is the insufficient width of shoulders for pulling vehicles aside – either because of malfunction or after traffic accident. Average width of personal cars is between 1.60 to 1.85 m (width 1.5 m is exceptional – e.g. Trabant). Therefore a shoulder with a width of 1.5 m is not wide enough to prevent the interference of the pulled aside vehicle with the traffic in the adjacent traffic lane. If the vehicle covers the adjacent lane, it creates inconspicuous danger, see accidents (TA no. 67, 82, 128 and 149).

Recommendation for decrease of accident rate:

1. Consider an increase in width of the shoulder to the detriment of adjacent lines (which is modern trend leading towards natural decrease of speed – in narrow lanes drivers tend to drive slower).
2. Create emergency stops for vehicles in predefined intervals (marked with traffic sign IP9).

Particular sections (high risk location 3) have completely flat surfaces of the asphalt road, which are exceptionally slippery under wet conditions. Furthermore, locations with specific aspects leading towards aquaplaning during heavy rain (high risk location 4) can be found along with locations that are characterized by uneven surface, or by elevated drainage shafts.

Accidents involving animals occur over the whole expressway R46. An evident increase in the number of accidents can be observed between the years 2007 and 2010, therefore the expressway should be secured over the whole length. A possible connection between changes of growing crops on surrounding land and animals involving accidents may exist. During these accidents the driver has to react suddenly to an obstacle. The reason is that the animal usually runs into the traffic lane. The resulting outcomes can be serious, especially in cases where the animal is hit in mid-air. This can lead even to perforation of windscreen of the vehicle.

Recommendation for decrease of accident rate:

1. placement of scent barriers
2. fencing around the concerned expressway

The amount of accidents is not only proportional to the animal population in the area, but mainly to the traffic volumes on the road.

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# Safety Elements of Bicycles and Definition of a Sitting Triangle

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**Abstract**

This article summarizes the results from student research focused on the safety of cyclists, their behaviour in traffic, riding style, level of compulsory equipment of bikes in use and other important aspects for forensic analysis of traffic accidents. The research has also focused on sitting triangle determination. Theoretical information were supported by data which were received from students semestral works. The data has been collected for two years. The statistical set contains more than 700 works, each work represents one bicycle with all monitored parameters (type, material, type of brakes, sitting triangle...). Statistical results give for example the general overview of level of the safety equipment of the average bicycle rider in the Czech Republic.
This article is also the first entrance study for research project called "Cyclist Trajectory and Dynamics of Motion (Description and Influencing Factors)". The aim of the project is studying of aspects which influence the riding dynamics and car/bicycle accident configuration and can help in accident analysis.

**Keywords:** bicycle; helmet; brakes; sitting position triangle; safety; compulsory equipment

## 1. INTRODUCTION

The cycling in the Czech Republic went through a relatively large development in recent years. Especially in terms of growth in the number of cyclists. In addition to active athletes - both professional cyclists and other athletes who use bicycle to improve their physical fitness - the number of people who understand cycling as a way of active relaxation increased dramatically. The amount of people using bicycle as a means of transport between home and work has been considerable.

With the change of number and representation of the age and social groups among cyclists, the composition of bicycles and bikes itself is changing too. There have been changes in riding characteristics, distribution and size of individual components, or other used materials. It is thereby possible to increase the safety of cycling, to a certain extent, especially if it is done in interaction interact with other transport subsystems.

This study is a contribution to the broader issue of safety of cyclists in traffic which the Faculty of Transportation Sciences (hereinafter referred to as CTU FTS) pursues. The article is based on the results of statistical research, conducted by bachelor level students at CTU FTS, on a statistical sample of about 700 currently used bicycles. One of the objectives is therefore to assess the level of bicycle equipment with safety features, compliance with applicable national legislation on the mandatory gear of a bicycle, active use of safety helmets by bike riders, the

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most common types, materials used and the age of the bikes owned in the Czech Republic. The statistical sample was also used to determine the rider's sitting position on different types of bikes, which can vary greatly. The results of this research are the input for a student research project titled "Cyclist Trajectory and Dynamics of Motion (Description and Influencing Factors)", which was supported by the CTU Student grant competition and will focus more on driving dynamics cyclist´s ride which is affected by e.g. long-term stress, fatigue, issued, exposé to a forced delta change in sitting position etc.

## 2. Data Collecting

Semestral works of students of the first year of the FTS, Introduction to Transport Accidents lectures, were used for a collection of all the relevant data. During the period of two years more than 700 studies in which students reported particular data about their own bicycle or about bicycle owned by somebody they know were accepted and approved.

The studies were handed in in the form of a filled in spreadsheet file. It ensured the transparency and mainly clarity of filling and simplified subsequent processing. File (questionnaire) was defined by the authors so that it restricted differentness in responses which would have limited the first semi-automatic control and processing of the studies.

More than 70 entries were found out for each bicycle. From the initial determination of the type of bike, its manufacturer and age, through information on its size (dimensions of the frame and wheels) and weight, the material from which it is made of (frame and fork), type of brakes, mandatory and optional accessories (fenders, bell, etc. ) to the identifiers of wheels (frame number, serial number, etc.). It included also questions on helmet use, namely whether the user owns and use bicycle helmet. In such a case data as the type, age of the helmet and weight were required to be filled in. Completion with photo documentation was an integral part of the questionnaire as well. The pictures were taken when viewed from the front, rear, both sides and top. Some detailed photos (brake system, handles and wheel axle, identifiers) or even photographs of the helmet were also required.

## 3. The Data Obtained

### *3.1. Bicycle type and age*

Bicycles can be classified according to a significant amount of aspects. Depending on the type of use and a type of the frame we recognize trial, BMX, fitness, freestyle, trekking, road, motocross and mountain bike. According to the statistics of importers of bicycles the best selling type of bike is a mountain bike. However the supreme position of a mountain bike has started to shake in recent years as sales of motocross bikes are increasing rapidly. The proportion of mountain bikes among the newly sold ones is decreasing but it is still the majority owned type in the population which was confirmed by the results of the survey.

The following graph shows that mountain bikes had with 417 pieces almost 60 % representation in the statistical file. Casual, trekking and road bikes followed (Fig. 1). Representation of other types of bikes was marginal in the file. Average bicycle is six years old.

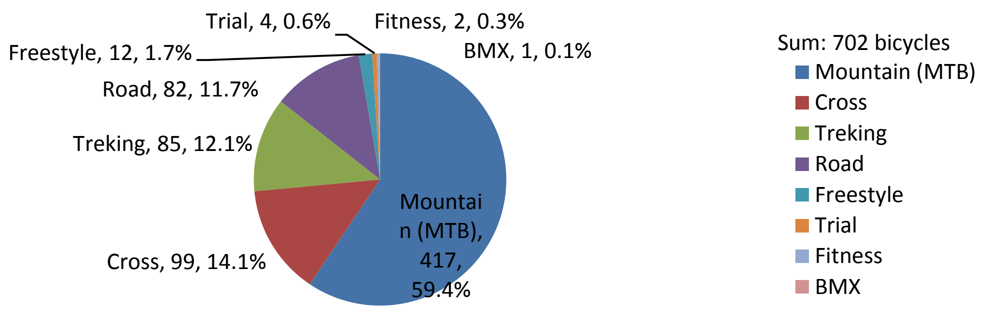


Fig. 1. Frequency of bicycle types

*3.2. Materials*

The basic materials used for the production of bicycle frames are steel, titanium, carbon and aluminium. Among the materials that are also used, but not on a massive scale, are magnesium and wood.

Large-scale aluminium alloys appeared a lot in the statistical sample. To a lesser extent followed carbon and steel. Other materials have appeared rarely (e.g. magnesium) or did not appear at all (wood, titanium). This result corresponds with the market situation. An exception is the relatively small number of carbon frames. However it can be assumed that its usage will grow in the future due to its falling prices.

*3.3. Size and weight*

The average weight of the bike without equipment was 12.9 kg in the monitored set. The total weight including the equipment was 13,4 kg. The average size of the bike set was: length 172 cm, width 60 cm, height 104 cm.

The average sizes of the frame as shown in Fig. 2 are:

- the length of the top tube 55 cm,
- seat tube length 26 cm,
- wheelbase of 104 cm.

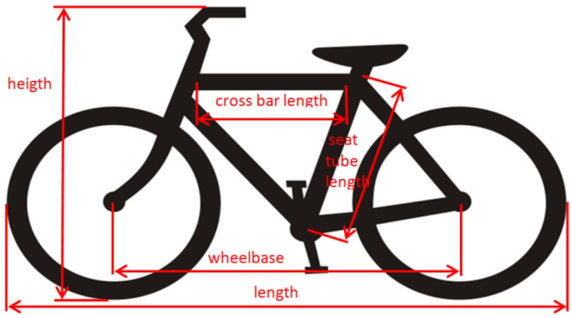


Fig. 2. Selected bicycles dimensions

*3.4. Brakes and cushion*

Almost all the bikes had the front and rear brake. Representation of different types of brakes is shown in the following graph on the Fig. 3. Brakes centric and eccentric were the most represented.

Most of the bikes were equipped with a set of front suspension fork (75 % of the total), while only 7 % of the bikes had the rear suspension fork.

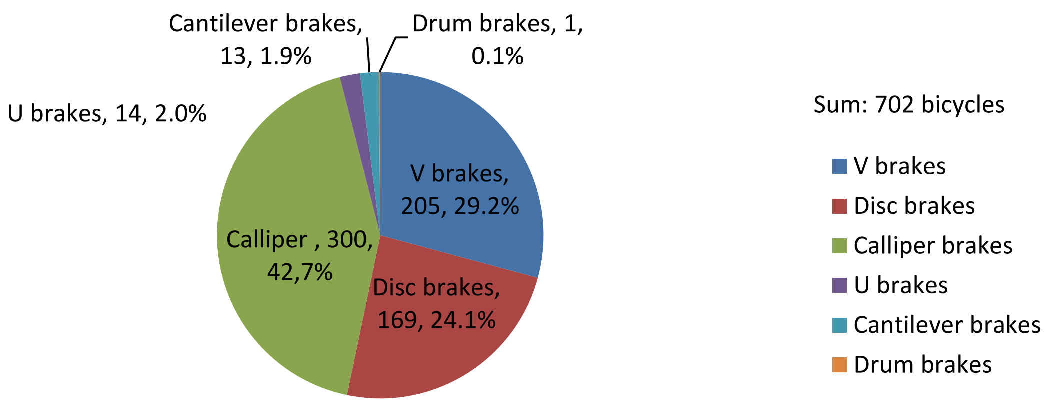


Fig. 3. Frequency of bicycle brakes

### *3.5. Equipment*

#### *3.5.1. Compulsory equipment*

One of the important issues of the safety of cyclists is their visibility. This area is covered by the Regulation of Ministry of Transport No. 341/2002 on the approval of technical competence and technical conditions for the operation of vehicles on the roads. This regulation is an implementing regulation of the Act No. 56/2001 Coll. and it is specified in its Annex 13 inter alia the technical requirements for bicycles.

The provisions concerning the right lighting and reflectors are an important point of this Directive. The bicycle must be equipped with: rear red reflector which can be combined with a red rear lamp or replaced with reflective materials with similar characteristics. Then it must have a white front reflector which can be replaced with reflective materials with similar characteristics, reflectors of orange colour on both sides of pedals. These reflectors can be replaced with light-reflecting materials placed on the shoe or near it, on the spokes of the front or rear wheel or both wheels of at least one side reflector of orange colour on each side of the wheel.

Bicycles for driving in poor visibility shall be equipped with a lamp shining white light in forward direction. The headlamp must be aligned and adjusted permanently so that the reference axis flux intersect the ground plane at a distance of 20 m away from the lamp (with sufficient and continual lighting lamp of white colour with flashing light). It must also include rear light of red colour (it can be replaced with the lamp flashing red light) and the power source. If it is an accumulator source, it has to ensure with its capacity the intensity of the lights for at least 1.5 hour without interruption. [1]

It was found out in the survey that only about 20 % of the bikes corresponds the Regulation No. 341/2002 and is properly equipped with reflectors. The relatively low figure is largely caused by the lack of reflectors on one or two places, but there were also bikes where the reflectors were missing entirely. The majority of bikes (about two thirds) were not equipped with headlights but they are not an obligatory part of the equipment. Headlights and power supply are required only for riding in poor visibility.

#### *3.5.2. Other equipment*

Other elements that occur on bicycles and can increase traffic safety were also included in the querying. These include for example the bell which is not a part of the mandatory equipment since 2002. The results are summarized in the percentages used in the following table 1.

Table 1. Frequency of compulsory equipment

| Fender | Lock | Tachometer | Bottle holder | Pump | Bell | Cycling Bag | Tools |
|---|---|---|---|---|---|---|---|
| 54% | 65% | 48% | 25% | 72% | 84% | 88% | 63% |

### *3.6. Head protection - helmet*

Use of the safety bicycle helmet is an important part of the safety of the cyclist. Head injuries are among the most serious when it comes to cyclists. The consequences of the absence of the helmet can be fatal even when the cyclist does not ride at high speed but only falls at a low speed. Bicycle helmet reduces the risk of injury of head and brain of cyclists greatly. [2], [3]

The percentage of cyclists who wear helmets when riding was increased after the legal force of amendment to the Act 411/2005 Coll. about the road traffic. This amendment provides in § 58 paragraph 1 obligation to wear a helmet for persons under 18 years. The aim of it was to avert the growing trend of young cyclists' injuries. Obligation to wear a helmet for persons under 18 years is likely to bring up a generation that will wear a helmet in a later age as they will consider it a natural part of their equipment. This statement can be confirmed by the results of the query of the statistical file because only 10 % of the studies stated that the helmet is not used.

Most helmets (84%) are of road or mountain type. The shells are made of expanded polystyrene foam. The surface is formed by a thin layer of plastic. Integral helmets whose representation is very low (2%) are based on the helmets for motorcycles and also resemble their shape. Integral helmet offers better protection including protection of the face. The last group are skate helmets (5%), which were originally designed for skateboarding. Repeated use of the helmet after a crash was considered during their development. [4]

### *3.7. Sitting*

#### *3.7.1. Definition of sitting*

The issue is the geometry of the rider sitting either in two or single-tracked vehicle. Proper seat adjustment is based on the need to ensure rider the option of comfortable and functional seating. The position mustn´t be uncomfortable for riders as it couldn´t exhaust the organism of rider and also reduce his concentration. The long term remaining in wrong position may also lead to changes in organism and cause pain and subsequent health problems. When it comes to the mentioned functionality all the devices and controls needed for riding must be within reach of the rider.

Seating can be considered as a static strain accompanied by a static muscular activity and causing insufficient blood flow to the muscles, overstrain and fatigue. Human body needs movement and changes. [5] This is a way how seating can be partially characterized in terms of biomechanics and biomedicine. Therefore various projects whose central factor is the triangle of sitting and which aim at the possibility to change seating position are arising. However these are the projects in the field of motor vehicles.

The situation is different when it comes to bicycles. For example the cyclist doesn´t sit in a rigid position like the rider on the motorbike. The muscle activity prevents static position and insufficient blood supply to the muscles. At the same time cyclist change his position on the bike by characteristics of the ride. When riding uphill he can benefit from the position of "of the saddle" and vice versa when driving downhill crouching to take a more aerodynamic shape.

The similarity lies in fatigue in this case mainly of physical activity. But even monotony may be the cause of fatigue of cyclists. Back or neck pains are frequent but can be affected by the adjustment of bike features such as the saddle height and handlebar. It is clear that the bicycle must be set according to parameters of the rider - especially the height – in order not to cause an unnecessary pain.

Seating has a similar effect to the dynamic characteristics of the vehicle – it influences the location of the centre of gravity, moments of inertia and drag. E.g. height of centre of gravity substantially contributes to the stability – the more the centre of gravity below the vehicle is the more it is stable. Seating also affects both active and passive safety. But in the area of cycling its effect is almost negligible.

Seating is defined by the horizontal and vertical triangle and the height of the points that create these triangles. These are (see Fig. 4):

- R point (H point) - an imaginary middle of the seat on its surface.
- $A_L$ ($A_P$) point - the reference point on the handlebars at the place where the palm touches it.
- $B_L$ ($B_P$) point - the reference point at the centre of the crank. [6]

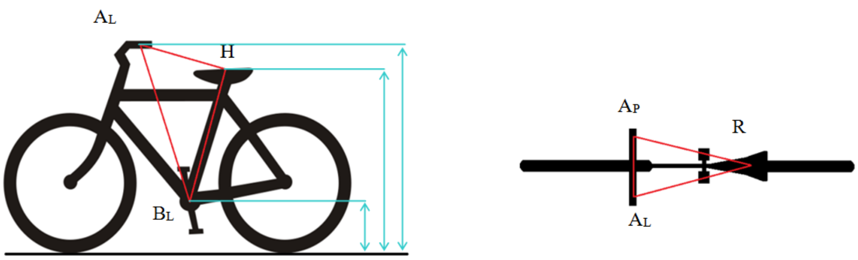


Fig. 4. Sitting triangle on a bicycle

Geometry of the position in which the cyclist is sitting also affects riders' kinematics during and after the crash. This was confirmed by the dynamic impact tests performed on CTU FTS. [2] Geometry of the sitting position of the cyclist (especially the height of his H-point) in relation to the geometry of the front of the car (especially in relation to the height of the bonnet leading edge) has a significant effect on the contact area of the car/rider impact and on the biomechanical load consequently. These parameters of the contact are important also for the accident analysis carried out by forensic experts. Geometry of the sitting position affects the point of impact of the head on the bonnet of the car, place of the contact of the pelvic area with the mask of the car and the resulting differences in the after crash kinematics. [2] This issue is a part of the research on FTS CTU. The research is also focused on the effect of fatigue to the geometry of sitting, reactions of cyclists exposed to a forced change of the sitting triangle. Parameters of the rider and parameters of the bicycle may help clarify configuration of crash in the analysis of traffic accidents.

*3.7.2. Size of the triangle*

Average sizes of triangles and heights of reference points were determined from obtained values. These were compared with the overall average triangle and wide relative deviations (for some values of up to ten percent) for types that were represented by a small number of bikes (trial, BMX, fitness, freestyle) were found out. Then the values of the four most representative types (trekking bikes, road, cross and mountain) were compared. The result was that the individual distances and reference points of the triangle differ by a few percent. However in most cases the heights of reference points differ by tens of percent.

Method of photogrammetry was tested for future detection of further results. As a cyclist is in a different position when he/she is steady or during movement in different driving modes (uphill, downhill, plane) the classical methods for determining distances such as the use of bandwidth are inappropriate. Independently on driving mode of cyclist the photo frame is capable to record all relevant information with minimal distortion quickly, comfortably and flexibly. That's why an experiment to verify the possibility of using photogrammetric determining of size and position of the desired parameters was made. [7]

Scanning was performed in the following way. At first a steady reference bike was photographed in outer positions of cycling path. Then images of two passages of the reference bike in a given direction were shot. After that a series of images of passaging cyclist were shot. In order to achieve higher accuracy assessment and to determine whether there has been a shift in the camera the scanning of the reference bike in steady and in the extreme positions has been repeated during the measurement. [7]

Graphical evaluation of the images was done in Autodesk AutoCAD 2012. For the image of the reference bike in the outer position a scale has been set due to a known wheelbase. Then the image was converted to the scale so that one unit corresponded to 1 mm. Gradually 4 scales has been obtained for each direction. A scale that corresponded to the image of passage through the centre of the lane for chosen direction was determined by an arithmetic mean. Then all remaining acquired images were transferred to the scale and a location of important points of the seating triangle and the eye height were graphically determined. Their mutual distance, length and position were then exported with use of DATAEXTRACTION function into Microsoft Office Excel 2007 where they were processed and evaluated. [7]

## 4. Conclusion

This study provides an input to the research project which partly builds on previous research done on CTU FTS. In particular the dynamic crash tests focused on unprotected road users. At the same time the project builds on students' thesis that dealt with improving the safety of cycling transportation with regard to the expansion of knowledge about the dynamics of cyclists - all with applications in forensic expert practice or more precisely in the analysis of traffic accidents. Statistical data as outlined in this article also serve as the input database showing e.g. the current level of equipment of bikes such as bicycle safety features. The level of this equipment can be considered below average. The following project will be focused on driving dynamics of the cyclist for the needs of forensic expertise. Monitoring the impact of long term strain on the reactions of cyclists in traffic, effect of fatigue, reactions of cyclists exposed to a forced change of the sitting triangle, watching the width of riding corridor of cyclists etc.

### Acknowledgements

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# DEPARTMENT OF SECURITY TECHNOLOGIES AND ENGINEERING

# K623

# Analysis of Cyber Networks

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**Abstract**

The aim of the paper is to show that all cyber networks (such as telecommunication, IT or ICT networks) are systemically identical or very similar, although each of them is applied in another industry or economy field or includes other added functional elements. The effort is to show that systemic identity (similarity) of the mentioned networks identifies the same set of network security threats that can be solved using the same approaches and techniques. The integrative approach based on the systematic approach enables to effectively use the efforts of professionals and all means target to the actual problem solving. The mentioned networks classification to the cyber critical infrastructures is also made based on this concept. Cyber system and cyber networks are threatened by both, the internal system deficits (technical and organisational nature) and the wide range of disasters: natural disasters - impacts primarily on the technical resources; intentional events caused by human vandalism, theft, terrorist attacks; technological accidents; and failure of electricity supply; etc. They threaten individual humans, human groups and states by their technical and organisational deficits and by the IT disuse.

**Keywords:** security; safety; sustainability; human system; strategic management scenarios; research scenarios

## 1. Introduction to problems

The cyber infrastructure belongs to the critical infrastructure that is fundamental territorial system that ensures daily needs of humans and at critical situations is important for response, stabilisation of situation and for start of renovation and development [1-3]. As each other infrastructure it consists of objects and networks. It is basic for collection, analysis and spreading the information across the users of different nature. The structure of whole cyber system, i.e. interconnected information and communication systems has three basic parts: procedural structure; technical structure (hardware); and program structure (software). The individual parts are mutually interfaced, i.e. mutually dependent. Each section then has its function and its structure [4]. The performed inventory showed that for cyber network safety the following critical items must be followed: processes; data sets; software; hardware; operators; and documentation [4].

The disasters that caused damages in cyber system and its infrastructure have an origin in: technology and infrastructure of system itself (construction, reliability, function and operation, material, organisation etc.); external disasters (natural disasters, technological disasters as fire, explosion, contamination by hazardous substances, failure of other infrastructures as electrical networks, control of territory etc.); human factor (human failure / error); and in human intent (viruses, hacking, terrorist attacks etc.) [1,4,5]. Because the cyber system and cyber infrastructure are relatively new aspects, so for their safety there have not been unified system of norms and standards yet. According to good engineering practice principles each problem should be solved on several levels, Figure 1 [6,7].

The cyber networks create at present the basic functional pillar of majority of systems in different branches of national and international economy, Figure 2. They are not only the tool for communication and exchange of structured information but also the means with help of which there is realised governance of vitally important infrastructures, e.g. remote control of transformers, dams etc. It is the reality that through them there are realised mutual interactions of networks that can lead to cascade failures of critical infrastructure [3], Figure 3.

In different economic sectors regarding to various use of appropriate cyber nets the followed networks have a different designation / label, as cyber networks, telecommunication networks, IT networks, ICT networks etc.

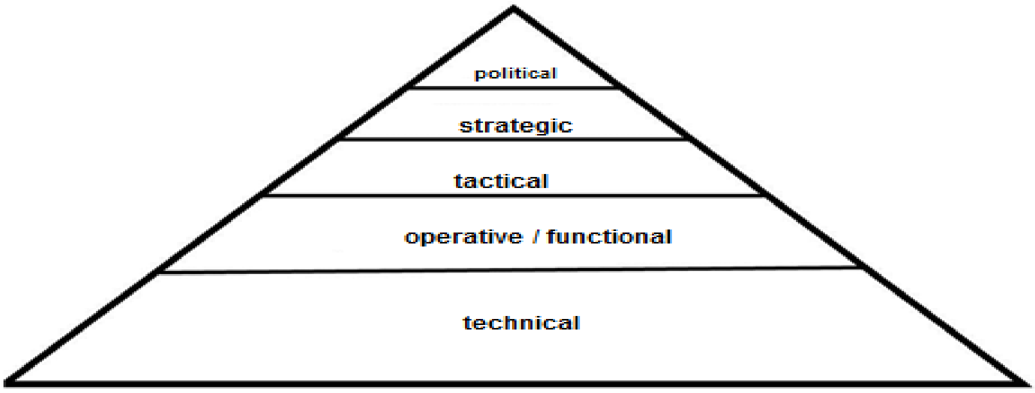


Fig.1. Levels on which security problems should be addressed [6,7]

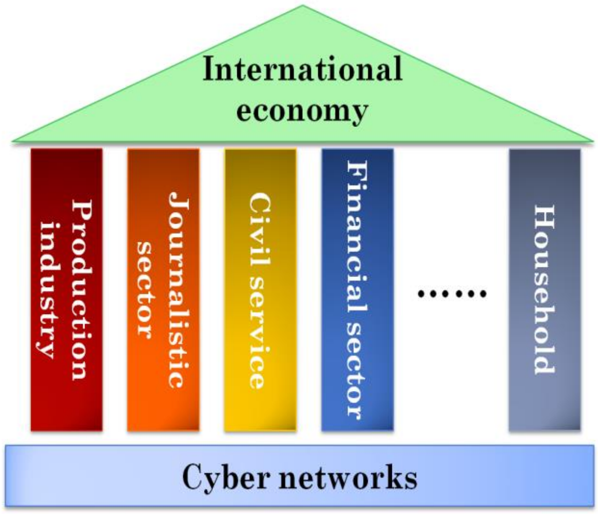


Fig.2. Cyber network value

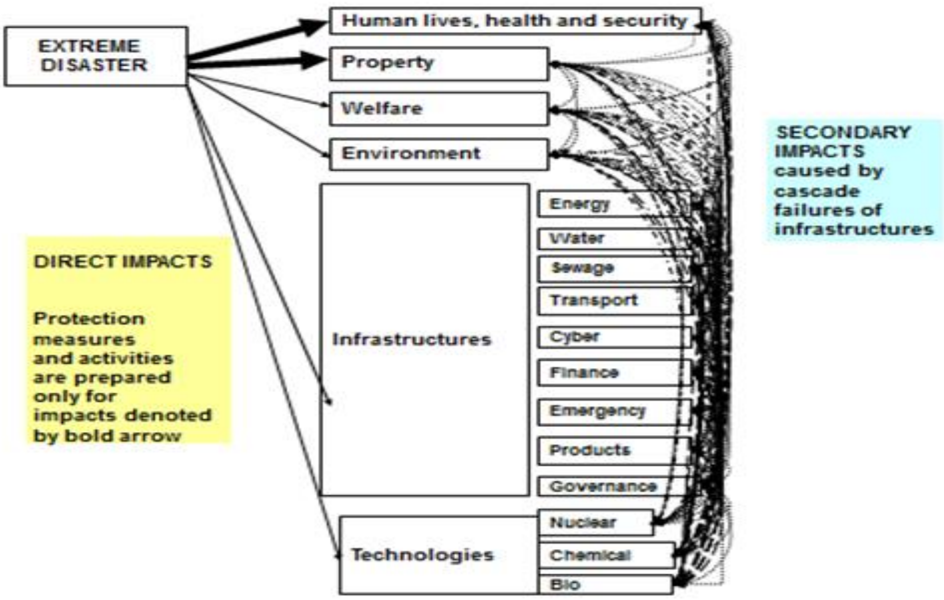


Fig. 3.Impacts of extreme disaster on territory and infrastructures [4]

For cyber system safety the most important system properties are: vulnerability; resilience; adaptability to changes induced by internal and external disasters [7]. In management and engineering disciplines there are special tools by which we identify, analyse, asses, manage and trade of with risks of various kinds including cross-sectional ones. The paper tries to compile general cyber network by help of which we can govern risks of all kinds for goal that is cyber systems´ safety, i.e. to ensure the safe cyber systems´ themselves and their safe vicinity; at present we mostly concentrate to cyber system security (the assets outside of cyber systems are only marginally solved [4].

## 2. Cyber networks

ICT network includes three basic professional parts: information, communication and technological. Under the term "ICT" is real technological network solution to which it belongs both, the computer network realisation and the telecommunication technology in dependence of actual solved problem [8].

The typical representant of IT networks is the worldside Internet, the architecture of which is in Figure 4. The Internet network architectute is on the top level created by national providers of internet services (NAP) that have their routers interconnected by high speed links either through network access points (NAP) or directly, i.e. peer-to-peer connections. On regional and local level the internet services providers are individual ISP who for data transfers uses data networks of national providers. The end users are connected to Internet network interface on local levels (ISP).

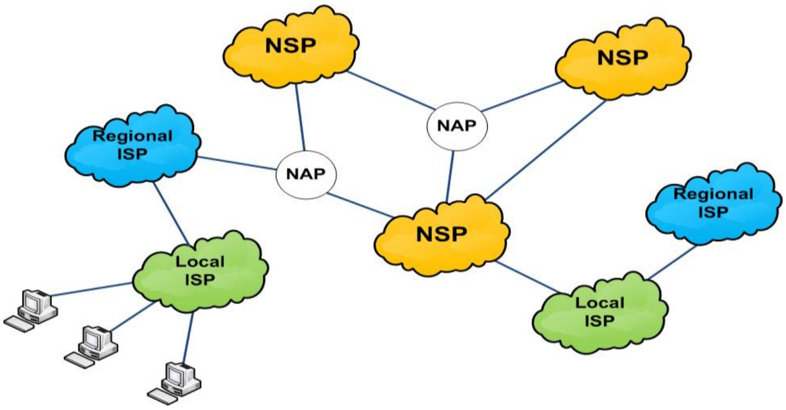


Fig. 4. IT networks´ architecture [9]

The model of telecommunication networks could be the classic GMS network with localisation system, the scheme of which is in Figure 5 [10]. Generally, it is possible to note that telecommunication networks (GMS, GPRS, UMTS and others) are in principle created by two basic subsystems [10]: the subsystem of base stations (BSS) with base stations (BTS) to which there are interfaced the mobile devices and their control (BSC – Base Station Controller); and network subsytem - the basis of which is created by mobile switching centre of appropriate operator (MSC – Mobile services Switching Centre) with register of all participants of mobile operator (HLR) and on participants being just in the vicinity of a given switching centre (VLR) and with authenticity centre (AuC) and a register of mobile devices (EIR). The other components are real network solution specific.

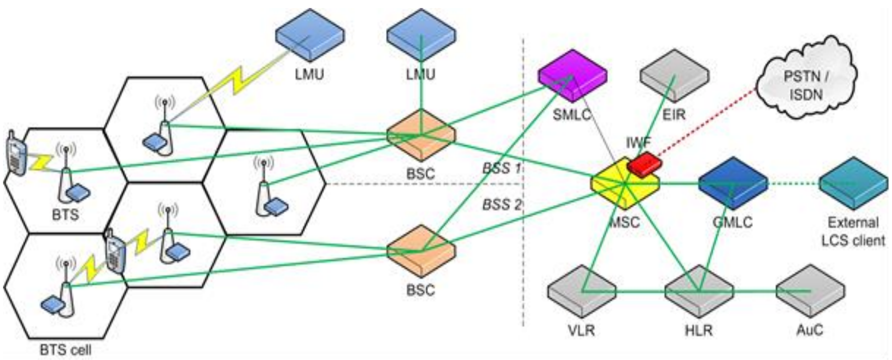


Fig.5. GMS model [10]

The CESNET network a national high speed computer network intended for science, research and education in the Czech Republic. Technological basis comes from the IT netwoeks but it has its own infrastructure interconnecting the university cities with high speed connections.

**3. System network model**

On the basis of present knowledge the infrastructures´ models are represented by model "System of Systems (SoS)" [7]. The SoS model allows to consider cross-sectional risks and internal dependencies and to understand the causes of domino effects, acceleration or synergis events etc. Based on Bayessian theory the complex systems with executive and control part communicating one another by help of real communication channels there is possible The according to work [12] to use the model of linkages in cyber system that is given in Figure 6.

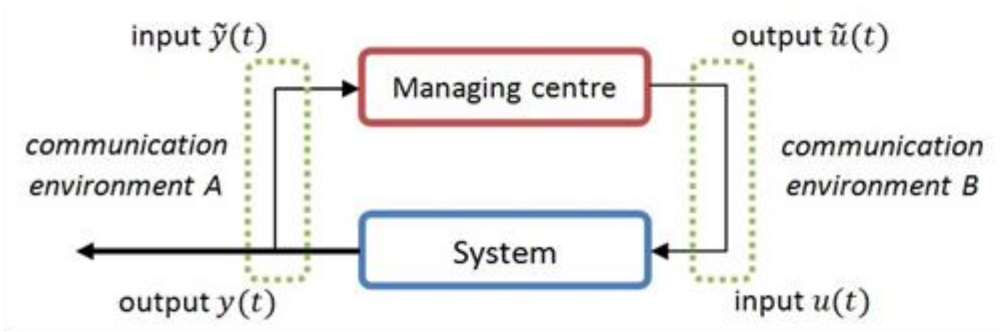


Fig. 6. Relations in the cyber system [12]

The given model expresses in cyber network functionality the typical process in which the control $\tilde{u}(t)$ influences the system functionality and at the same time, the outputs from the given system $y(t)$ retrospectively influence the given control. At the same time we consider an opportunity of modification (intentional or non-intentional) damage of transferred data when control $\tilde{u}(t)$ is by transfer modified to control $u(t)$ and the system output $y(t)$ is modified to the system output $\tilde{y}(t)$. From the model it follows that whole cyber system functionality is influenced by two main factors:

- correct behaviour of system, i.e. demanded system outputs in each time point of its operation, and corresponding system control, i.e. operating / control instructions that lead to correct system behaviour,
- correct transfer of data among cyber system components.

In next we concentrate to the transfer infrastructure of cyber systems, i.e. to the second mentioned item and the first one we assume as fulfilled.

The cyber networks are systems of organize set of bundles that create their logical elements that are mutually interfaced in compliance with a given order by selected physical layer. The suitable model is the Gauss transfer channel with one data input $x(t)$ and one output $y(t)$, Figure 7 [13].

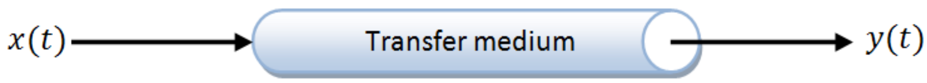


Fig. 7. Gauss transfer channel[13]

The Bayesian theory (conditional probability density) is then to use for exact mathematical description of both, the individual communication channels and the whole cyber system [12,13], i.e. for:

- communication channel without memory (without regard to outputs in time smaller that point *t*) it is valid: $p(y(t) \mid x(t))$,
- communication channel with memory (e.g. for channel with backward control) it is valid: $p(y(t) \mid y(t-1), y(t-2),..., y(t-M), x(t))$ for data up to time point M round,
- cyber system described in Figure 6 with parameters $\Theta = \{\theta_1, \theta_2,..., \theta_N\}$ it is possible to derive the following relations:

- cyber system: $p(y(t) \mid y(t-1),\ldots,y(t-M),u(t),\ldots,u(t-M),\Theta)$,
- control centre: $p(\tilde{u}(t) \mid \tilde{y}(t-1),\ldots,\tilde{y}(t-M),\tilde{u}(t-1),\ldots,\tilde{u}(t-M))$,
- communication medium A: $p(\tilde{y}(t) \mid y(t)), p(y(t) \mid \tilde{y}(t))$,
- communication medium B: $p(u(t) \mid \tilde{u}(t)), p(\tilde{u}(t) \mid u(t))$.

## 4. General model of cyber networks

For the IT networks it is typical that on lower hierarchy levels the system and its control is realised on the same logical bundle of network, and therefore, in this case we separate both parts. Contrary, the IT networks of higher hierarchy level usually act as their control centres (e.g. they create logic interfaces in network framework). The non-negligible element of IT networks is the human who adjusts the functional rules of given network. From the view of system and system control, the general model of IT network is shown in Figure 8. A lot of networks overlapping are

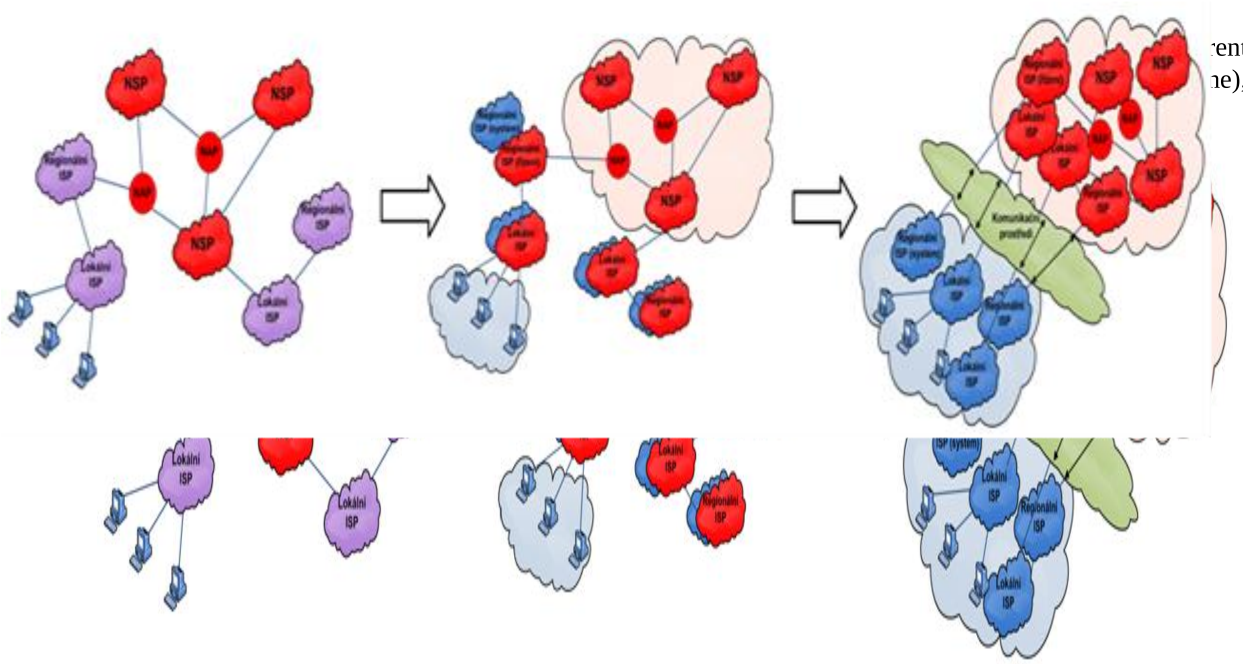


Fig. 8. Composition of IT networks

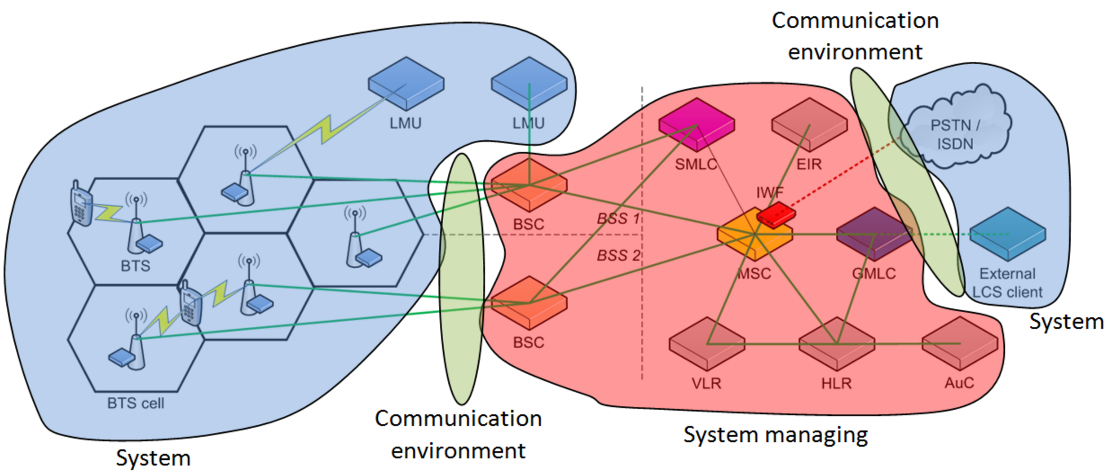


Fig. 9. Composition of telecommunication networks

## 5. Methods for study of cyber networks

As we said above the present problems of cyber networks are interdependences that are connected with system architecture and the real impacts of various disasters on cyber networks and on other public assets [11]. The first task means usually the solution of non-structure problems, i.e. determination of critical items of cyber networks. For such case it is suitable the Analytical hierarchy process (AHP) method [14] by which we can solve tasks as: determination of cyber network structure; results for individual levels of network problem in selected hierarchy; and aggregate results for the whole. The other suitable methods are benchmarking, Ishikawa diagram, criticality matrix, responsibility matrix, the Delphi method, case study method, panel discussion, Petri nets, Bayesians ´nets, SWOT analysis, checklist analysis, FTA etc. [5].

## 6. Results

For the other mentioned task the standardized method What, If analysis is very suitable [14]. For determination of impacts of disasters on cyber networks and for cyber network failure on public assets we use the standardised form described in Table 1. The impacts of monitored disaster (all hazard approach [15] is used), i.e. including the cyber system failure, are followed in the territory in the disaster origin time (0h), 3h, 6h … measured from disaster origin; for times equal or higher than 3h the differentiation of primary and secondary impacts is performed - secondary ones are caused by failure of infrastructures and technologies. With regard to good engineering practice principles [14] in solution of practical problems we ddistinguish three variants: V - standard disaster size, C - critical disaster size and E - extreme disaster size. The examples of impacts are given in [4,5,7,11].

Table 1. Standardised method What, If analysis [14]

| **Protected interest / asset** | | **Impacts** |
|---|---|---|
| Possible impacts on lives and health of people | | |
| Possible impacts on people security | | |
| Potential impacts on property | | |
| Potential impacts on public welfare | | |
| Possible impacts on the environment | | |
| Possible impacts on infrastructure and technology | Failure of energy supply (electricity, heat, gas) | |
| | Failure of water supply drinking utility | |
| | Failure of sewage | |
| | Failure of the transport network | |
| | Failure of cyber infrastructure (communication and information networks) | |
| | Failure of the banking and financial sector | |
| | Failure of emergency services (police, fire fighters, paramedics) | |
| | Failure of essential services in the area (food supply, waste disposal, social services, funeral services), industry, agriculture | |
| | Failure of state and local government, i.e. the management of territory and human society | |

The direct and indirect impacts you can see on Figures 10 and 11. By the considered method we also compiled the cyber infrastructure critical failute scenario for medium-size town and its vicinity by help of experts. The critical failure scenario of cyber infrastructure failure is in Table 2.

Table 2. The scenario of cyber infrastructure failure [5]

| Time measure from the failure origin time | Impacts on cyber network and other assets |
|---|---|
| 0 h | - security incidents remote reporting failure (if the communication infrastructure is based on IT infrastructure) |
| | - unavailability of web bank applications and bank services based on IT infrastructures |
| | - monitoring services failure (especially camera systems) |
| | - unavailability of certain public institutions services (central registers), limited point services |
| 3 h | - stress from the inability to fully perform job (e.g. emails) |
| | - late or none action of the Integrated Rescue System (IRS) – by the fire detection or by the forced entry into real estate – caused due to inability to inform IRS through the automatic signaling system based on the IT infrastructure → property damage (fire, theft, …) |
| | - inaccessible electronic timetables (buses, trains etc.) → passengers transport limitations |
| 6 h | - not working or unavailable internet shops, |
| | - inaccessible databases of logistic companies → loss of profit, |
| | - limited supply |
| 14 h | - increasing stress |
| | - people cannot communicate (email, Skype, IP phones, facebook etc.) |
| | - people cannot fulfill their obligations (e.g. invoices payment) |
| | - people have no access to their finances |
| | - etc. |

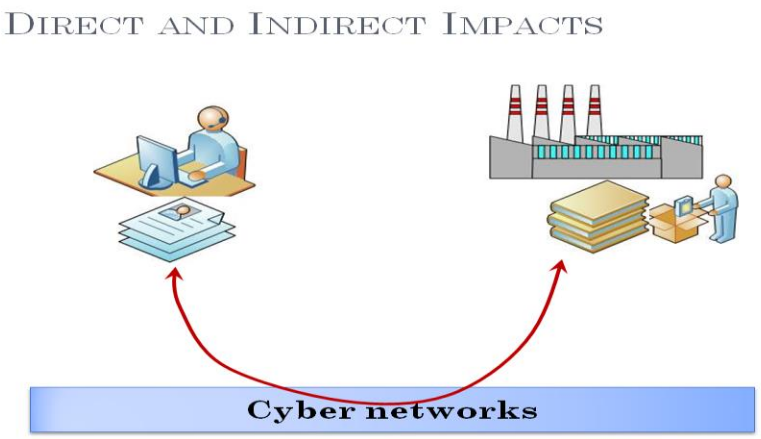


Fig. 10. Direct impacts of cyber network failure

The expert judgement of the critical scenario of cyber infrastructure failure revealed also the impacts that threaten not only human security but also the state security, consider the following impacts: the subway emergency stop; the navigating systems collapse - connection failure with space satellites; the national defence collapse - electronically controlled military technology; police cannot use the computer databases vehicles register, human‘s identification and verification, comparing traces (fingerprints, ballistics); failure of security devices and systems – increased crime; inability to ensure the air transport safety; public transport collapses – no remote control; lack of information – panic, riots etc.; access to ATMs failure and thus to their own finances; failure of heat and electricity supply; troubles in building security and subsequent human checks; night street lights are not working; inability to pay pensions and social benefits; etc.

For safety of cyber networks we shall construct the safety management system the model of which is in Figure 12 [11] that is suitable for solution of open complex systems.

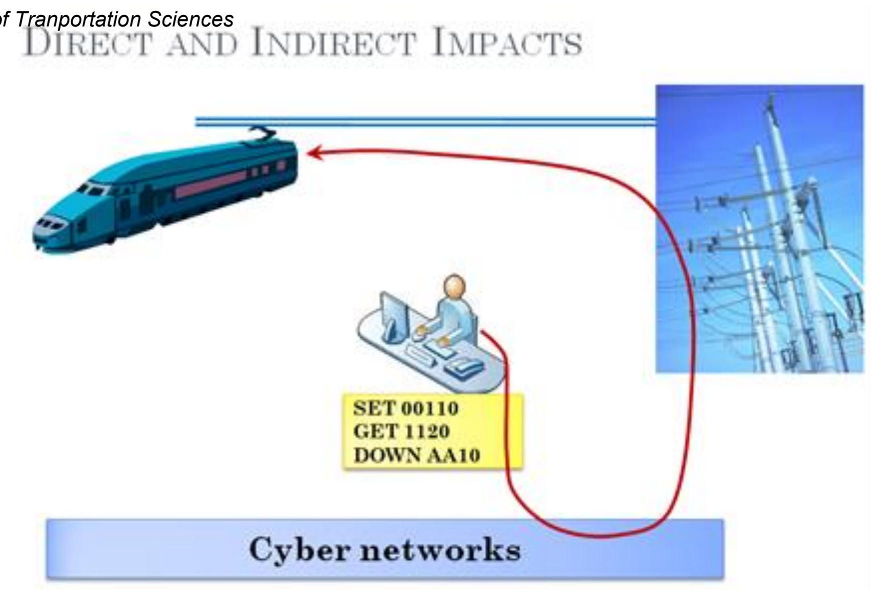


Fig. 11. Indirect impact of cyber network failure

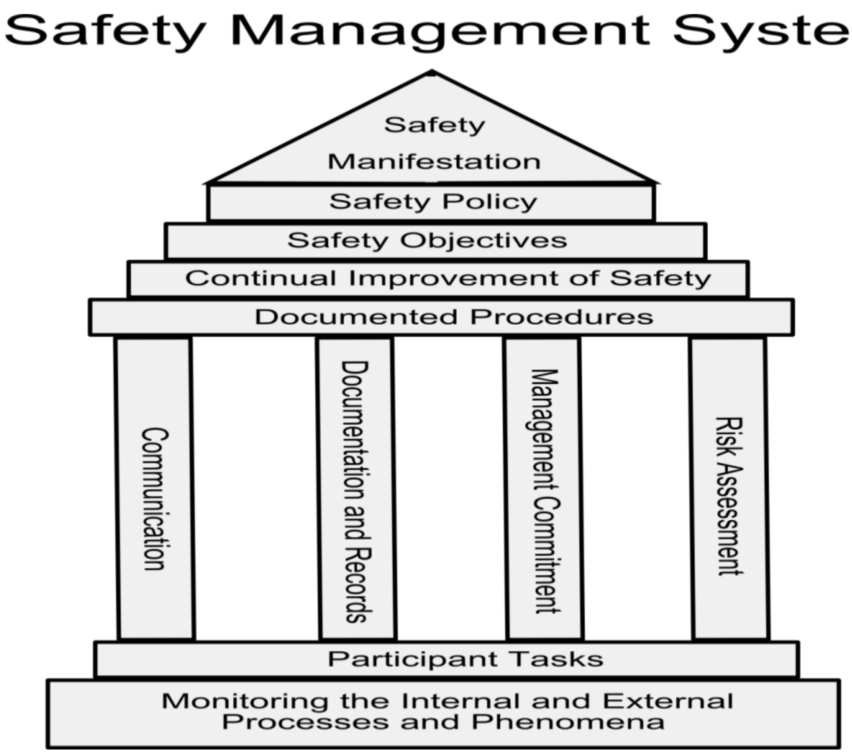


Fig. 12. Safety management system for open complex systems

## 7. Conclusion

Cyber infrastructure is one of the critical infrastructures on the grounds of its failure has a critical impact on the protected assets. It creates with other infrastructures the open complex system denoted the critical infrastructure. Cyber infrastructures are threatening from several different sources (technology, disaster and the human factor intentional/unintentional). They are very vulnerable because no security standards and norms on technical and functional levels on sufficient level ensuring their resilience and robustness are applied. It is also true that low attention has been paid to aspects connected with safe vicinity of cyber networks. The real in-depth research should be continued in solution of problems of interdependences and their causes and in protection of public assets against to impacts of cyber system failures.

## Acknowledgement

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# Possible Scenarios of Human System Development and of EU Research

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**Abstract**

Security situation in the world and in each territory continuously changes with time, and therefore, it is necessary to form new safety culture for ensuring the human security and sustainable development in the EU. After experiencing many crises in the last few years, it is clear that the security and sustainable development concept of the EU should be changed. It should not cover only the inner market but also other areas supporting the real economy and mainly, it has to contain the systematic support of the European inhabitants. One of the targets is to build a safe community with a sufficient sustainability. The paper gives six scenarios of the human system sustainable development. Because the qualified research is very important for strategic management ensuring the conditions for security and sustainable development the six possible scenarios of disaster research and their management in the EU is created and tested.

**Keywords:** security; safety; sustainability; human system; strategic management scenarios; research scenarios

## 1. Introduction

Security situation in the EU, world and in each territory continuously changes with time, and therefore, it is necessary to form new safety culture taking into account actual knowledge and experiences with interdependences among the public assets leading to extreme social crises (in history e.g. great famines). With regard to the historical development there are: a lot of preventive and mitigation measures that have been applied into practice by legal rules, technical standards and norms and public instructions; response systems; and renovation ways. However, it is true that their effectiveness decreases with time because new risks emerge and territory and human vulnerabilities increase in all domains. With regard to this reality the research would originate the optimal strategy for further development. Evaluating the present knowledge, experiences and conditions in the EU, the paper proposes six possible human system development scenarios and six possible research scenarios and results of their assessments from the viewpoint of optimal security and development of the EU up to 2035.

## 2. What we know on the EU security and sustainable development

Present goal of humans is to live at safe space, and therefore, the UN formulated the aim of a "safe human system" in 1994 [1] and the EU "safe community" in 2004 [2]. In agreement with the EU and UN proclamations and the professional knowledge there is necessary for conservation and sustainable development of the human society to create the safe territory. With regard to present knowledge we should consider that we want to build safe open dynamically variable system that is a complex system the model of which is the system of systems (SoS), i.e. several overlapping systems [3]. The concept of the EU security is described in detail in [4].

The human system security and development are disturbed by disasters, i.e. internal or external phenomena that lead or from a certain size can lead to damages, harms and losses on system assets. It means that human system safety is affected by both, the processes, actions and phenomena that are under way in human society, environment, planet system, galaxy and other higher systems, and the human management acts. Therefore, for safety reasons we must negotiate with risks of different origin and kind. The research performed under the FOCUS project [5] deals with principles of negotiation with risk at stages of its mitigating and managing in selected sections of human system management and it gives tools for public administration for public affairs governance because it is responsible for territory governance and conditions. Especially, it concentrates to the EU governance. There are used results of sets of national and international projects realised in the EU, Member States and elsewhere in the world; e.g. the USA (especially FEMA), Russian Federation, Japan, China, India, Brazil etc., which are documented by professional literature.

## 3. Method of scenario compilation

Generally, the scenario is a set of isolated and interconnected processes or phenomena in time and space, which takes place at different spatial and temporal scales. Scenarios are used for different purposes. It is de facto succession, a chain of events in time, area, space or space-time. This string can be deterministically given or stochastically random and the degree of randomness can in some cases be evaluated by statistical methods, by methods based on fuzzy sets and by experts. In terms of present knowledge, we know that there are sets of events that seemingly have no visible internal connection, but the result of which is some specific state of the system. In these cases we talk about so-called deterministic chaos. In systems engineering, there exist methods to describe and understand it.

Scenario-as a tool of proactive management is historical-system model which describes the development of process in its different forms (variants) depending on the conditions or decisions taken. It mimics the mechanisms and processes that take place in the system. Its aim is primarily to identify critical phenomena or points, which affect further development, i.e. which provide alternative choices between different final states. For the purposes of emergency planning and crisis management in practice, we put together the following types of scenarios: scenario of impact of any disaster, scenario of response to the occurrence of disasters; scenario management.

The FOCUS project aim is foresight, i.e. not prediction or prognosis, and therefore, the method of scenario compilation is rather liberal. In spite of this we respect at scenarios compilation the following steps:

- identification of key assumptions or factors that affect the form of scenarios,
- focusing on factors that have a high potential impact on the shape, size, scope, etc.,
- identification of factors with an uncertain nature and try alternative solution of the scenario.

A prerequisite, however, is a relatively small number of factors that could be incorporated into the possible variants.

Development of scenarios consists of:

- gathering of prognostic information about the system and its surroundings,
- identification of targets of studied system,
- identification of internal factors, or. barriers to development of the system,
- identification of external factors, or. barriers to development of the system,
- identification of alternative management strategies for the system (it is necessary to take into account existing management mechanism and its variants, which can be realized in future periods, simultaneously it is necessary to formulate a strategy for development of the system - which direction is desirable),
- compilation of scenario,
- interpretation of scenario.

In all the steps above given it is necessary to consider:

- assessment of current state and current decisions in terms of future development,
- qualitative factors and strategies of various participants,
- the fact that the future is uncertain and multidimensional,
- the fact that each system must be examined globally and systemically,
- the fact that the information and strategies are not neutral, but biased,
- multiple approaches that are complementary,
- the fact that there are biases in strategies of people and prevent them.

Management scenarios can have different forms, depending on the use intended. Development of scenarios from the perspective of strategic management has the strict procedure [6] but the FOCUS project scenarios are only foresight, and therefore, they cannot respect the strict procedure as in engineering domain.

## 4. Scenarios

After experiencing many crises in the last few years, it is clear that the security and sustainable development concept of the EU should be changed. It should not cover only the inner market but also other areas supporting the real economy and mainly, it has to contain the systematic support of the European inhabitants. One of the targets is to build a safe community with a sufficient sustainability. This means to correctly manage the observed area and to ensure the daily needs of the EU citizens, to render help after disasters, transform the way of financing of emergency situations based on insurance etc.

With regard to current knowledge, it is necessary to use a systematic approach and to seek consensus among the three basic systems that is the system of the environment, social system and technological system. The above-given systems create the human system representing every area at dealing with problems connected with sustainability and security.

### *4.1. Background for sustainability*

On the basis of current knowledge, the fulfilment of physiological needs only is not sufficient for a human life anymore. H. Maslow [7] showed that there are other needs such as security and safety, self-realization and social asserting. The basic orientation of research and public administration to security, safety and sustainability, and on their management started after the big terrorist attacks in the USA 11/09/2001, 11/03/2004 in Madrid, 03/09/2004 in Beslan, 07/07/2005 in London etc. after which humans finally realized what security means for them and their development and what really has the biggest value for human.

Current knowledge and experience [3] show that in order to reach the demanded state of a system, including the human system and its development, it is important to set targets and procedures for their achieving that are dependent on sources, forces and means, which are always a lack. Therefore, it is necessary to focus on priorities and manage sources, forces and means in space and time to a gradual target fulfilment.

Orientation to the human system allows on one side to use the apparatus of systematic analysis and systematic engineering [3], on the other side to understand security and sustainability in a wider sense than it is usual; military-political orientation has prevailed until now – e.g. in documents of Pan-European Conference in Haag, in 2004. Systematic concept also allows understanding of the inner interconnections that are caused by the flows of capital, information, things, energies, arms, drugs and human mobility. Apart from this, it is necessary to know the area and its protected assets, possible disasters threatening it, ways of threatening, accessible sources, sources of energy and food [3].

Research scenarios come out of the EU security concept [4]. Concept is a common feature or characteristic. Concepts are necessary for the development of scientific knowledge and as an abstract expression they serve as key factors in development and testing of theories. In order to create a conception of no-matter-what system development, we must use data, leave the pseudo-philosophizing and lean on two pillars: that are knowledge and engineering approach at handling a risk, since the engineering approach unlike empty specifying must always find a site specific solution. First, we are going to give the EU concept of sustainable development as a scheme, in which there are both elements and data taken into account for the sustainable development of the EU. It contains both the vision about the sustainable development of the EU, and the vision of its ensuring. On the basis of assessment of data and knowledge from professional publications, the list of which is in [3], the concept is made with help of a complex approach [4], targets and principles given in the conception of the UN "The safety of human system" [1] and in the conception of the EU "Safe community" [2]. The basis of conception is to control with qualification all the phases of disaster management of all kinds [8], i.e. to pointedly, with qualification and interconnection ensure the management focused on security and sustainable development, emergency management and crisis management [3].

### *4.2. Scenarios of the human system sustainable development*

Scenario is generally a complex of both isolated and interconnected processes and phenomena in time and space that run in various spatial and time scales. Scenarios are used for various reasons. It is de facto about succession, chain of events in time, area, space or space-time that can be deterministically given or stochastically random, while in some cases it is possible to assess the rate of randomness by statistical methods, methods based on fuzzy sets or with help of experts [9].

Current level of knowledge requires supplying a theoretical concept of sustainable development by accessible political and normative measures. Applying of the precautionary principle is in accord with the very weakly sustainable development. For the assessment of the development plans of big area complexes, it is necessary to generate specific indicators of sustainable development that will allow us to assess the homeostasis on a regional level. Paradigm of the current assessment of region development and development concepts heads for the pseudo-sustainable development with various level of profit [10]. Therefore, the optimal result requires applying of more variants of solutions, i.e. set of various scenarios and applying the formalized multi-criteria analysis [9].

Catalogue of the methodical scenarios for the strategic assessment of impacts of development intentions on the environment under the big area complexes (regions) and the requirement of sustainable development according to work [11] contain 6 scenarios of sustainable development. Variants were created by the methodical elaboration of works of Turner from 1995, who applied the Solow´s theory, holder of the Nobel prize for economy from 1987 for the "neoclassical model of growth" [12]. The comparison or the variants with principles and requirements for the strategic safety management targeted to security and sustainable development of protected assets [3] show that the variants correspond to the current knowledge and experience. On the basis of knowledge on human system, its assets (lives and health of humans; property; public welfare; environment, critical infrastructures and technologies) and priorities (safe human system in a dynamically variable world), variants of sustainable development scenarios were created, by the method of analogy, Table 1.

Table 1. Scenarios of the human system sustainable development

| | |
|---|---|
| **A** | *Name:* ***Zero variant of the human system development***<br>*Target:* Preserving of the current trend<br>*Characteristics:* a variant without elaborating the strategic plan of the community development, i.e. interest area including human society; development of interest community on the basis of a current state prolongation; preserving the current trends of community development and that both the negative and positive ones. |
| **B** | *Name:* ***Variant of the very highly sustainable development of the environment***<br>*Target:* Absolute preference of the environment protection. Stationary phenomenon of economy.<br>*Characteristics*: industry reduction; all mining areas closure; minimization of using the non-renewable sources in energetic; no more new land acquisition; reduction of the quantitative development of transport infrastructure; no more new sources of air pollution; request for the construction of sewage and sewage water treatment plants in all villages; extending the number and area of all types of protected areas and the areas of ecological stability; decentralized and extensive agriculture with putting the stress on landscape maintenance; forests with original wood composition return; renovation of wetlands of small brooks and ponds; untouchables of outside-forest green and of small landscape elements; strict protection of cultural heritage; only dispersed recreational activities. |
| **C** | *Name:* ***Variant of the weekly sustainable development of the human system***<br>*Target:* Preference of the environment protection and significantly limited economic development.<br>*Characteristics:* Considerate exploiting of non-renewable sources; using the renewable sources under their regeneration capacity; strict selection of localities for new economic activities, the place change principle; the condition of applying the best accessible technologies for these activities; preference of the reconstruction of old industrial structures before a new land acquisition; support of the railway, at road transport only the quantitative changes, support of gas in villages, sewage water treatment plant construction; limitation of mass recreational activity; extending the area of protected places of all types; Areas with ecological stability system development; strict protection of water and wetlands ecosystems and outside-forest green; both economic and microeconomic compensation of residual impacts. |
| **D** | *Name:* ***Variant of the medium sustainable development of the human system***<br>*Target:* Stress on the critical natural capital protection. Economic development with partial limitations. Debasement of the environment can be replaced by the artificial capital (apart from the critical natural capital).<br>*Characteristics:* Development of the system of small area and big area protected territories; global limitation of the Areas with ecological stability system; protection of the environment focused only on the protected areas; on all the other areas the development of economic activities is preferred; acceptable wide acquisitions of land for transport infrastructure and industrial zones; new energetic infrastructure construction support; new water works, stream regulations, hydro-melioration; intensive agricultural mass production; concentration of housing and recreation functions; natural sources and the environment decrease is replace by help of economic or technical compensations. |
| **E** | *Name:* ***Variant of the highly sustainable development of the human system***<br>*Target:* Preference of an economic development. Compensation of damages on the environment.<br>*Characteristics:* Development of economic activities similar to the previous case – D; protected areas limited both in extension and degree of protection; development of economic activities also in protected areas (natural resources mining, agricultural production etc.); placement of recreational and sport activities into the naturally most valuable areas; economic compensation of ecological loss for both the individuals and society; technical compensations (precious ecosystem transfer, artificial creation of the environment, reclamation). |
| **F** | *Name:* ***Variant of the maximum economic development***<br>*Target*: Economic development at the expense of the environment, without limitations or compensations.<br>*Characteristics:* Maximization of economic profit; unlimited exploiting of all the natural sources; placement of new infrastructure and economic activities with no regard to the natural conditions and impacts on the environment; qualitative limitation in favour of economic aims is acceptable also for the housing and recreational function ; for the development of technical, energetic and water |

| |
|---|
| infrastructure, economic targets are preferred instead of the social, hygienic and environmental ones; preference of the new saving and economical technologies only at the basis of the CBA analysis results; economic value of the environment and natural resources is seen as zero, therefore, no compensations of the caused impacts are considered. |

Analysis of Table 1 shows that from viewpoint of human needs [3] and from the perspective of development:

- variants B, F, A are unacceptable,
- variant E is unreal, since the prove from viewpoint of precaution that there are no hidden risks is missing,
- with intended targeted effort, it is necessary to realize variant C or D. At variant D, which allows bigger interventions into the environment than variant C, it is necessary to apply strictly the precautionary principle and at the negotiation with risks to also focus on the possible impact of decisions for the future.

Continuing dynamic development in the controlled treatment of human system allow us to see deep facts that not possible to ignore. On one side, it is about the gradual elaboration of supportive work tools in favour of sustainable development, mainly the indicators of sustainable development, development of legal norms and following methodology in area of impact on human system assessment, including the growing number of home strategic development concepts. On the other side, the fatal collapse is evident of the theoretical concept of sustainable development on global scale. As a replacement for the scientific concept failure, passing of political and normative measures is demanded. In contrary, for the socially-economic and technically-area development the strict application of precautionary principle is demanded currently. The phenomenon of increasing risk orders a need to admit the coexistence of the environmental, technological (economic) and social system and to seek consensus for their common development.

Recent results of the project FOCUS [5] show that the main problems of the EU, i.e. the EU vulnerabilities that are obstacles to sustainable development are the following: all hazard approach [8] is not systematically applied; some disasters are underestimated; systematic, strategic and proactive management is not implemented in practice; there are gaps in the management of risks, engineering of risk and in negotiating (trade-off) with risks; research do not appoints priority orientations, its targets are influenced by politicians or lobbyists; methods of application and orientation of strategies are not regularly controlled; reasonable strategy for disaster management is missing; disaster management often does no respect the cycle of disaster occurrence; stress on the problem solution is missing, there are only many discussions about it; there is a lack of sources for the implementation of human needs; there is a lack of tools for the EU financial stability ensuring; there is a lack of management tools that support the protection of inhabitants and sustainable development.

*4.3. Scenarios of research*

Concept respecting the given knowledge and approaches is the basis on which the FOCUS project builds on [5]. It executes both the revision of the current inner frame of the EU and proposes areas that are important for the EU sustainability enforcement. According to principles of a good practice, only the systematic, persistent and well managed complex of measures and activities guarantees achieving the EU sustainability now and in the future.

Supervisory measure of scenario opportune ness at processing the model framework for logical model of EU research to 2035:

1. Description of the process - the EU decision-making and management will be based on present findings and experiences
2. The EU security concept that is described above [4] will be step by step realized.
3. The critical points of the process will be step by step removed - the EU vulnerabilities are the following: all hazard approach is not systemically applied; some disasters are underestimated; systemic, strategic and proactive management is not implemented into practice; gaps in risk management, risk engineering and in trade-off with risks; research does not determine priority orientations, its targets are influenced by politicians or lobbies; application procedures and orientation of strategies are not regularly verified; reasonable strategy for disaster management is missing; the disaster management does not often respect disaster life cycle; accent to problem solving is missing, still only a lot of discussions on problems; lack of resources; lack of instrument for ensuring the EU finance stability; lack of management supporting the public protection and sustainable development.

On the basis of the targeted method of scenario creation (see chapter Methods) and aims and facts described above, the scenarios of research are created, Table 2.

Table 2. Possible scenarios of disaster research and their management in the EU

| | |
|---|---|
| **A** | *Name:* ***Zero variant of research***<br>*Target:* Preserving the current trend.<br>*Characteristics:* Variant without any elaboration of the strategic plan of disaster research and their management in the EU, i.e. projects of research will be assigned oriented to disaster research and management in the same way as today and no attention will be paid to interconnection of outcomes and to obtaining realizable solutions in favour of the compact concept of safe community with sustainable development progress. |
| **B** | *Name:* ***Variant underestimating research – market will deal with no matter what***<br>*Target:* Absolute underestimation of research.<br>*Characteristics:* Research will be conducted ad hoc since there is a faith that market is best for the safe community and its development ensuring (preference of market and faith in the omnipotence of economy). Every citizen must arrange for his own safety, i.e. he must procure knowledge, information and relevant tools to himself. |
| **C** | *Name:* ***Variant of research oriented only to applied research***<br>*Target:* Preference of a research only in parts, where there are problems, currently.<br>*Characteristics:* Only those parts are investigated in research that the administration needs for the current deciding, no systematic knowledge for dealing with future problems are gathered. |
| **D** | *Name:* ***Variant of research oriented to basic and applied research***<br>*Target:* Stress at the choice of projects is put on the medium sustainable development of the EU communities.<br>*Characteristics:*. Development of a research is concentrated both on basic tasks and on the applied research that deals with both current urgent tasks and prepares the basis for dealing with the future tasks that outcome from the concept of a safe community with sustainable development. Meaningful projects are set, the results of which it is possible to interconnect and they outcome from verified data and right methods for their elaboration. |
| **E** | *Name:* ***Variant of research oriented to strategic division of support of basic and applied research with emphasis on the results succession***<br>*Target:* Stress is put on such a choice of projects that will provide the preference of a safe community with sustainable development today and in the following 20 years along with a prospect to another 50 years.<br>*Characteristics:* Development of a research is defined by the strategic plan that is elaborated on the basis of a safe community with sustainable development concept based on the systematic and proactive approach reacting to the dynamic development of a community, having clear priorities that are always supported by the EU. Meaningful projects are set in basic and applied research, the results of which are possible to mutually interconnect and they outcome of verified data and right methods for their elaboration. |
| **F** | *Name:* ***Variant of a maximum support to basic research***<br>*Target:* Mainly, it is necessary to support basic research.<br>*Characteristics:* Maximization of demands for basic research, transforming the results into practice is underestimated. It based on the idea that research brings knowledge but it is not able to deal with current problems since the implementation of results lasts too long. |

Expert assessment of data in Table 2 (5 experts – university education, more than 30 years practice in research and in research management, more than 10 years with responsibility on research results) shows that from viewpoint of human needs [3] and from the perspective of human system development:

- variants A, B, C are unacceptable,
- variant F is unreal, since the research loses capability to support security needs in human live practice,
- with intended targeted effort, it is necessary to realize variant D or E. The variant E has higher priority for realisation with regard to targets given in the EU security concept [2].

From the viewpoint of management the following facts regarding to the type of research characterisation, hold:

1. The worse research scenario $\Rightarrow$ the EU disaster management is ad-hoc $\Rightarrow$ the EU is not capable systematically to solve critical problems $\Rightarrow$ the EU decline.
2. The bad research scenario $\Rightarrow$ the EU disaster management is only oriented to crises $\Rightarrow$ the EU will only solve crises but with many difficulties $\Rightarrow$ slow declination of the EU present trend of development.
3. The mean research scenario $\Rightarrow$ the EU disaster management is progressive, i.e. it creates fundament for problem solving $\Rightarrow$ the EU will be capable to solve problems based on knowledge management principles $\Rightarrow$ conservation of present trend.
4. The good research scenario $\Rightarrow$ the EU disaster management is strategically created $\Rightarrow$ the EU creates strategic plan of development based on present knowledge and experiences $\Rightarrow$ the EU will belong to global security actor because it will have strong fundament for problem solving.

For Europeans there is necessary minimally to realise variant three.

## 5. Critical review of present situation in the EU

The critical assessments performed in the FOCUS project by the CVUT team [5] revealed the critical items that might be considered in the EU development strategy, research and legislation. These critical points must be getting over in order that the way to reaching the EU aim "EU is global actor" might be open.

The research described in Annexes to [5]:

- deals with the EU governance level from the viewpoint of natural disaster management. It identifies deficits at natural disaster management from the viewpoint of safe community concept that has been promoted by the EU since 2004. For its realisation there is necessary sophistically managing the disasters that damaged the security of community and its assets, i.e. to apply measures and activities of prevention, preparedness, response and renovation. For practical purposes there are necessary good technical solutions based on recent findings and experiences and correctly aimed governance of public affairs supported by legislative with sufficient legal force, finances, qualified human personnel and material base,
- concentrates to disasters that are connected with processes by which environment and planet itself react to human activities and it judges the level of governance of public affairs in the EU from viewpoint of strategic management of these disasters that is aimed to constitution of safe community,
- concentrates to social domain in which there are a lot of phenomena that threaten security of humans, public assets and whole communities. Considering the number of victims of extremist Breivik at July 22, 2011, civil disturbances, traffic with children, socially segregated localities etc., so we see that there is necessary also to manage disasters that are represented by prejudicial phenomena at social domain that damaged the security of community and its protected assets,
- concentrates not only to basic system elements (assets), but also to links among assets (physical - matter-of-fact, territorial, cyber, logical) and flows which create more or less important couplings that in some case quite fundamentally determine the behaviour of human system. The disasters damage critical infrastructure and the supply chains. Therefore, the disaster management have been gained the upper significance with grow of human demands on life quality and with human vulnerability increase and with drop of natural sources,
- concentrates to problems in public administration (governance of public affairs) management, because the social crisis can origin always when it fails.

If the human system is understood as human's live space, it is open system that is in interaction with its vicinity. On human activities there are reacted both, the planet system and the environment. The European Union has promoted the safe community concept since 2004. For concept realisation there is necessary sophistically to manage disasters that disturb security of community and their assets, i.e. to apply measures of prevention, preparedness, response and renovation. For practical realisation there are necessary good technical solutions based on recent findings and experiences and correctly aimed good governance (public affair management) that is supported by legislative of sufficient legal force, finances, qualified human personnel and material base.

## 6. Conclusion

Because it is well known that each concept enables to solve only problems that it can differentiate, we choose for research the complex EU security concept based on system insight. The concept is based on all advanced get-at-able knowledge that is accessible in public sources and on experts´ experiences from problems´ solutions in strategic management, emergency management and crisis management on the different international, governmental and sector levels.

Research of both disasters and the ways of their management is important for ensuring the safe community with sustainable development. There are many problems necessary to solve in the monitored segment and they are on different levels, i.e. technical, operative, tactical, strategic and political. The basic requirement is so that:

1. The research was targeted, i.e. the already-known was not researched without a good reason.
2. The research sought and solved open problems, namely correctly with regard to current knowledge and experiences on ensuring the safe community and its sustainable development.
3. The research demanded objective results under given conditions, i.e. to systematically present the results in front of a relevant expert community and to make them be a subject to a public opponent control. With this, plagiarism can be avoided, the real protection of intellectual property will be ensured and the

development of creative abilities of individuals that has a creative potential and that are willing to give it in favour of the EU and its inhabitants' development will be supported.

4. The research would not distort the results – the style "the fundamental is what an authority says" holds development back. Therefore, it is necessary not to dissimulate conflicts among outcomes of projects since their existence is normal. Under the effort of finding the right solution, it is necessary to make it a subject of a thorough investigation with aim to find the causes of problems and to define an optimal solution of them in a given conditions and within the given possibilities.

The main task of the future EU security research is to create systems for knowledge-based decisions and effective utilisation of land and nature. Therefore, the EU must remove prejudice in favour of lobbying groups the interest of which is different from public interest.

In the previous chapters, the base is given summarizing the current knowledge, on the basis of which the knowledge level research was conducted in the area of disasters and their management in the EU with regard to building the EU as a safe community with sustainable development. On the basis of verified data files made by qualified methods, many real gaps of higher or lower importance were discovered. The basic system's gaps were marked in chapter "What is necessary to improve". According to the level of their handling, six possible scenarios of the EU research were compiled, from which it clearly follows that the research is important and that it must be clearly targeted according to a strategic plan put together with regard to current professional concept of the EU as a safe community with sustainable development and to the fact that the EU, as every other community, has only limited possibilities; therefore the solution of problems must be divided into suitable time intervals, must be flexible and all the participants, according to their possibilities, must take part in the problem solution.

Results given above and in detail described in [5] show the need of qualified research based on system concept of the world (including the EU) performed without pre-arranged parti pris that is sometimes is source of preferential treatment of some groups, i.e. corruption that is always brake of long-term development.. With regard to above given results it is clear that we build world (including the EU) for the humans, and therefore, it is necessary to do both, the support of new technologies and new infrastructures enabling the human sustainable development and the reduction or at least mitigation of their impacts on human health and security by strategic risk management, the caution against lobbying in research is very necessary.

The lobbying at decision-making in the EU is much extended; it is observed also in the research. Because no strict boundary between lobbying and corruption, which brake development, it is necessary to apply management that will support good to public interests.

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