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PROBLEMS OF ROAD COVERAGE QUALITY ESTIMATION BY GPR PROBING METHOD

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This work deals with problems of flexible pavement structure quality estimation with help of ground-penetrating radars (GPR). Forward and inverse problems of flexible pavement structure GPR probing are discussed. Iterative procedure to solve the inverse problem in frequency domain is used on the base of aim function minimization by using the genetic algorithm. The results of reconstruction of electro-physical characteristics for model of flexible pavement structure are presented.

Keywords: radar probing, inverse problem, genetic algorithm, reconstruction of electro-physical characteristics

1. Introduction

For optimisation of exploitation, upkeep and reconstruction of road cover certain information is crucial, such as condition of its internal layers and the processes taking place within them.

Basic flexible pavement structure is shown on Figure 1. A typical flexible pavement structure consists of the surface course, the underlying base and subbase courses [1].

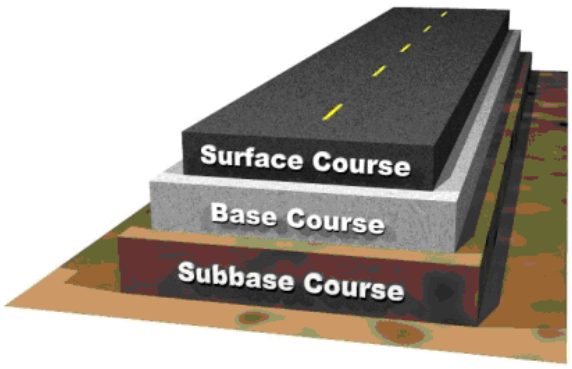

Figure 1. Basic flexible pavement structure

The surface course is the layer in contact with traffic loads and normally contains the highest quality materials. This top structural layer of material is sometimes subdivided into two layers: wearing course and intermediate/binder course. First of them is the layer in direct contact with traffic loads, and second layer provides the bulk of the HMA structure. The base course is immediately beneath the surface course. It provides additional load distribution and contributes to drainage and frost resistance. The subbase course is between the base course and the subgrade. It functions primarily as structural support.

To improve road safety it is necessary to constantly monitor the condition of the inner layers of the road structure. Nowadays to research the inner structure of flexible pavement Ground – penetrating radar (GPR) is widely used [2, 3]. In spite of substantial achievements in research and development of GPR there are some problems to improve the interpretation of radar probing data. Flexible pavement is a complex multi-layered construction, various layers of which consist of materials of different durability. It is well-known that in different times of the year and in different environmental conditions the preservation of road cover depends not only on usage but also on different climate-related factors. This is why it is necessary to constantly monitor the condition of the inner layers of the road structure, in order to act in time in response to the changes the state of its layers.

Traditional GPR has not sufficient time resolution and therefore do not provide the required effectiveness of flexible pavement structure monitoring. It is necessary to perform reconstruction of electro-physical parameters of roadway coverage with detection and identification of inner zones and objects. Reconstruction of electro-physical characteristics of the pavement structure is in essence identification of electro-physical parameters of the layers, which can be achieved by solving the inverse problem of flexible pavement structure monitoring which is in general ill-posed and not unique. To overcome these difficulties the comparison method may be used in which the results of the radar forward problem solution for an assumed subsurface structure with limited area of electro-physical parameters changing are comparing with data of radar probing. In this way a solution of the inverse problem can be found both in the time and the frequency domain.

2. Frequency Model for GPR Probing of Flexible Pavement Structure

A typical GPR has three main components: a transmitter and a receiver are directly connected to their antennas, and a control unit with a display [3, 4]. The transmitting antenna radiates a short high-frequency electromagnetic (EM) pulse into the inspected medium, where it is refracted, diffracted and reflected primarily as it encounters changes in dielectric permittivity and electric conductivity. Waves that are reflected back by the probed medium induce signals in the receiving antenna, and are recorded as digitised signals for display and further analysis.

The GPR antennas are usually located above the roadway coverage at a low height H and are parallel to each other. The boundary of the air – the top layer of roadway coverage in the near field (H << λ, where λ is the signal wavelength in air), and therefore has an influences on the characteristics of antennas. In this case the received signal consists of the following components: the direct signal, the lateral signal and the signal reflected from the internal boundaries of roadway coverage [5, 6]. According to that, the signal forming channel in frequency domain may be presented as it is shown on Figure 2, where

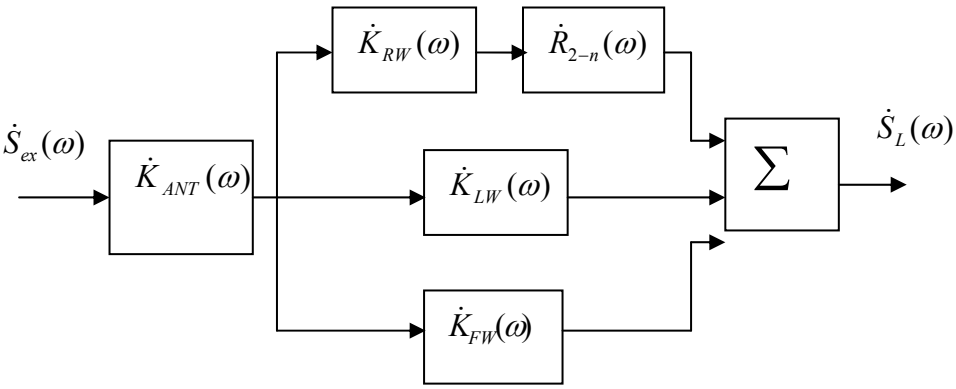

Figure 2. Signal forming channel for subsurface GPR probing of flexible pavement in frequency domain

the following denotations are used:

- $\dot{K}_{FW}(\omega)$ is a complex transfer function of direct signal,
- $\dot{K}_{LW}(\omega)$ is a complex transfer function of lateral signal,
- $\dot{K}_{RW}(\omega)$ is a complex transfer function of the signal reflected from the subsurface ideal reflector, located at a depth equal to the thickness of the first layer of roadway coverage,
- $\dot{R}_{2-n}(\omega)$ is a reflection coefficient of 2-n layers of the roadway coverage,
- $\dot{K}_{ANT}(\omega)$ is complex transfer function of the antenna system,
- $\dot{S}_{ex}(\omega)$ is the signal spectrum, which is used for impact excitation of the transmitting antenna,
- $\dot{S}_{L}(\omega)$ is the spectrum of the signal across the load resistance of the receiving antenna.

As a result, complex transfer function of signal forming channel for subsurface radar probing may be represented in the following way:

$$\dot{K}_{RAD}(\omega) = \dot{S}_L(\omega)/\dot{S}_{ex}(\omega) = \dot{K}_{ANT}(\omega)\cdot\left(\dot{K}_{FW}(\omega) + \dot{K}_{LW}(\omega) + \dot{K}_{RW}(\omega)\dot{R}_{2-n}(\omega)\right). \quad (1)$$

It depends on the conditions of the subsurface radar probing, as well as on the geometry of the antennas location.

Then complex transfer function of the antenna system $\dot{K}_{ANT}(\omega)$ for linear vibrators may be presented as [5]

$$\dot{K}_{ANT}(\omega) = -j\frac{30k_0\dot{L}^2_{eff}(\omega)R_L}{[R_L + \dot{Z}_{in}(\omega)]^2}, \quad (2)$$

where $j = \sqrt{-1}$ is image unity; $k_0 = \omega/c$ is the wave number for free space; $\omega = 2\pi f$ is the angular frequency of monochromatic wave with liner frequency f; $\dot{Z}_{in}(\omega)$ is input impedance of radar antennas; R_L is load resistor of the receiving antenna; $\dot{L}_{eff}(\omega)$ is effective antennas length, which is expressed as

$$\dot{L}_{eff}(\omega) = \frac{2}{\dot{k}_L}\cdot\frac{1-\cos\dot{k}_L l}{\sin\dot{k}_L l}. \quad (3)$$

l is half length of linear antenna; $\dot{k}_L$ is complex wave number of wave propagation in antenna which is expressed in the following way [7]:

$$\dot{k}_L = k_0\left\{1 + \frac{2}{\ln\frac{2H}{a}}\left[\frac{1}{(2k_0\dot{n}H)^2} - \frac{K_1(2k_0\dot{n}H)}{2k_0\dot{n}H} + j\left(\frac{\pi I_1(2k_0\dot{n}H)}{4k_0\dot{n}H} - \sum_{i=1}^{\infty}\frac{(2k_0\dot{n}H)^{(2i-1)}}{(2i-1)!\cdot(2i+1)!}\right)\right]\right\}^{\frac{1}{2}} \quad (4)$$

and depends on antennas diameter a, antennas high H over upper boundary of inspected medium, and complex refraction coefficient $\dot{n} = \sqrt{\dot{\varepsilon}_2(\omega)}$ for complex permittivity $\dot{\varepsilon}_2$ of inspected medium (surface course of the pavement structure). In (4) $K_1(.)$ and $I_1(.)$ are a modified Bessel functions of the first order.

In accordance to [3], complex transfer function of direct signal is expressed as

$$\dot{K}_{FW}(\omega) = \frac{2\cos\theta_1}{\cos\theta_1 - \sqrt{\dot{\varepsilon}_2(\omega) - \sin^2\theta_1}}\cdot\frac{e^{-jk_0R_1}}{R_1}, \quad (5)$$

where $\theta_1 = arctg(d/2H)$ is angle of incidence on the boundary of the air – the top layer of the pavement; d is distance between the antennas and $R_1 = \sqrt{d^2 + (2H)^2}$.

Lateral wave occurs when a spherical wave is refracted at the critical angle of incidence θ_{cr}. Complex transfer function of lateral signal $\dot{K}_{LW}(\omega)$ is expressed as [6]:

$$\dot{K}_{LW}(\omega) = \frac{j2\dot{\varepsilon}_2(\omega)}{k_0\cdot(\dot{\varepsilon}_2(\omega)-1)\sqrt{d}\cdot L^{3/2}}\cdot e^{-jk_0\left(L+\sqrt{\dot{\varepsilon}_2(\omega)}L_0\right)}, \quad (6)$$

where $L_0 = \frac{2h_2}{\cos\theta_{cr.tr}}$ is length of the propagation path of lateral signal in the top layer of roadway coverage; h_2 is thickness of the top layer of the pavement; $L = d - 2\cdot h_2\cdot tg\theta_{cr.tr.}$ – is length of

the propagation path of lateral signal along the boundary of the air – the top layer of roadway coverage; $\theta_{cr.tr.} = arctg\left(\mathrm{Re}\left(\dot{tg}(\dot{\theta}_{cr})\right)\right) = arctg\left(\mathrm{Re}\left(\frac{1}{\sqrt{\dot{\varepsilon}_2(\omega)-1}}\right)\right)$ is the true value of the critical angle of incidence θ_{cr}.

Complex transfer function of $\dot{K}_{RW}(\omega)$ describes the reflection from a subsurface target if a height of antennas location H over upper medium boundary is sufficient small ($H \approx 0$). When the roadway coverage probing $\dot{K}_{RW}(\omega)$ is expressed as [4]:

$$\dot{K}_{RW}(\omega) = \frac{2\sqrt{\dot{\varepsilon}_2(\omega)}\cos\theta_2}{\sqrt{1-\dot{\varepsilon}_2(\omega)\sin^2\theta_2} + \sqrt{\dot{\varepsilon}_2(\omega)}\cos\theta_2} \cdot \frac{e^{-jk_0\sqrt{\dot{\varepsilon}_2(\omega)}R_2}}{R_2} \quad \text{for } \theta_2 \le \theta_{cr} \tag{7}$$

and

$$\dot{K}_{RW}(\omega) = \frac{2\sqrt{\dot{\varepsilon}_2(\omega)}\cos\theta_2}{-j\sqrt{1-\dot{\varepsilon}_2(\omega)\sin^2\theta_2} + \sqrt{\dot{\varepsilon}_2(\omega)}\cos\theta_2} \cdot \frac{e^{-jk_0\sqrt{\dot{\varepsilon}_2(\omega)}R_2}}{R_2} \quad \text{for } \theta_2 > \theta_{cr}, \tag{8}$$

where $\theta_2 = arctg(d/2h_2)$ is an angle of incidence on the boundary of air – surface course of the pavement, and $R_2 = \sqrt{d^2 + (2h_2)^2}$ is length of the propagation path for signal reflected from surface course of the pavement.

The model of roadway coverage may be conceived as homogeneous horizontal layers. Therefore reflection coefficient $\dot{R}_{2-n}(\omega)$ in (2) is expressed as a complex reflection coefficient for oblique incidence of plane wave on the upper boundary of the second layer of the pavement structure model. Calculation of $\dot{R}_{2-n}(\omega)$ is performed by using the expressions (9–12):

$$\dot{R}_{2,n}(\omega) = \frac{\dot{R}_{2,3}(\omega) + \dot{R}_{3,n}(\omega)\cdot\exp(-j2k_0\sqrt{\dot{\varepsilon}_3(\omega)}h_3/\cos\theta_{3ucm})}{1+\dot{R}_{2,3}(\omega)\cdot\dot{R}_{3,n}(\omega)\cdot\exp(-j2k_0\sqrt{\dot{\varepsilon}_3(\omega)}h_3/\cos\theta_{3ucm})}, \tag{9}$$

$$\dot{R}_{i,k}(\omega) = \frac{\dot{R}_{i,i+1}(\omega) + \dot{R}_{i+1,k}(\omega)\cdot\exp(-j2k_0\sqrt{\dot{\varepsilon}_{i+1}(\omega)}h_{i+1}/\cos\theta_{i+1ucm})}{1+\dot{R}_{i,i+1}(\omega)\cdot\dot{R}_{i+1,k}(\omega)\cdot\exp(-j2k_0\sqrt{\dot{\varepsilon}_{i+1}(\omega)}h_{i+1}/\cos\theta_{i+1ucm})}, \text{ for } k \ne i, k \ne i+1, \tag{10}$$

$$\dot{R}_{i,i+1}(\omega) = \frac{\sqrt{\dot{\varepsilon}_i(\omega)}\cos\theta_i - \sqrt{\dot{\varepsilon}_{i+1}(\omega) - \dot{\varepsilon}_i(\omega)\sin^2\theta_i}}{\sqrt{\dot{\varepsilon}_i(\omega)}\cos\theta_i + \sqrt{\dot{\varepsilon}_{i+1}(\omega) - \dot{\varepsilon}_i(\omega)\sin^2\theta_i}}, \tag{11}$$

$$\sin\theta_i = \frac{\dot{\varepsilon}_{i-1}(\omega)}{\dot{\varepsilon}_i(\omega)}\sin\theta_{i-1}, \tag{12}$$

where $\dot{\varepsilon}_i(\omega)$ – the relative complex permittivity of (i-1)-th layer; θ_i – is angle of incidence on the boundary of (i-1)-th layer – i-th layer of roadway coverage; h_i – the thickness of (i-1)-th layer.

The electro-physical parameters of the modelled pavement structure are presented in Table 1.

Table 1. Electro-physical parameters of partial model media

№	Partial medium of model	Electro-physical parameters of partial model medium		
		$\dot{\varepsilon}'$	σ, s/m	h, m
1	Air	1	0	∞
2	Dense grated HMA	2,9	$5*10^{-9}$	0,06
3	Coarse-grained asphalt 2 marks	3,6	$5*10^{-8}$	0,08
4	Coarse asphalt 2 marks	5,0	$5*10^{-6}$	0,12
5	Crushed stone	7,0	$5*10^{-4}$	0,33
6	Sand	9,0	$5*10^{-3}$	0,65
7	Loam	15,0	$5*10^{-2}$	∞

The electro-physical parameters of the pavement structure has been modelled taking into account that the roadway coverage layers are composed of such materials as asphalt, concrete, crushed stone, crushed slag, sand and others. The number of the layers can vary but the electro-physical characteristics of some layers can be very similar or even equal. The five-layered model of the pavement structure has been used in our investigations. Electro-physical parameters of the model partial layers as well as the parameters of two semi-infinite spaces: upper space – air, and low space – subgrade.

3. Forward Modelling of Flexible Pavement Structure GPR Probing

Forward problem of the flexible pavement structure GPR probing was solving numerically with the using of the frequency model described above. Calculations were carried out under the following conditions:

- distance between the antennas ……...……..1 m;
- antennas high over upper boundary.....5 m;
- half length of linear antennas.....0,25 m, 0,50 m, 0,75 m;
- diameter of antennas.....0,0025 m;
- load resistor of the receiving antenna..... 425 Om.

The probing signal was generated by the shock excitation of the transmitting antenna by triangular video pulse duration of which was equal to 2 ns, and its was equal to 100 V.

Complex transfer function $\dot{K}_{RAD}(\omega, \vec{P})$ is calculated according to equations (1)–(12) for vector $\vec{P}$, components of which are corresponded data presented in Table 1.

The spectrum of receiving signal is computed in the following form:

$$\dot{S}_L(\omega) = \dot{K}_{RAD}(\omega) \cdot \dot{S}_{ex}(\omega), \tag{13}$$

where

$$\dot{S}_{ex}(\omega) = \int_{-\infty}^{\infty} u_{ex}(t) \cdot e^{-j\omega t} dt \tag{14}$$

is spectrum of excitation signal $u_{ex}(t)$.

To obtain time shape of the received signal inverse Fourier transform in form was performed:

$$u_L(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \dot{S}_L(\omega) e^{j\omega t} d\omega. \tag{15}$$

Frequency dependence complex transfer function of signal forming channel for the flexible pavement structure GPR probing are shown on Figure 3 for three half length of linear antennas, which are equal 0,25 m, 0,50 m, and 0,75 m.

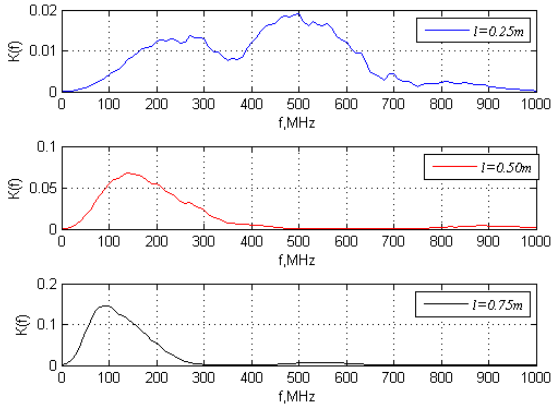

Figure 3. Transfer functions of signal forming channel for different half lengths of used linear antennas

This dependence shows that the increasing of antennas length gave the same effect both on antennas broadband and on the total level of the complex transfer function $\dot{K}_{RAD}(\omega, \vec{P})$ module.

The corresponding Frequency dependences of effective antennas length $\dot{L}_{eff}(\omega)$ are shown on Figure 4. It is shown as the half length of linear antennas decreases the characteristic $\dot{L}_{eff}(\omega)$ becomes more narrowband, frequency of the first peak decreases and the value of all the peaks is increased.

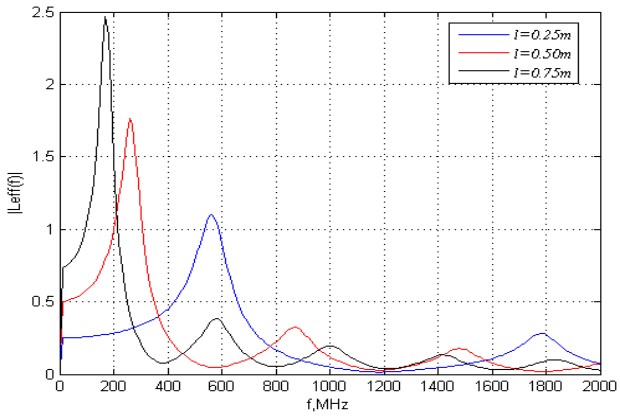

Figure 4. Frequency dependence of effective antennas length

Signals on output of receiving antenna and their spectrum modules for antennas half lengths, which are 0,25 m, 0,50 m, and 0,75 m are shown on Figure 5a,b.

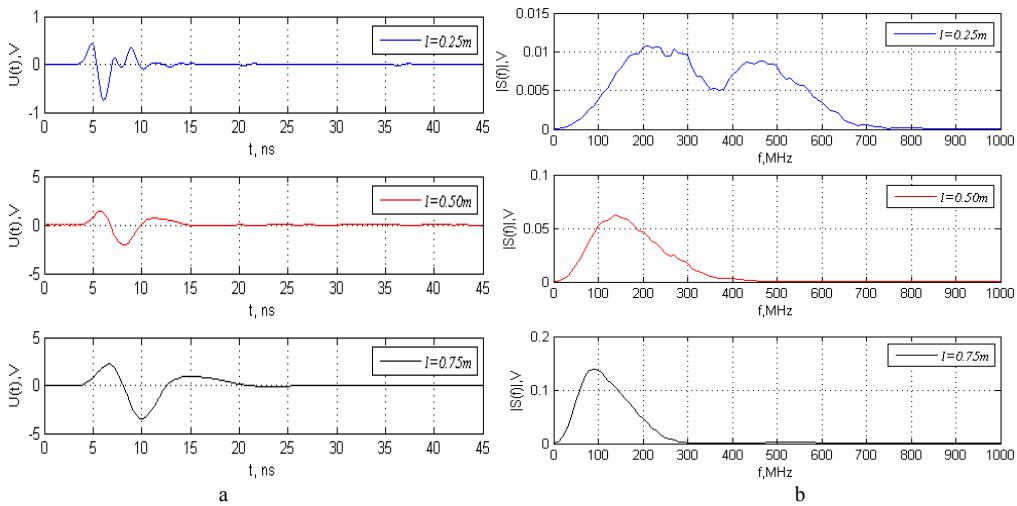

Figure 5. Characteristics of the signals on output of receiving antenna in the time (a) and frequency (b) domain

The modules of the received signal spectral densities are practically the same as the corresponding dependence of the complex transfer function of signal forming channel $\dot{K}_{RAD}(\omega, \vec{P})$, that are shown on Figure 2. It is seen that with decreasing length of the antenna resolution is getting worse, so determine the time delay of the signals reflected from the boundaries of the layers is impossible. Therefore, it is impossible to determine the thickness of each layer of roadway coverage, using amplitudes of the received signals.

The received signal and its components are shown on Figure 6 for the half length of used linear antenna l = 0,25 m. Figure 6 shows that levels of the lateral signal and direct signal are comparable to the level of the signal reflected from the bottom of the first layer of roadway coverage. Since the duration of the forward and lateral signals more double passing time of reflected signal through the top layer of roadway coverage, the initial part of the received signal is the result of interference of the three signals. The reflected signal consists of the signals reflected from the entire boundary between the layers of roadway coverage. The signals reflected from the lower layers have significantly lower levels. When l = 0,50 m or l = 0,75 m the relative level of signals reflected from the lower layers are even smaller [6]. This eliminates the possibility to determine the thickness of the layers of roadway coverage by analysing the received signals.

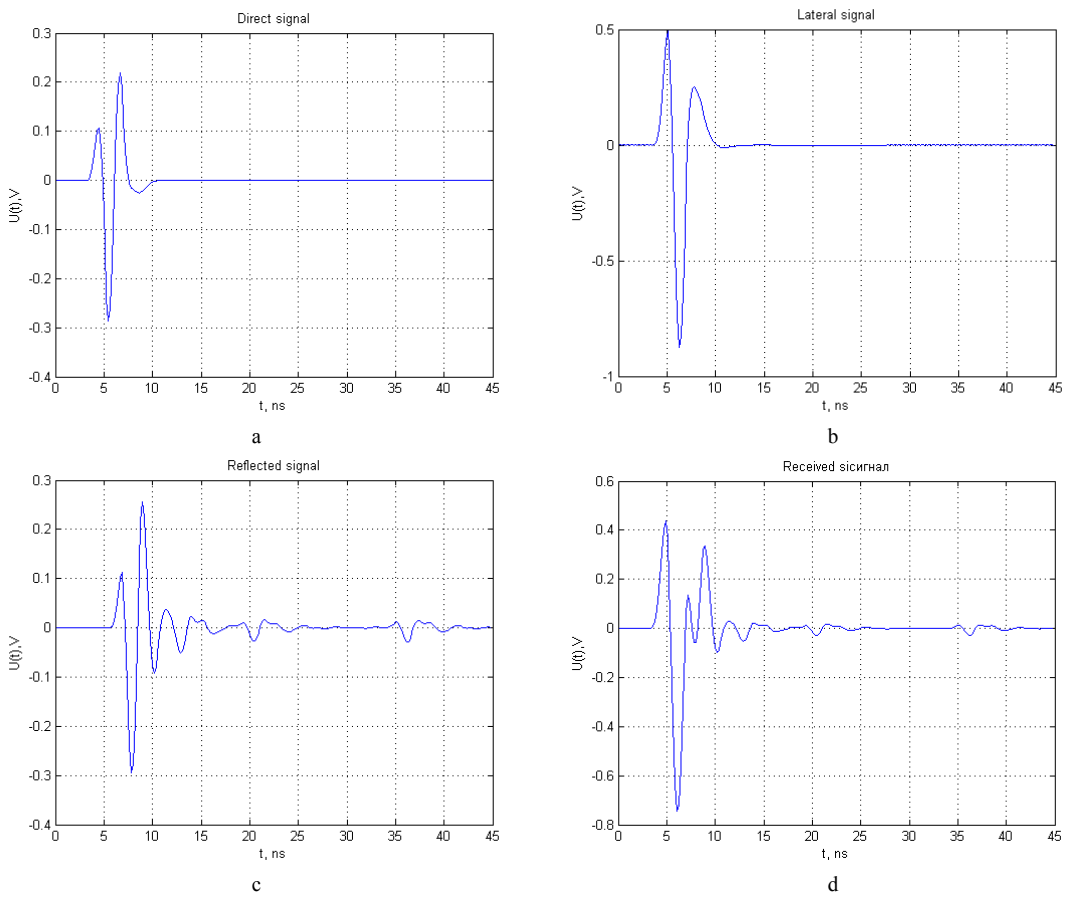

Figure 6. Received signal and its components:
a – direct signal; b – lateral signal; c – reflected signal; d – total signal received by GPR antenna

4. Inverse Problem of Flexible Pavement Structure GPR Probing

In [8] we investigated the inverse problem of roadway coverage radar probing in the frequency domain using vector $\vec{P} = \{p_1, p_2, ..., p_n\}$, in which components p_i were electro-physical parameters of layers for n-layered model of probed media. Electro-physical parameters of each layer are as follows: thickness *h*, conductivity σ and the real part of relative complex permittivity ε' of the layer's materials.

The solution of the inverse problem of radar probing has been received in the frequency domain by the method of comparison in which used the aim function Φ in the following form:

$$\Phi = \frac{1}{n_{\max}} \sum_{i=0}^{n_{\max}} \left| B_e\left(\omega_i, \vec{P}\right) - B_t\left(\omega_i, \vec{P}_M\right) \right|^2 , \tag{16}$$

where n_{max} is number of the spectral component with frequency f_{max}; $B_e\left(\omega_i, \vec{P}\right)$ is value of function of parameter vector $\vec{P}$ for angular frequency ω_i ,which is derived from the reflected signal; $B_t\left(\omega_i, \vec{P}_M\right)$ is value of the model function of parameter vector $\vec{P}_M$ for angular frequency ω_i which is derived from the solving of forward problem of GPR probing. To calculate $B_t\left(\omega_i, \vec{P}_M\right)$ the vector of parameters $\vec{P}_M$ was limited by the set of allowed values of parameters $\vec{P}_{POS}$. The solution of the inverse problem was the vector of parameters $\vec{P}_M$ which corresponded to the global minimum of the aim function Φ. The complex spectral density $\dot{S}_e\left(\omega_i, \vec{P}\right)$ as well as module of spectral density $\left|\dot{S}_e\left(\omega_i, \vec{P}\right)\right|$ was used in [8, 9] as function of parameters B_e. Iterative procedure was used for finding of the aim function Φ global minimum with help of the genetic algorithm (GA).

It had been found that the parameter's search range affects the error of recovery parameters of pavement. To reduce the error recovery of the road surface parameters we used the algorithm, which is shown on Figure 7. The main elements and parameters that characterize the features of this algorithm are as follows:

- vector of minimum values $\vec{P}_{\min}$ of the parameters of the probed medium,
- the vector of maximum values $\vec{P}_{\max}$ of the parameters of the probed medium,
- population size N_{pop},
- the value of a threshold α and dimensionless coefficient K).

It has been suggested [9] that the value of α is set as follows:

$$\alpha = \frac{P_{av}}{K}, \tag{17}$$

where P_{av} – the averaged mean power of those spectral components $\dot{S}_e\left(\omega_i, \vec{P}\right)$, which are used for calculating of aim function Φ .

The values of the search range $\vec{P}_{\min}$ and $\vec{P}_{\max}$ are determined a priori information about the probed pavements. values K and N_{pop} are set by the user at the beginning of solving the inverse problem. Therefore we refined the search range in the first stage, when the K value was low.

For the given parameters of genetic algorithm initial population is generated. Then, for each chromosome objective function is calculated in accordance with (16). If the initial search range is used, the best chromosomes are sought, such whose aim function is less than α. If the number of best chromosomes in the population is less than half of the population size, the new generation is created and a new iteration of the inverse problem solution is performed. If the number of best chromosomes in the population is more than half of the population size, the new ranges are determined by searching for each parameter. For this case the best chromosomes of generation are used in order to calculate the averages (means) and root-mean-square values for each recovery parameter. The obtained estimations allow to use a new range for searching of pavement parameters $\vec{P}_{\min}$ and $\vec{P}_{\max}$. This allowed us to narrow the search range adaptively, and for each electro-physical parameter differently.

In the second stage value K was set by large, therefore the threshold α was reduced, and then searched the parameters of the $\vec{P}_M$ vector. The new generation is formed with the using of new $\vec{P}_{\min}$ and $\vec{P}_{\max}$, and then the next iteration of the inverse problem is performed. However, one of the best individual of generation is sought in the second stage If the value of the aim function Φ for such chromosome is not more than the value of a threshold α, then solving the inverse structure problem is finished. The values of the best chromosome parameters are used to determine the vector $\vec{P}_M^*$, which is the solution of the inverse problem.

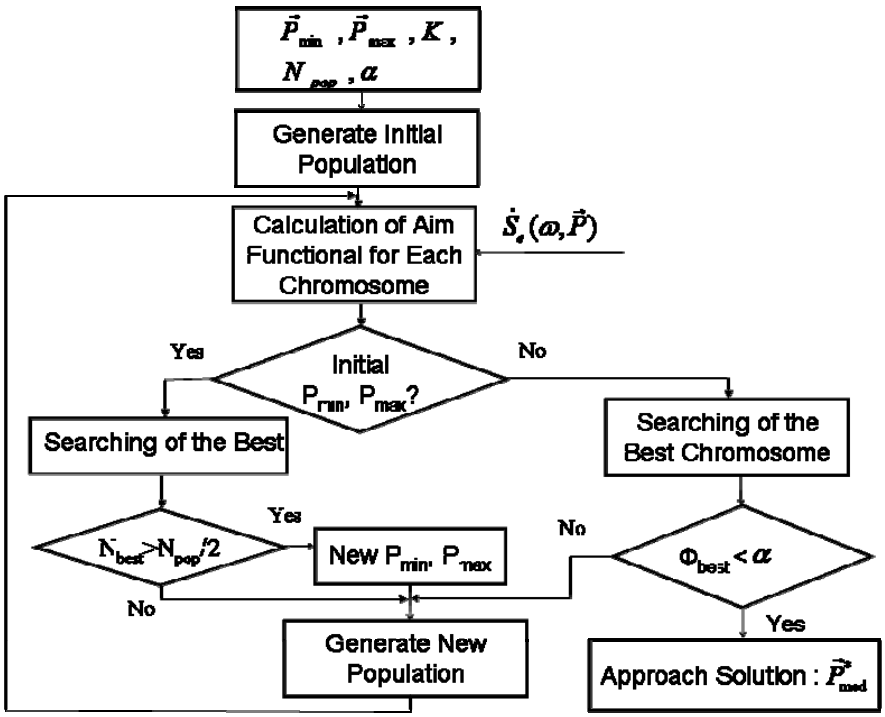

Figure 7. Block diagram of iterative procedure to solve radar inverse problem in frequency domain

To obtain statistical assessment about 100 solutions of the inverse problem for two different models of flexible pavement structure were used.

In Table 3 are presented the relative errors of reconstruction of electro-physical parameters of flexible pavement structure (Table 1) for half length of used linear antennas equal l = 0.25 m.

Table 3. Relative errors of reconstruction of electro-physical parameters

№	Partial medium of model	Relative errors,%		
		$\delta_{\dot{\varepsilon}'}$	δ_{σ}	δ_{h}
1	Dense grated HMA	<1,0	15-20	<1,0
2	Coarse-grained asphalt 2 marks	<2,0	15-20	<1,0
3	Coarse asphalt 2 marks	<3,0	15-20	<2,0
4	Crushed stone	<3,0	15-20	<2,0
5	Sand	<2,0	15-20	<2,0
6	Loam	<2,0	15-20	-

Statistical assessment of reconstruction of electro-physical parameters of modelling flexible pavement structure were obtained also for the half length of used linear antennas l = 0,50 m, and l = 0,75 m. By increasing the half length of used linear antennas do not increase of the error values.

5. Conclusions

The following verities are proved in this research:

- the inverse problem of flexible pavement structure GPR probing may be solved by taking into account the influence of GPR antenna system characteristics as well as the influence of probed medium;
- the reconstruction of electro-physical parameters for flexible pavement structure is possible with high accuracy for linear antennas with half length 0,25 m, 0,50 m, and 0,75 m;
- using an adaptive algorithm of search ranges parameters is possible to reduce the error reconstruction of parameters and the duration of the inverse problem solving.

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MULTIAGENT MODELING AND XML-LIKE DESCRIPTION OF DISCRETE TRANSPORT SYSTEM

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The paper describes a novel idea to monitoring and modeling of Discrete Transport System (*DTS*). We propose the formal model of the transport system with the approach to its modelling based on the system behaviour observation. The proposed method is based on specified description languages that can be seen as a bridge between the system description (as a mathematical or expert specification) and the analysis tools. The *DTS* is a simplified case of the Polish Post. Using a multilevel-agent based architecture the realistic data are collected. Described architecture can be found as a basis for a tool that can visualize and analyze data, with respect to the real parameters. Absence of any restrictions on the system structure and on the kind of distribution describing the system functional and reliability parameters is the main advantage of the approach. The paper presents some exemplar system modeling based on a case study. The proposed approach can be used as a helpful tool to administrate the system.

Keywords: Discrete Transport System, reliability, agent management system

1. Introduction

The transportation systems are characterized by a very complex structure. This complexity affects a need to use mechanisms and helpful means to actual data collecting and to administrate the system (i.e. make decisions related to the performance). The building or the optimization of the transportation systems can be expensive and problematic.

The necessary analysis mechanisms should be created not only for the money saving, by also as a tool for the future administration of the system and decision support (based on some specified metrics). The main problem is to realize multi-criteria optimization for the transport system management. The solution ought to combine the sets of reliability, functional and economic parameters. The mentioned data are modeled by distributions, so it makes the optimization problem more sophisticated. The classic solution way is based on the human-expert experience to play the dispatcher or the manager role. But nowadays the elements of the transportation systems are characterized by more and more screwed-up parameters and the historical experience is not enough to create the real and actual solution for the transportation systems driving. This is the reason why we propose the computational collective intelligence to create the device to support human's decisions.

The presented work uses the agents in task of the transportation system monitoring and modelling, so we propose the following description of the most important agent features [13]:

- unique identification within the proposed architecture,
- interaction abilities and proper interfaces for communication and different data transfer,
- secure protocols necessary for communication purposes,
- hardware and / or software implementation,
- plug-and-play ability to guarantee promising scalable and flexible structure.

The temporary computer engineering still does not define an "agent" term in detailed way, but it is not a real barrier to establish the unified semantic meaning of the word in technical point of view. The agent can play the role of the autonomous entity [4] as a model or software component for example. The agent behaviour can be noticed as trivial reactions, but it is not limited – so we can easily find agents characterised by the complex adaptive intelligence. Sometimes it is important to point the potential

adaptive abilities of the agents [7]. It means the agent can gather knowledge from the environment around and to adjust its behaviour as a reaction for different events.

This way we can say the agents belong to the soft-computing world. The agent structure is not obligatory plain. We can easily [2] find at least two levels (lower, higher) of the rules created for the agents. This approach allows adjusting the level of the sensitivity for the environment and defining the vitality feature of the agent understood as activity or passivity [9, 10].

The agent-based approach provides the really great effectiveness comparing to the classical architectures if we think about the data gathering and aggregation from the really sophisticated system characterised by the large network, significant number of nodes and non-trivial addressing aspects. This way it is easy to create the global and detailed enough view for multilevel systems with elements described by the various sets of features. We propose to use the agents to create the intelligent hierarchical monitoring architecture (described in Section 3) for the Discrete Transport System (*DTS*) defined in Section 2.

The section 4 presents an authors' solution of a description language for a proposed model, called *DTSML* (Discrete Transport System Modelling Language). The format of the proposed language *XML* (Extensible Markup Language) has been chosen. The main reason is a simple (easy to learn) and readable structure, that can be easily convert to the text or other format.

Moreover, *XML* is supported not only with various tools (providing validation possibilities) but is also supported with many programming languages and framework in case of quicker and more efficient implementation.

Section 5 is focused on simulation methodology. The approach is based on Monte-Carlo technique. The simulator is constructed using *SSF Net* device by adding the necessary objects to reflect the mean features characterizing Discrete Transport Systems.

Next section defines the availability as a metrics to evaluate the quality of the system. The availability is estimated basing on the delays noticed during the system work. Finally we present the case study with a set of results calculated using the approach described in the paper.

2. Transport Model

2.1. Preface

Depending on the level of detail in modelling the granularity of the traffic flow, the traffic models are broadly divided into two categories: macroscopic and microscopic models. According to Gartner et al. [5], a macroscopic model describes the traffic flow as a fluid process with aggregate variables, such as flow and density. The state of the system is then simulated using the analytical relationships between average variables such as a traffic density, a traffic volume, and average speed.

On the other hand, a microscopic model reproduces interaction of punctual elements (vehicles, road segments, intersections, etc) in the traffic network [1]. Each vehicle in the system is emulated according to its individual characteristics (length, speed, acceleration, etc.) [3]. Traffic is then simulated, using processing logic and models describing vehicle driving behaviour, such as car-following and lane-changing models. These models reproduce the driver-driver and driver-road interactions [8].

Despite its great accuracy level, for many years this highly detailed modelling has been considered a computationally intensive approach. For the last twenty years, with the improvements in processing speed, this microscopic approach has become more attractive [12].

2.2. System Description

The analyzed transportation system is a simplified case of the Polish Post. The business service [14], [6], [17] provided the Polish Post is the delivery of mails. The system consists of a set of nodes placed in different geographical locations. We have the headquarter (*HQ*) located in the central part of Poland and two kinds of nodes can be distinguished: the central nodes (*CN*) and the ordinary nodes (*ON*).

There are bidirectional routes between the nodes. Mails are distributed among the ordinary nodes by trucks, whereas between the central nodes by trucks, railway or by plane. The mail distribution can be understood by tracing the delivery of some mail from point *A* to point *B*.

At first the mail is transported to the nearest ordinary node *A*. Different mails are collected in the ordinary nodes, packed in larger units called containers and then transported by trucks scheduled according to the management architecture decision to the nearest central node.

In the central node the containers are repacked and delivered to the appropriate (according to the delivery address of each mail) central node. In the second – the closest to the destination place – central node the mail is again repacked and delivered in a container to the destination ordinary node.

The headquarter collects all data about the actual situation in the whole transportation system and makes the necessary decisions as the reaction for the temporary needs. The headquarter is not in use in transportation action – if we think about the loading, unloading processes, etc. The central nodes aggregate the data from the single region of the country. And finally the ordinary nodes control the local situation to the end user. The scale of necessary actions depends on the actual needs.

In the Polish Post there are 14 central nodes and more than 300 ordinary nodes. There more than one million mails going through one central node within 24 hours. It gives a very large system to be modeled and simulated.

The process of any system modeling requires defining the level of details. Increase of the details of the system causes the simulation to become useless due to the computational complexity and a large number of the required parameter values to be given.

2.3. Model

We can model Discrete Transport System described above as a 4-tuple [15]:

$$DTS = \langle Client, BS, TI, MA \rangle, \tag{1}$$

where: *Client* – client model, *BS* – business service, a finite set of service components, *TI* – technical infrastructure, *MA* – monitoring architecture.

The technical infrastructure of *DTS* can be described by three elements:

$$TI = \langle No, V, MM \rangle, \tag{2}$$

where: *No* – the set of nodes; *V* – the set of vehicles; *MM* – the maintenance model.

The set of nodes (*No*) consists of a single headquarter (*HQ*), the central nodes (*CR*), a given number of ordinary nodes (*ON*). The distance between each two nodes is defined by the function:

$$distance : No \times No \rightarrow R_+ . \tag{3}$$

Each node has one functional parameter – the mean (normal distribution) time of loading a vehicle:

$$loading : No \rightarrow R_+ . \tag{4}$$

Moreover, the central node (*CR*) has additional functional parameter: the number of service points (in each ordinary node there is only one service point):

$$servicepoints : CN \rightarrow N_+ . \tag{5}$$

Each vehicle is described by the following functional and reliability parameters [16]:

- mean speed of a journey

$$meanspeed : V \rightarrow R_+ , \tag{6}$$

- capacity – number of containers which can be loaded

$$capacity : V \rightarrow R_+ , \tag{7}$$

- mean time to failure

$$MTTF : V \rightarrow R_{+}, \tag{8}$$

a time when failure occurs is given by exponential distribution with mean equal to a value of *MTTF* function,

- mean repair time

$$MRT : V \rightarrow R_{+}. \tag{9}$$

The traffic is modelled by a random value of vehicle speed and therefore the time of vehicle (v) going from one node (n_1) to another (n_2) is given by a formula:

$$time(v, n_1, n_2) = \frac{distance(n_1, n_2)}{Normal(meanspeed(v), 0.1 \cdot meanspeed(v))}, \tag{10}$$

where *Normal* denotes a random value with the Gaussian distribution [17].

The maintenance model (*MM)* consists of a set of maintenance crews which are identical and unrecognized. The crews are not combined to any node, are not combined to any route, they operate in the whole system and are described only by the number of them.

The time when a vehicle is repaired is equal to the time of waiting for a free maintains crew (if all crews involved into maintenance procedures) and the time of a vehicle repair which is a random value with the Gaussian distribution: *(Normal(MRT(v), 0,1·MRT(v))*.

Business service [17] (*BS*) is a set of services based on a business logic, that can be loaded and repeatedly used for concrete business handling process.

Business service can be seen as a set of service components and tasks that are used to provide service in accordance with the business logic for this process. Therefore, *BS* is modelled by a set of business service components (*sc*),):

$$BS = \{sc_{1,} ..., sc_n\}, n \ = length(BS) > 0, \tag{11}$$

the function *length*(*X*) denotes the size of any set or any sequence .*X*

The service implemented by the clients of the transport system, sending the mails from a source node to a destination one [15]. Client model consist of a set of clients (*C*).

Each client is allocated in one of the nodes of the transport system:

$$allocation : C \rightarrow No. \tag{12}$$

A client allocated in an ordinary node is generating containers (since we have decided to monitor the containers, but not the separate mails during the simulation) according to the Poisson process with destination address set to ordinary nodes. In the central node, there is a set of clients, one for each ordinary node. Each client generates the containers by a separate Poisson process and is described by the intensity of container generation:

$$intensity : C \rightarrow R_{+}. \tag{13}$$

The management model controls the movement of trucks. We proposed a promising and effective heuristic management approach [14] which allows reacting for the critical situations which can occur

during the normal system work [15]. The decisions (to send a truck to a given destination node) are taken in the moments when a container arrives to the central node.

The truck is send to a trip if: the number of containers waiting in for delivery in the central node of the same destination address as that just arrived is larger than a given number, there is at least one available vehicle, the simulated time is between 6 am and 22 pm minus the average time of going to and returning from the destination node.

The truck is send to a node defined by a destination address of just arrived container. If there is more than one vehicle available in the central node, the vehicle with size that fits best to the number of available containers is selected, i.e. the largest vehicle that can be fully loaded.

If there are several trucks with the same capacity available the selection is done randomly. On the other hand we observe in the same way the vehicles available in the ordinary nodes. The only difference is the greater level of threshold to initialize the vehicle journey.

3. Monitoring Architecture

In case of Monitoring Architecture representation and distributed multilevel agent-based architecture can be constructed. Figure 1 shows the diversification of complexity of a system into layers and their placement in a system.

The lowest components of the structure are *Node Probes* which are the simplest pieces of the architecture representing resident level (i.e. vehicles). These are the simplest and easy to get data that at this level represent small value that is why they are aggregated in upper units, forwarded to appropriate supervising *Node Sensors*.

Next *Node Sensors* collect the data and create an image of the particular area – so they are located in the ordinary nodes (*ON*). Again the information is sent to a higher level – *Local Agent* – combined to the central nodes (*CN*).

$$NS_i = \bigcup_j NP_j;\ j \in N. \tag{14}$$

This set of information creates a database building representation of the local part of the system (sub-network). It means that the local view of the system and partial administration in the system can be done at this level.

$$LA_i = \bigcup_j NS_j;\ j \in N. \tag{15}$$

The highest components of this structure are the *Global Agent* – working in the headquarter (*HQ*), that picks and processes the local information and views one central unit.

$$GA = \bigcup_j LA_j;\ j \in N. \tag{16}$$

This module stores all information from the whole system. It is situated in one point and one dedicated machine (with a strong backup). Assembling all local views at this level we get one homogenous global view. At this level, data-mining techniques can be used since we know the politics of the Transportation Company as much all information is about parcels.

Figure 2 shows the same tree of hierarchy, where we can see that *Node Probes* can be seen as the lowest point in the system – cars, tracks, etc. Next the nearest or small office can be presented as a *Node Sensors*. Each Post – ordinary node (*ON*) area belongs to a bigger Post Office (mainly located in a big city) – called the central node (*CN*) during our analysis.

Afterwards, all information and some packages (i.e. in case of international packages) are sent to Central Unit – the headquarter (*HQ*) located in one Central point in the Country.

Looking at Figure 1 and Figure 2, we can see that the set of information flow goes to the central unit – *Global Agent*. For this reason it is the most complex and the simplicity of the data that are needed to describe the system in this point is the highest in hierarchy.

4. Transport Language

Since the purpose of the work is to analyze the transportation system based on a specified mathematical model, there is a need to transfer the data into a format that would be useful in an analysis tool. It requires specifying the data format that can be easily shared between various tools or even several transport architectures (independent form complexity). Several data sharing and exchange standards have been developed in the Intelligent Transport Systems [8].

They define a standard data format for the sharing and exchange of the transportation data mostly based on *UML* (Unified Modeling Language) diagrams. Other solutions, i.e. Japanese standard called *UTMS* (Universal Traffic Management Systems) focuses rather on the road traffic system.

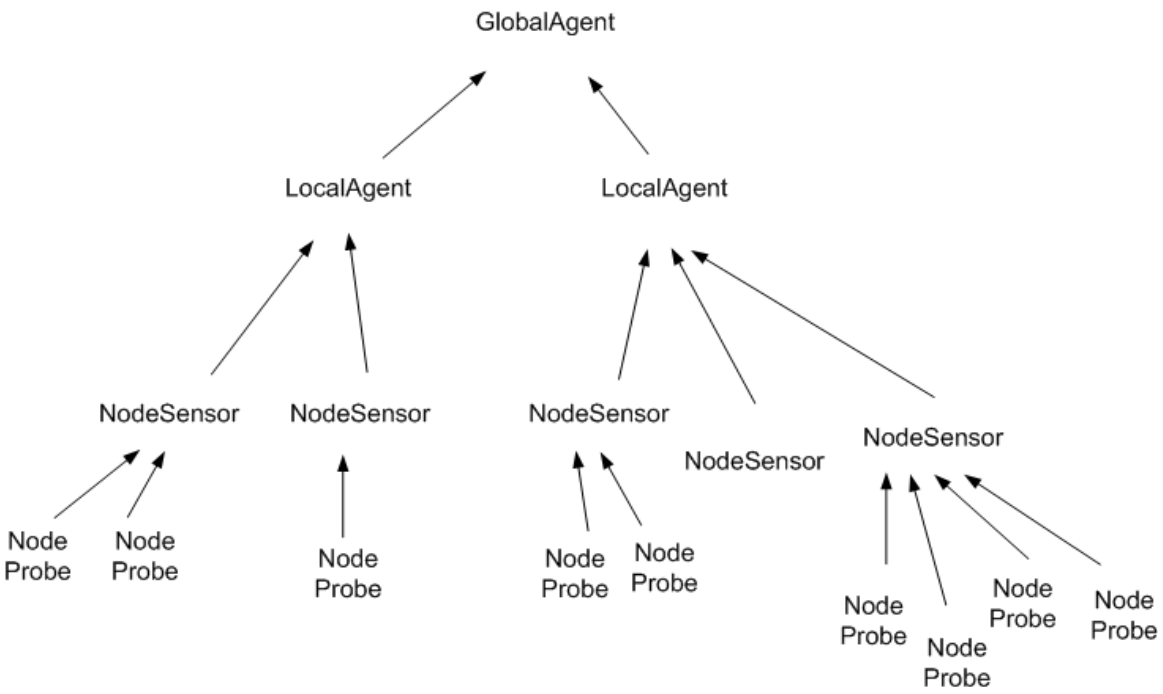

Figure 1. Multilevel architecture scheme

Still none of them is coherent with the solutions proposed in this paper, since they describe the different types of transport system. Moreover, they are based on *UML* diagrams, which are the graphical representation of a model, but not the one, that can be simply used as an input format for any available analysis tool (computer simulator). Additionally description language for this system should be as close as real, not only to a mathematical description of the system, but to the real system behavior and its parameters.

In Section 3 we have mentioned that the View of the Transport System can be implemented on two levels (local and global). To do that, the tool for visualisation and data processing is needed. Furthermore, having this tool we can not only see the topology of the system, but also its elements and parameters.

It gives us an opportunity to see the system more precisely or even make some analysis on a real data that comes from the proposed multilevel agent-based architecture.

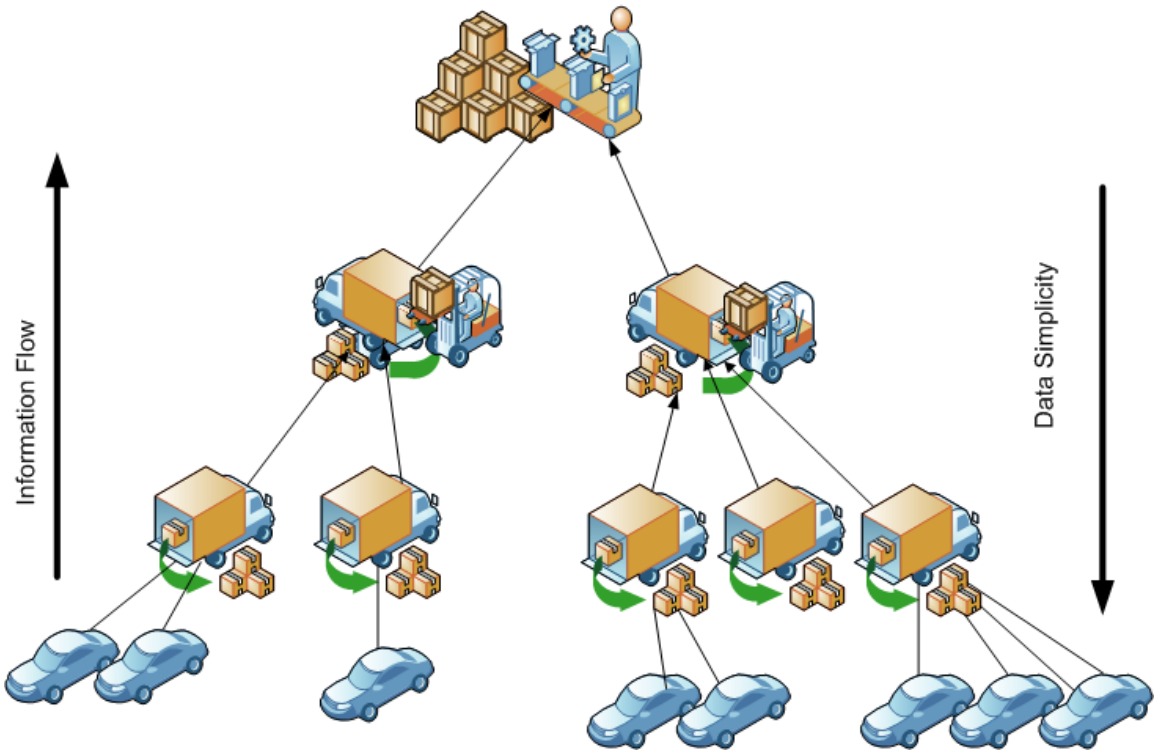

Figure 2. Architecture concept

Still, it requires specifying data format that can be shared between tools, but since of the data exchange is done basing on *UML* diagrams, there is a need to use some other solution that will be more suitable. Since *UML* diagrams are mostly graphical representation of a model, we propose an authors' solution of a *description language* for a proposed (Section 2.3) model, called *DTSML* (Discrete Transport System Modelling Language) [11]. Format of this language is based on *XML* standards, since it is easy to use, and extendable. Moreover, the format allows using the language without special tools, since *XML* is supported by many tools.

Figure 4 shows a fragment of the language with the appropriate elements and attributes related to the mathematical model described in Section 2.3. Figure 3 shows a part of the XML Scheme for Discrete Transport System Modeling Language. As it can be seen, each element of the system described in Section 3 is modeled as a complex element with the appropriate sub-elements and attributes.

The proposed language assures aggregation of dependability and functionality aspects of the examined systems. One language describes the whole system and provides a universal solution for various techniques of computer analysis as an effective and suitable input for those tools.

Expected easiness of potential soft-computing analysis, promising scalability and portability (between analysis tools) can be named as a main advantage of the language usage.

The proposed language is easy to read and to process using popular and open-source tools; however the metadata used in this format are still a significant problem in case of file processing (large size of the file). Nevertheless, since *XML* format is strongly supported by programming languages like: *Java*, *C#*, the usage as much as processing of the file can be done irrespectively to the application language.

As previously described (Fig. 1.) data send by *Node Probe* are combined in the *Node Sensors*. Each of these entities has assigned to it a supervisor – *Local Agent* that accumulates these files in order to create a local view.

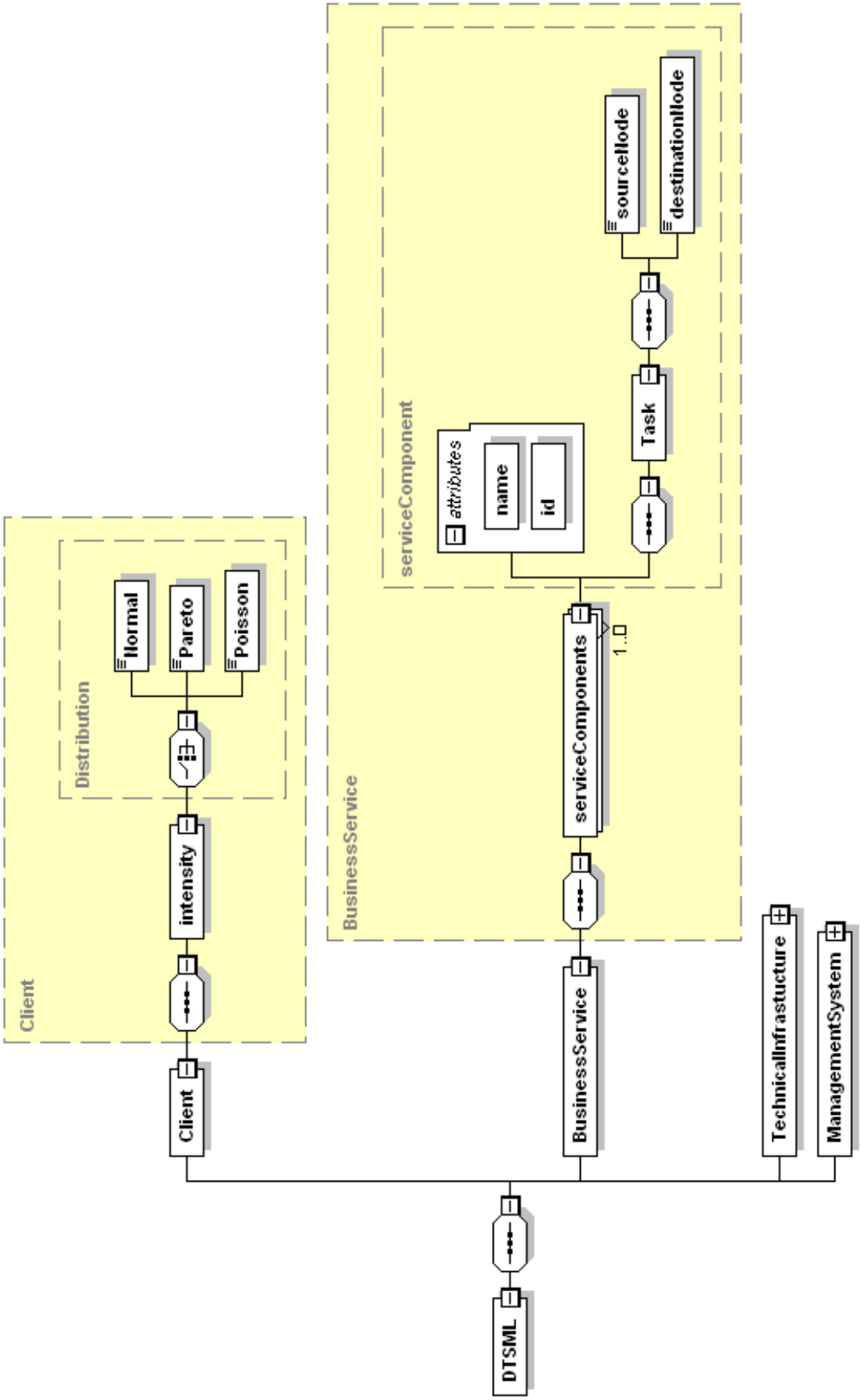

Figure 3. XML Scheme for Discrete Transport System Modeling Language

```
<Node>
         <SingleCentralNode to="string1">
          <numberOfPackages>3455</numberOfPackages>
          <numberOfVehicules>8990</numberOfVehicules>
          <ManagementSystem />
          <TechnicalInfastuctureTopology numberofOrdinaryNodes="5819">
                   <timeBetweenSpecificNodes>
                       <linksBetweenNodes from="Wroclaw" to="Opole" />
                        <time>5.7</time>
                    </timeBetweenSpecificNodes>
                </TechnicalInfastuctureTopology>
            </SingleCentralNode>
        </Node>
        <Vehicule>
            <meanspeed>9.7</meanspeed>
            <capacity>678</capacity>
            <MTTF>10.05</MTTF>
            <MRT>50.98</MRT>
        </Vehicle>
```

Figure 4. DTSML – fragment of the language

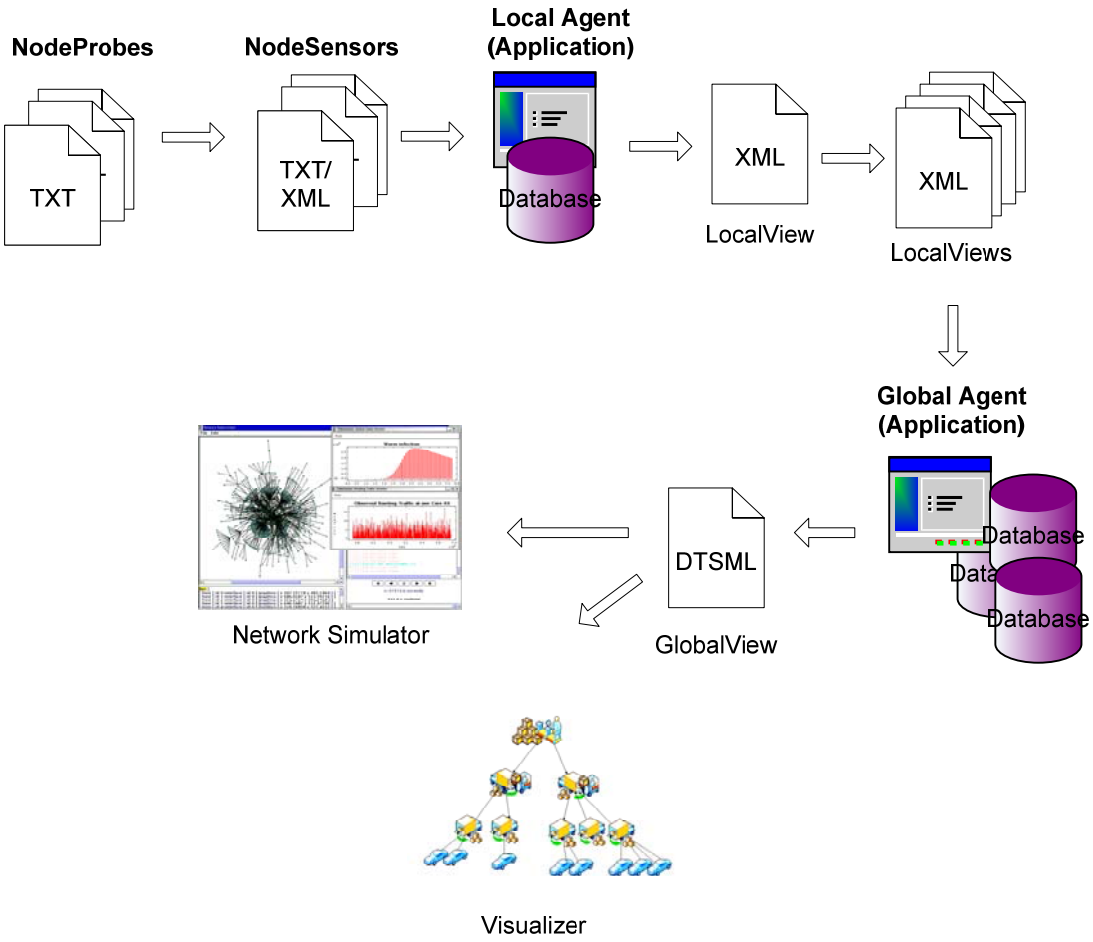

Figure 5. Multi-agent Monitoring Application – architecture concept

This level is more compound and computationally complex than the previous one considering the installed database and some methods that solve additional problems. In this way *XML* files transferred from the simplest level to the next one, creating views on the upper level.

Global Agent collects this information and similarly to Local Agent combines all information included in the dedicated *DTSML* file. As this Global Agent is the most resourceful entity it may be distributed, so it can contain more than one database. At the end, full description of the system is created, visualised and analysed with respect to the dedicated analysis tools.

5. Simulation Methodology

A simulator, performing a Monte-Carlo simulation [16], is composed of four basic elements: input data file, system description language analyzer, event-driven simulator, output data file. The system description language analyzer creates, basing on the data taken from the input file objects which represent system in the memory.

The event-driven simulator repeats *N*-times the following loop [17]:

- initial state of a *DTS* – event initial state, set $t = 0$ – repeat until $t < T$:
- take first event from event list – set time equals time of event – implement the event.

The event is a basis for a simulation process. It is described by the following data: time of event occurring, type of event – vehicle failure for example, part of the *DTS* where event has its influence. The events are placed in the ordered list. Time of event occurring is the key for the list order.

We have the following events in the *DTS*: vehicle reached the node, vehicle is failing, vehicle is repaired, task is starting, end of simulation [14]. For the purpose of simulating *DTS* we have used Parallel Real-time Immersive Modeling Environment (*PRIME*) [16] implementation of *SSF* due to much better documentation then that available for the original *SSF* [14].

We have developed a generic class (named *DTSObject*) derived from *SSF Entity* [6] which is a base of classes modeling *DTS* objects like: scheduler, node, truck and crew which model the behavior of presented in Section 2 Discrete Transport System. Due to a presence of randomness in the *DTS* model the analysis of it has to be done basing on Monte-Carlo approach. It requires a large number of repeated simulations.

The *SSF* is not a Monte-Carlo framework but by simple re-execution of the same code (of course we have to start from different values of random number seed) the statistical analysis of the system behavior can be realized [10]. Data stored in the output file can be used for different measures calculations.

The presented approach to simulation can be enhanced to global hybrid system to analyze the DTS (Fig. 6). We are going to create the modules to combine the economic aspects, dispatching problems and the feedback from the actual situation noticed in the system manoeuvre.

6. System Availability

One can define the availability in different ways, but the value of availability can always be easily transformed into economic or functional parameters perfectly understood by owner of the system.

The availability is mostly understood as a probability that the system is up and is defined as a ratio of the expected value of the uptime of a system to the observation time. It is a simple definition but it requires defining what it means that the transportation system is working.

The similar metric is the acceptance ratio defined by information as a number of accepted requests to the total number of requests.

In paper [16] we have proposed the definition of up time as a time when the number of delayed containers does not exceed a given threshold. Let us introduce the following notation:

- T –a time measured from the moment when the container has been introduced to the system to the moment when the container has been transferred to the destination (random value),
- T_g – a guaranteed time of delivery, if exceeded the container is delayed.
- $N_{delayed}(t)$ – a stochastic process describing the number of delayed containers at time t, i.e. the number of containers for which $T > T_g$.

Therefore, the functional availability $A_k(t)$ can be defined as a probability that the number of delayed containers at time t does not exceed k, the value k is the level of acceptable delay:

$$A_k(t) = \Pr\left\{ N_{delayed}(t) \le k \right\}. \tag{17}$$

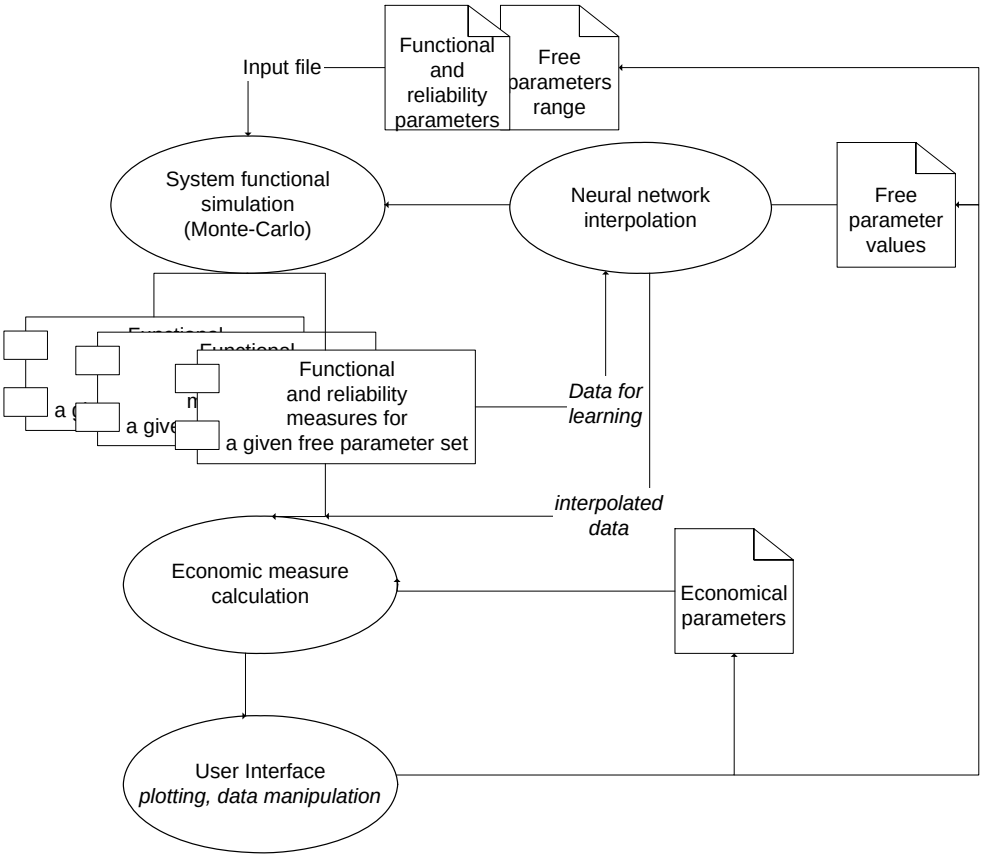

Figure 6. Idea of the global hybrid system for DTS analyzing

7. Case Study

For testing purposes of the presented system (section 2) exemplar transport system has been proposed. It consists of one central node (city Wroclaw, Poland) and three ordinary nodes (cities nearby Wroclaw: Rawicz, Trzebnica and Opole). The distances between the nodes have been set approximating the real distances between used cities and they equal to: 85, 60 and 30 km. We assumed a usage of 5 trucks (two with capacity set to 10 and three with capacity 15) with mean speed of 50km/h.

The vehicles have 19 trips a day: from the central node to the ordinary node and the return trip (i.e. Wroclaw-Opole). Failures of the trucks have been modeled by exponential distribution with mean time of failure equal to 1000h.

The repair time has been modeled by normal distribution with mean value equal to 2h and variance of 0.5h. The containers addressed to the ordinary nodes have been available in the central node at every 0.5, 0.4 and 0.3 of an hour respectively. Containers addressed to the central node have been generated at every 0.6, 0.4, and 0.3 of hour in the following ordinary nodes.

There has been a single maintenance crew. The availability of the system $A_k(t)$ has been calculated with guaranteed time $T_g = 24$h and parameter $k = 20$. Basing on 10 000 time simulations (in each 100 days) the availability of the system has been calculated. The results presented in Fig. 6, Fig. 7 show the periodic changes.

The situation is an effect of used method of containers generation. The containers are generated during all day (by Poisson process) but according to the management system assumptions trucks do not operate at night. The probability of delay increases at night, but the selected number of trucks (5) is satisfactory for the given system. We have also analyzed a system with a reduced number of vehicles (with 4). The resulting value of the availability function is presented also in Fig. 7 and Fig. 8.

It can be noticed that the availability of the system decreases due to the lack of sufficient number of trucks. It should be noticed here that looking at the used management rules and not taking into consideration a randomness of the transport system (failures and traffic jams) only three vehicles can be enough to transport all the generated containers.

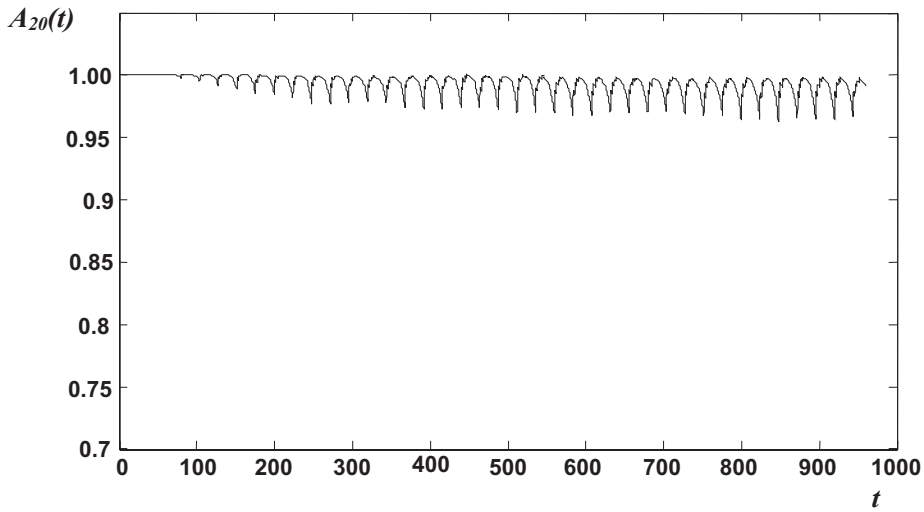

Figure 7. Functional availability of *DTS* – 5 vehicles

8. Conclusion

We have presented a formal model of discrete transportation system (*DTS*) including reliability and functional parameters. The *DTS* model is based on the Polish Post regional transportation system. Using a multilevel-agent based architecture the realistic data are collected and presented in one common language that is an authors' solution.

The proposed description language is helpful for the creation of a computer-aided analysis tools processing according to *DTS* model. The main advantage is the language supporting the further usage of analysis tools.

Moreover, the format of the proposed language is fully expendable since wide support of the *XML* tools. For this reason it can be seen as a base for further (even more precise) system description in case of both dependability and detailed description of the system.

The described architecture can be found as an idea of a tool that can visualize and analyze data, with respect to real parameters. Absence of any restrictions on the system structure and on a kind of distribution describing the system functional and reliability parameters is the main advantage of the approach.

The proposed dependability metrics can be used as an example of an attempt for reaching dependability and functional characteristics as it has been shown in a case study. Further work is to extend the proposed model (DTSML language) with more detailed description that allows even more detailed system specification of its accurate behavior.

The presented solution can be used as a practical tool for defining an organization of vehicle maintenance and transportation system logistics.

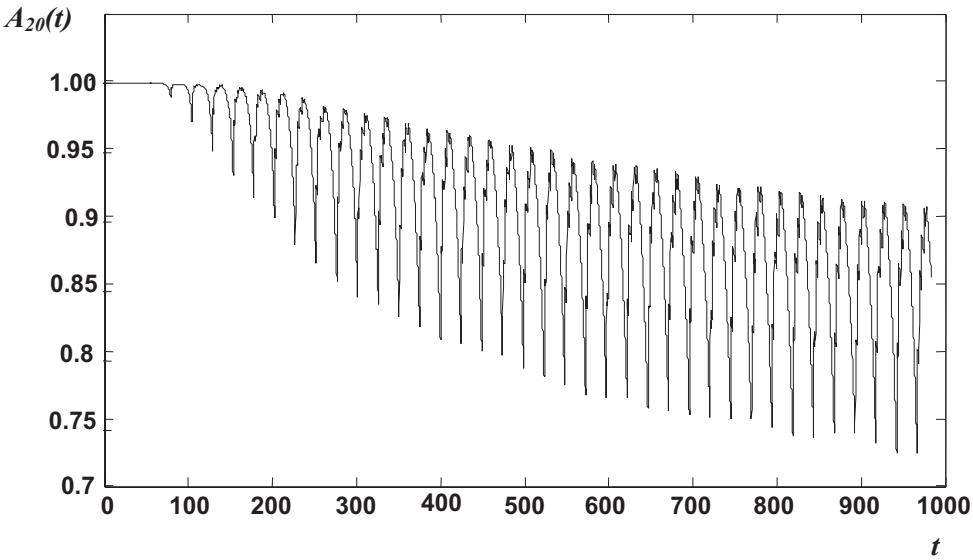

Figure 8. Functional availability of *DTS* – 4 vehicles

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WEIGHT-IN-MOTION (WIM) MEASUREMENTS BY FIBER OPTIC SENSOR: PROBLEMS AND SOLUTIONS

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In the present study the authors are discussing the possibility of fibre optic sensor application for weighing road vehicles in motion (WIM – weight-in-motion). The various factors affecting the accuracy of fibre optic sensors measurement are considered to be: features of the installation in the roadway, the nonlinearity and inertia of the sensor, the thermal effect, the inertial force of the vibrating vehicle and the extremely short time of the load standing on the sensor. The examples of the record signals, transferring to a fibre optic sensor, are made. The analysis of the causes of measurement error and possible ways to improve the accuracy of weighing for the solution of the pre-selection of road vehicles in motion upon the dynamic load on the axis is submitted.

Keywords: intelligent transport system, vehicle detection, weight-in-motion, fibre optic sensors, dynamic measurement, digital signal processing

1. Introduction

The growth of the level of traffic intensity in the European Union countries, the creation of the traffic control intelligent transport systems (ITS) and problems of maintaining the quality of road surfaces have led to the creation of sensor networks for weighing road vehicles. The capacitive, piezoelectric and strain gauge sensors [1], with a relatively high cost and low lifetime (10 years) are mainly used as such sensors.

In the last decade the weight fibre optic sensors, based on the change in the optical signal parameters due to optic fibre strain under the weight of a passing transport vehicle [2], have gained popularity. These sensors are more durable, they are relatively cheap in manufacture and operation. However, they are mainly used as detectors for vehicles because of the low accuracy of weight measurement (especially weight-in-motion) and high dependence on weather conditions.

In the 1990s the weighing and control of transport in motion systems using fibre optic force sensors appeared. Their usage was justified by the low cost and ease of installation on roads with heavy traffic. Fibre optic cables are placed in narrow grooves across the road and are filled with resilient rubber, transmitting the tyre pressure on the cord. The traffic flow should not be interrupted for a long time, so the ease and speed of the sensors' installation outweighed its drawback – low measurement accuracy. The tasks of weight-in-motion systems are the following [2]:

- Sorting of vehicles by type with the accumulation of statistics. This allows us to determine the traffic load and load on the road surface during the specified periods of time;
- Selection from the traffic flow of vehicles, axes of which, according to system indicated value, exceed the axle weight limit. After weighing the vehicle on more accurate scales, it is released, but it is assessed upon violation of rules.
- Transfer of the statistical data into a centralized system of transport accounting and traffic management in the region.

Analysis of current trends on WIM issues indicates that optical sensors, which are more reliable and durable in comparison with tensor and piezoelectric, are based on two main principles:

- Bragg grating (the change of diffraction in a channel under deformations)
- Change under deformations of the fibre optical properties (transparency, frequency, phase, polarization). It is the change of transparency (the intensity of the light signal) which is used in the SENSOR LINE SPT experimental sensors [5] on which these studies were carried out.

2. Operating Principles of the Fibre Optic Force Sensor

The fibre optic force sensor is a cable consisting of a photoconductive polymer fibres coated with a thin light-reflective layer (Fig. 1). A light conductor is created in this way, from which the light cannot escape. If you direct a beam of light to one end of the cable, it will come out from the other end, and in this case the cable can be twisted in any manner. It is known that such light conductors are widely used in medicine for the illumination and examination of human internal organs.

In order to measure the force acting on the cable, somehow you need to change and measure the characteristics of the light beam when the load changes. For this purpose, different technology is used, which is based on well-known principles of physics [2]:

- the phase technology with a coherent source of radiation, in this case the phase shift of the outgoing beam with respect to the incoming beam is measured
- the tunnel technology, using the physical effects, which occur when the light passes through a small hole;
- the polarization technology, measuring the change in the polarization of light in case of the light conductor geometry changing under the load;
- the spectral technology, responsive to changes in the spectral characteristics of optical path under a load;
- the amplitude technology, which measures the optical path intensity, which changes while pushing on the light conductor along its points.

At these points the deflection of a light conductor and reflective coating occurs, that is why the conditions of light reflection inside are changed, and some of it escapes. The greater the load – the less light comes from the second end of the light conductor. Therefore the sensor has the unusual characteristic for personnel, familiar with strain gauges: the greater the load – the lower the output is. Apart from the fact that it is reversed and in addition to this it is non-linear.

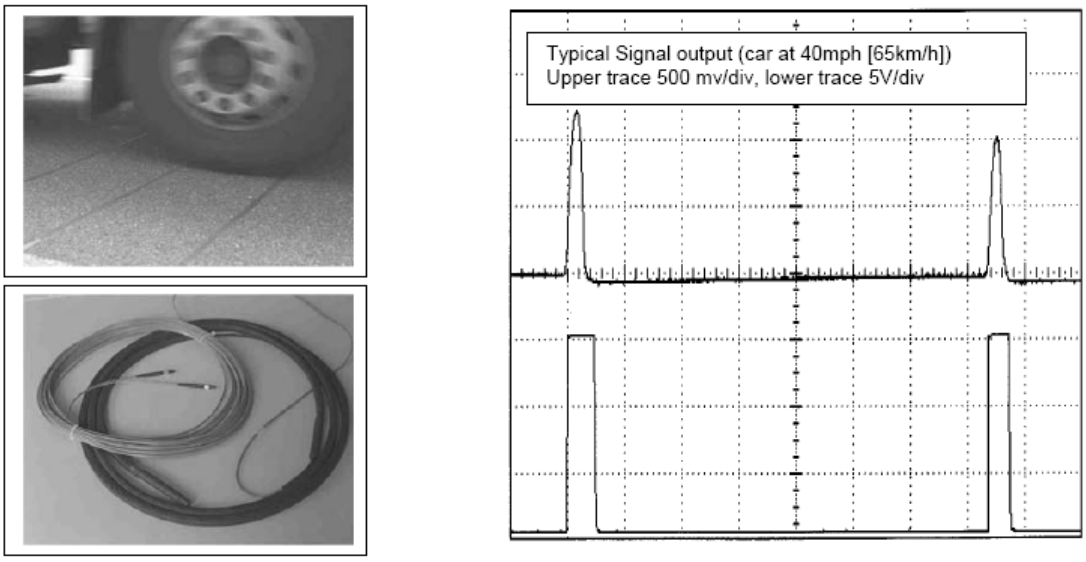

Figure 1. Location and waveform of the SENSOR LINE SPT fibre optic sensor [5]

All the aforementioned technologies, except for the last one, feature complex electronic circuits and algorithms which convert the physical effect change in the electrical signal of the required form. They are highly accurate but expensive in cost and difficult to configure and calibrate. Therefore the sophisticated technologies are not widely used in real structures. At the same time the amplitude technology is simple in the technical implementation and cheap in cost, but it has low accuracy. In the present article only the amplitude technology, which by means of using cheap microelectronics can overcome its drawbacks, while maintaining all the advantages, will be covered.

3. Sensor Output Characteristics

Load characteristic was measured from the SENSOR LINE SPT fibre optic sensor by means of a SL Transducer (optical interface) optical signal analyser developed by SensorLine GmbH [5]. The measuring length of the sensor was 49 cm, and the special instalment was made for the experiments. The optical signal analyser, which is connected to the sensor, has a transmitter and receiver of the light beam, as well as an electronic circuit which converts the change of the optical path to voltage change. The load was varied from 0 to 60 kg in a pitch of 10 kg. The results of one experiment are presented in Table 1. The data received from other experiments was similar.

Table 1. Load characteristic of the SENSOR LINE SPT [5] fibre optic sensor

Load, kg	**0.0**	**10.0**	**20.0**	**30.0**	**40.0**	**50.0**	**60.0**
Output signal, V (load)	**6.22**	**5.00**	**4.10**	**3.15**	**2.27**	**1.70**	**1.07**
Output signal, V (unload)	**6.21**	**4.73**	**3.66**	**2.90**	**2.09**	**1.58**	**1.07**

A graphic representation of the received experimental data is presented on Fig. 2, where the solid line is the load characteristic, and the dashed line is unloading characteristic. As it can be seen from the figure, the sensor has a nonlinear output characteristic and significant hysteresis, which reaches 10.7-10.9% in the middle of curve lines. A common feature of numerous data, obtained in experiments, is that as far as the load increases, the first derivate of load curve line approaches to 0, reminding an exponent by itself. Therefore the increase of the output voltage under heavy load does not make it possible to reliably distinguish one load from another:

$$\Delta U / \Delta G = k \to 0, \qquad \Delta U = \Delta G \cdot k \to 0 \tag{1}$$

Consequently, even if you use this sensor with the analyser as the threshold device in order to select the overloaded axes, one cannot guarantee it will work consistently.

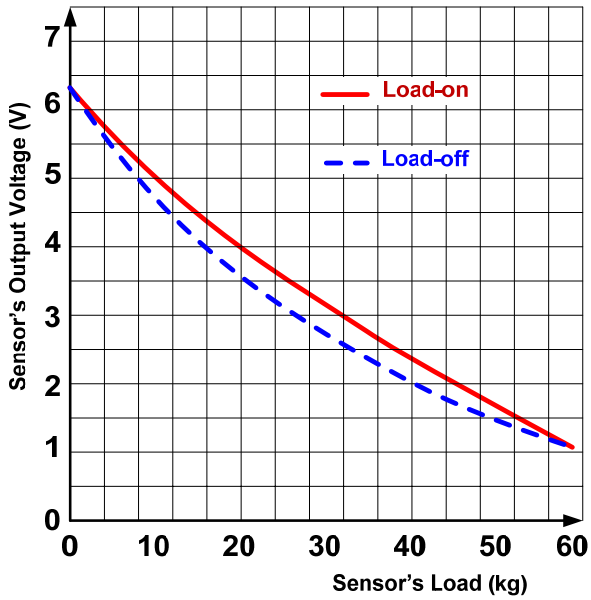

Figure 2. Output characteristic of the fibre optic sensor: solid line is the load characteristic, and the dashed line is unloading characteristic

The approximation upon the least square method of the stress sensor output U from the applied load F by the second-order polynomial during the load increment gives the following expression:

$$U(F) = 5.642845 \cdot 10^{-4} \cdot F^2 - 0.119143 \cdot F + 6.19929. \tag{2}$$

Modern microelectronics, particularly the PIC-processors, make it possible to overcome this drawback and to create an optical signal analyser with a linear output characteristic. Such an analyser

together with the fibre optic sensors will find use not only in vehicle weigh-in-motion systems, but also in many other spheres of industry, agriculture, medicine and everyday life. The guarantee of this is the fact that all currently existing monitors of strain gauge scales are adapted for use with strain gauge sensors having a linear characteristic of direct action: the more power – the more output. If you set a goal to replace the expensive strain gauge sensors with the cheap fibre optic sensors, the fibre optic sensors should have similar characteristics. Only this property allows fibre optic sensors to compete with strain gauge sensors and will not specify any special requirements for existing monitors. In other words, the weighing system does not have "to be aware of" the replacement of sensors.

In the overwhelming majority of applications the presence of hysteresis is not an obstacle, because the weights user is only interested in weighing the load, laid on the scales. For example, during the multi-component dosing the weight loading is gradual, with interruptions – a component by component. But as for the process of unloading, when the scales bottom is opened, nobody cares. After unloading the pause is performed, the scales are "reset" and the next weighing begins. As you can see, hysteresis does not get in the way.

The different picture can be seen in the axis weighing systems of vehicles in motion. Several axes of one vehicle or multiple axes of traffic flow can pass through the sensor in a very short period of time when the vehicle speed is high. In this case the load changes from zero to maximum values. Therefore the deformed sensor needs to recover in time before it will be crossed by the next wheel set. The ideal for this application would have been the sensor, generally with no hysteresis. The task of creating elastomeric polymer light conductor, changing the transparency under the loads, arises from that fact.

4. Principles of Weighing the Vehicle in Motion

As was mentioned above, fibre optic load-measuring cables are placed in gap across the road and are filled with resilient rubber. The gap width is 30–50 mm. Since the sensor width is smaller than the tyre footprint on the surface, the sensor takes only part of the weight axis. Two methods are used in the existing systems to calculate the total weight of the axle [1]: the Basic Method and the Area Method. The following formula is used to calculate the total weight of the axis using the Basic Method:

$$\boldsymbol{W_{ha} = A_t \cdot P_t}, \tag{3}$$

where

$\boldsymbol{W_{ha}}$ – weight on half-axle,
$\boldsymbol{A_t}$ – area of the tyre footprint,
$\boldsymbol{P_t}$ – air pressure inside the tyre.

As you can see the exact values of the formula factors are unknown. The area of the tyre footprint is calculated roughly by the length of the output voltage impulse, which in its turn depends on the vehicle speed. The manufacturer's recommendations for the given vehicle type are used as pressure in the tyre.

The Area Method uses the assumption that the area under the recorded impulse curve line, in other words – the integral, characterizes the load on the axle. To calculate the integral, the curve line is approximated by the trapezoid. In this case the smaller the integral – the greater the load. This method does not require knowing the tyre pressure, but it requires the time-consuming on-site calibration. Also keep in mind that the time of the tyre passing on the sensor is too small to get an electrical signal of high quality for its further mathematical processing.

Evaluating this method and the methods of calculating the weight of vehicles in motion, one should expect very low accuracy. This is confirmed by the studies conducted at the Florida Institute of Technology (*Florida Tech*) [2]. To calculate the weight of the vehicle the Basic Method was used. The results are the following:

- front half-axle weighing errors – from –11 to +7%;
- rear half-axle weighing errors – from +8 to +36%;
- vehicle weighing error – from –1 to +18%.

If the Area Method is used, the errors turned out to be even greater: the measured and calculated weight of the vehicle was different from the real within the range from –43 to +37%.

As it turned out, the errors are highly dependent on vehicle speed and its low-frequency vibrations on the springs, in other words, on the inertial forces affected the sensor. In this regard the International Recommendation [4] contains the requirement that the road within the length of at least 30 m should be flat and horizontal before the scales approach. This reduces the vertical vibration of the vehicles and lowers the dynamic errors.

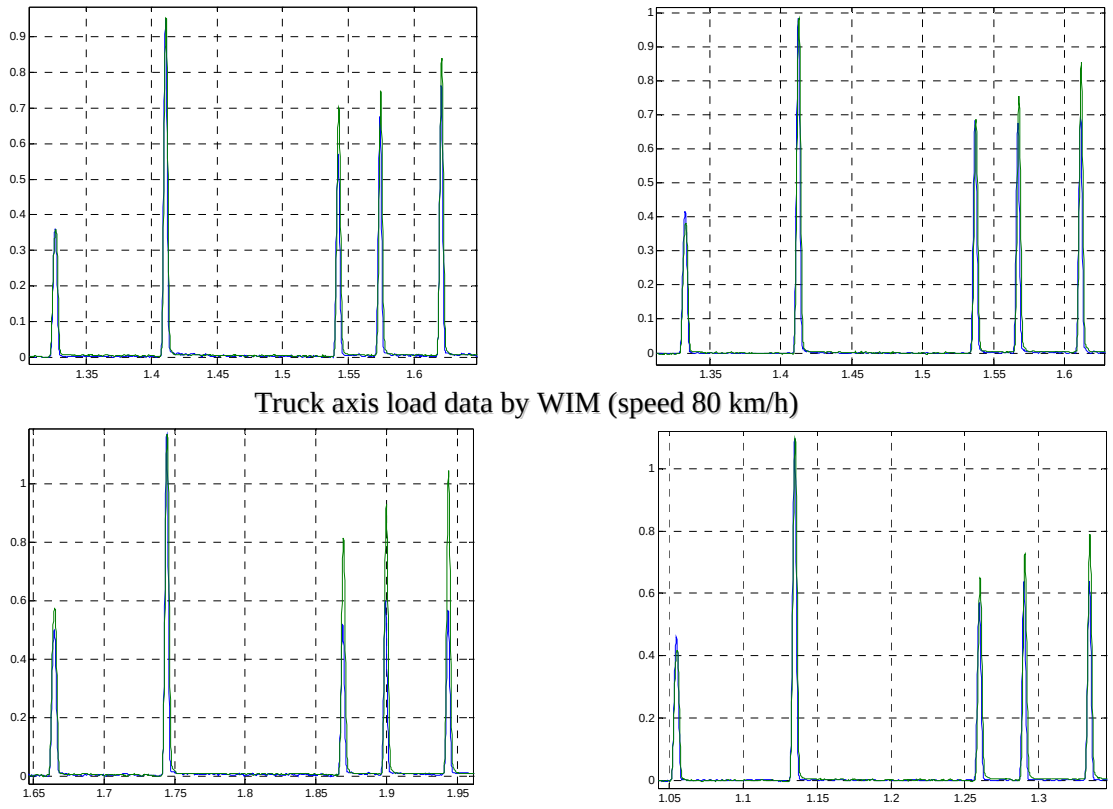

Figure 3. Examples of fiber optic WIM sensor after testing truck (5 axes) with the same speed (80 km/h)

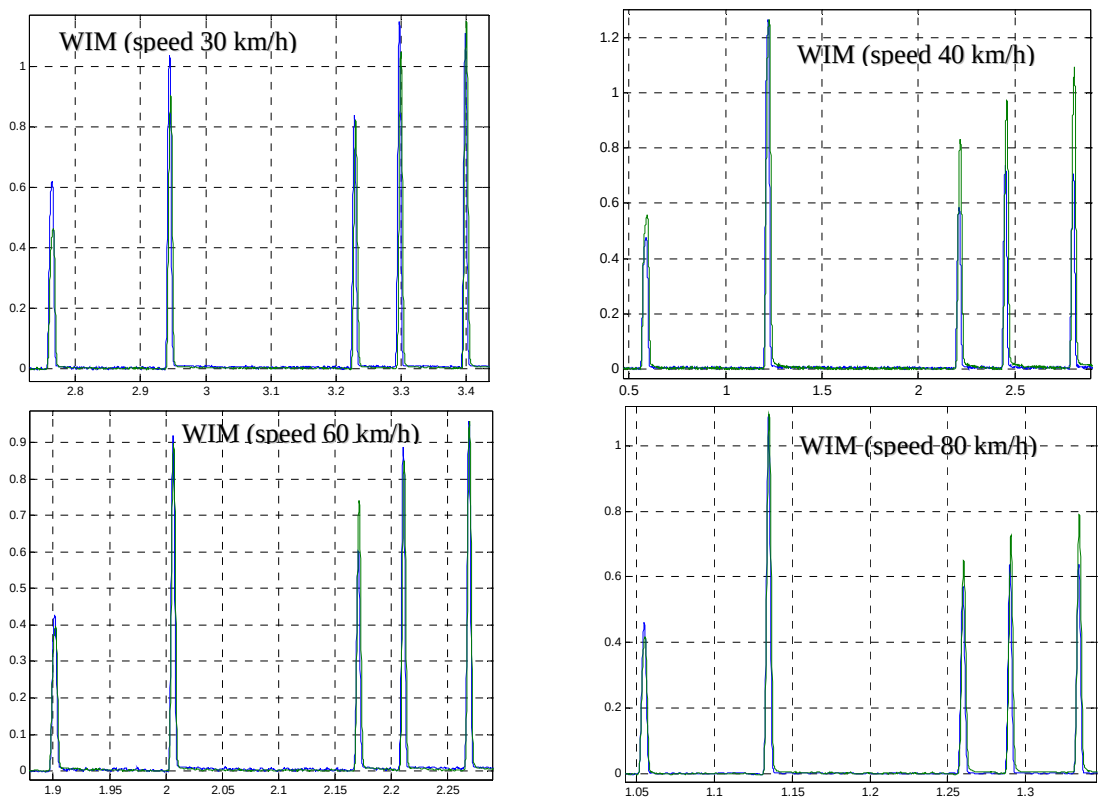

Figure 4. Examples of fiber optic WIM sensor after testing truck (5 axes) with various speed (30–80 km/h)

It is commonly known that the gap in the roadway is filled with resilient rubber after placing the cable in it. The resilient rubber slowly takes its original shape, so the sensor gain is lowered under frequent periodic loads.

From the aforementioned it follows that the substantial systems can only capture the moment of vehicles passage and carry out its rough sorting by class in the operating principle. The usage of fibre optic sensors in these systems is possible, but all of the aforementioned drawbacks will remain. Obviously that the firms, offering such methods, consider it permissible to put up with these drawbacks for the sake of simplicity and cheapness, not only the sensors itself but the ways of its laying on the road as well. However, to create scales with an accuracy of less than 5% the different approaches and methods are required. The obvious solution, which is devoid of the main drawbacks of the cable systems, is the platform version of the scales using the same fibre optic sensors.

It should be noted that the platform versions are also available, but they are fundamentally different from the classic design, that's why they retain the main drawbacks of the cable systems. The classic platform scales of axle weighing allow the axle to weigh, not to calculate its approximate weight. The platform width is typically less than 70 cm and is determined by the distance between the axles of the coupled suspension and tyre footprint width. It is obvious that such scales are more expensive than the cables placing in the road surface. However, the fibre optic sensors, installed in them instead of the strain gauge sensors, greatly simplify their design and reduce the cost. Furthermore, and it is more significantly, with the accurate scales on the road, the installation of expensive precision balance on the parallel road near the Point of weight control will not be required. With the help of the precision balance on the road it will be an accurate sorting and the weight of the vehicle will not be needed to retest. At the same time the highway capacity will be significantly increased, because the control scales and the queue to them will disappear. Such ideal hypothetical option is analysed in [4].

5. Discussion

The accuracy of weighing the vehicle in motion depends on many factors, but the main errors in the existing systems consist of the following: non-linearity and inertia of the sensor, thermal effects, inertial force of an oscillating vehicle and an extremely short time of the load being on the sensor. Therefore, the further improvement of the system should minimize the impact of the aforementioned factors. Possible areas might be:

- the non-linearity of characteristic can be eliminated mathematically by using PIC-processor;
- the thermal effect can be reduced by known methods of temperature compensation and periodical "zeroing" of the output signal;
- the use of platform increases the exposure time of load to the sensors, which facilitates receiving a reliable electric signal;
- the platform design also allows calculating the vehicle speed without implementation of any special sensors;
- the platform design of the scales allows testing the separation method of gravitational and inertial forces by known method used in the naval scale showing the exact weight of the cargo at the ship pitching. It may be possible to exclude the influence of the inertial forces caused by the vehicle vibrations on the spring suspension.

The aforementioned possible ways of increasing the accuracy of weighing vehicles in motion were used by the authors in the previous works and there is no doubt in their implementation and effectiveness.

While measuring the mass (weight) of vehicle in motion (Weight in Motion – WIM) the information only about the pressure, exerted by this vehicle to the sensor, laid deep into the road bed, is not enough, according to the well-known indeterminacy principle. The accuracy of weighing a vehicle in motion depends on many factors, but the main errors in the existing systems consist of the following: non-linearity and inertia of the sensor, thermal effects, inertial force of an oscillating vehicle and an extremely short time of the load being on the sensor.

At the present time fibre optic load-measuring cables are placed in gap across the road and are filled with resilient rubber. The gap width is 30–50 mm. The familiarization with the existing systems leads to the following conclusions:

- the width of the sensor is smaller than the tyre footprint on the surface, so it carries only part of the axle weight (see Fig. 3), and what is more, the tyre surface is uneven – it has a notch;
- the tyre transmission time on the sensor is too short to get an electrical signal of high quality for its further mathematical processing;

- due to the fact that the gap in the roadway after laying the cable in it is filled with resilient rubber, the sensor has a non-linearity and hysteresis. The resilient rubber slowly takes its original shape, that's why the sensor gain is changed by frequent periodic loads;
- the real system with fibre optic sensors are successfully applied only to control the traffic flow, considering that high error of weighing a vehicle in motion, namely up to 30% (see Fig. 4), makes it possible only to capture the moment of vehicles passage and carry out its rough sorting by class.

One of the solutions to solve the problem is the platform construction of the sensors instalment, which also makes it possible to calculate the vehicle speed without application of any special sensors, and the separation of gravitational and inertial forces is possible by known method used in the naval scale showing the exact weight of the cargo at the ship pitching.

At the same time, when the vehicle is in motion, the deformation of the road surface occurs, accompanied by vibrations and movement of the road surface in the horizontal plane. With high sensitivity of the sensor, the sensor responds to the deformation of the road surface earlier than the vehicle, and it will immediately put pressure on the sensor.

That's why **the second solution** is a joint information processing about the deformation of road surface and the sensor pressure makes it possible to determine (with a tolerance probability) class of the vehicle (light or freight), its speed and weight.

To register the deformation of the road surface while a vehicle is in motion, probably one may need a special way to fix the sensor in the road bed in order to increase its sensitivity to loads in the horizontal plane.

The mathematical tool for the aforementioned joint information processing about the deformation of road surface and sensor pressure is the correlation and spectral analysis of random processes treatment.

The processing algorithms should use a priori data:

- about the differences of radial wheel sizes, the distances between the wheel pairs, tyre pressure, load distribution between front and rear light and freight wheel drives, etc.;
- the statistical data about the interrelation of wheel sizes, distances between wheel pairs, tyre pressure, load distribution between front and rear wheel drive of the vehicle, moving at a certain speed and the sensor response to the deformation of road surface, and also the pressure exerted by a vehicle in motion.

Such data should be obtained by the experimental and expert ways, and they should make a certain database for the application of the correlation analysis methods in solving the aforementioned tasks of determining the type of the vehicle, its speed and weight.

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BASIC CONCEPT OF THE TECHNICAL STUDY OF THE TRAFFIC CONTROL SYSTEM IN PREŠOV

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The project „Support Programme for the development of intelligent transport systems – National Traffic Information System for Slovakia“ also includes implementation of ITS of 11 chosen Slovak urban agglomerations. For the purposes of this project Technical study document for each town was elaborated in the first phase. The Technical study analyses existing and expected situation, defines critical localities on the basis of this analysis, which is necessary to solve and defines a framework for solution and its technical characteristics, respectively different alternatives of solutions. The article describes the current state of the ITS in the Slovak Republic, the scope of the Technical study of urban ITS and an ideological proposal of the Traffic Control System (TCS) in Prešov town, which has been elaborated at the author's' workplace. The urban ITS with respect to main goal – capacity increasing of existing urban road network and traffic congestion reducing – has been designed. In the article, functions and connections of all subsystems of TCS Prešov, their location within the town and connection to the NTIC (National Traffic Information Centre) master system are described in more details.

Keywords*:* intelligent transport system, ITS, traffic control system, detection system, traffic control centre

1. Introduction

The mobility of inhabitants and degree of motorization was increased not only in other developed countries but also in Slovakia. This has resulted in increased traffic loading and overloading of existing urban road networks. Problems are most evident in towns where there is a growth in traffic congestions, traffic accidents and negative impacts on the environment. Intelligent Transport Systems (ITS) implementation is one of the ways to effectively use the existing road network in the towns and increase its capacity and safety [1].

ITS is inevitable within the state, thus in towns, to be built in coordination and consistently on basis of interoperable systems based on open and public standards. Design of urban ITS in Slovakia must be in accordance with the „Support Programme for the development of intelligent transport systems – National Traffic Information System for Slovakia“ in accordance with the resolution of the Government of Slovakia No. 22/2009 dated 14.01.2009. The framework for implementation of the National Traffic Information System (NaTIS) was established within this Program.

The part of the proposed system environment NaTIS is implementation of ITS in 11 chosen towns in Slovakia. For the purposes of this project Technical study document for each town was elaborated in the first phase. The Technical study analyses existing and expected situation, defines critical localities on the basis of this analysis, which is necessary to solve and defines a framework for solution and its technical characteristics, respectively different alternatives of solutions.

The article describes the current state of the ITS in the Slovak Republic, the scope of the Technical study of urban ITS and an ideological proposal of the Traffic Control System (TCS) in Prešov town, which has been elaborated at the author's' workplace. In the article, functions and connections of all subsystems, their location within the town and connection to the NTIC (National Traffic Information Centre) master system are described in more details.

2. Design of Urban ITS as a Part of NaTIS Project

Compared to the Slovak Republic some advanced EU countries have already had for several years operational systems enabling reception and distribution of relevant information related to road transport not only on domestic roads, but also on interstate roads. Although Slovakia is for a relatively long time a part of the EU, in the field of creation and mainly exchange of traffic information with foreign countries it is significantly behind. The situation should by improved by creating a National Traffic Information System, which should be a complex system environment for acquisition, processing, sharing and distribution of traffic data from information and communication systems and technologies on the road network in Slovakia.

To ensure the basic functionality of NaTIS Slovakia, four realisation domains presented in the figure 1 were allocated. Moreover, they could be built separately and in future connected to each other:

- **Implementation domain of NTIC** – central system for securing the acquisition of traffic data from various agent based information and telematic applications, processing, exchange, publication and distribution of traffic data,
- **Implementation domain of Production and acquisition of information** – central evidence system of closed roads, system of planned road servicing, agenda system of oversize and dangerous cargo, etc.,
- **Implementation domain of ITS of main roads** – extension of technological equipment and improvement of telematic applications on main roads (mainly, the I. class roads) which secure the detection of traffic flow characteristics, automatic traffic counting, queue detection, acquisition of the meteorological data and state of road surface.
- **Implementation domain of ITS of agglomerations**.

From the viewpoint of ITS implementation in towns, the essential part of NaTIS project creates the 4-th realisation domain which represents solution of integrated ITSs systems for 11 chosen agglomerations in the Slovak Republic. The third biggest town Prešov has been chosen, too. Currently, in the Slovak Republic no integrated urban ITS has been completed and made functional yet.

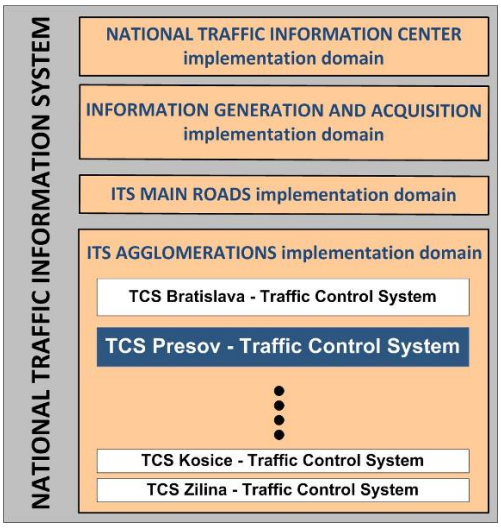

Figure 1. Realisation domains of NaTIS project

3. Basic Steps of ITS Agglomerations Implementation – Technical Study

In ITS systems design the process shown on Figure 2 was generally accepted in accordance with the technical regulation TP 09/2008 [2], where the phased process of ITS systems creation (a necessary design documentation process) is described. These stages are closely related to each other and result in an integrated implementation of transport systems that are solving the transport service for a defined territory.

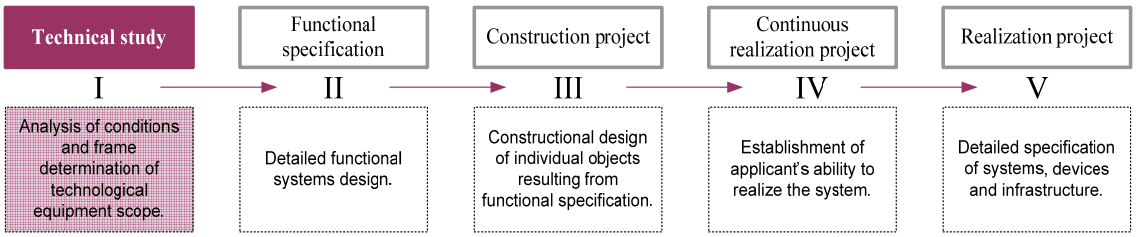

Figure 2. Phases of ITS implementation

For realisation purposes of the NaTIS project it is necessary in the first phase of implementation domain of ITS agglomerations to elaborate the Technical study (TS) for each town agglomeration, i.e. a document which:

- analyses the existing and expected situation,
- defines problems on the basis of this analysis, which is necessary to be solved,
- defines a framework for solution and its technical characteristics, or different alternatives of solutions.

The aim of TS is an analysis of external conditions in particular solving urban area of agglomeration (Table 1) and framework for determination of the extent of technological equipment (Table 2) in terms of the technical regulation TP 09/2008 [2] and instructions of the Slovak Road Administration (SRA). The SRA is actively taking part in the NaTIS project. A prognostic period of TS is 10 years.

The minimal range of external conditions analysis is as follows:

- classification of individual road sections,
- constructional properties of roads,
- identification of road sections in which capacity is reduced (according to TP 10/2010) because of objective or subjective reasons,
- identification of critical locations from traffic point of view,
- identification of critical locations from meteorological point of view,
- determination of sections from which traffic has to be instantly excluded in case of need,
- determination of network control need,
- constructional properties analysis of tunnels (for each tunnel separately),
- analysis of other important factors.

The range of a basic framework design infrastructure is as follows:

- power supply infrastructure,
- communication infrastructure and
- operator workplaces equipment.

In an analysis of external conditions, the following primary inputs have been considered: analysis of construction conditions and traffic volume of the road network, capacity analysis of roads and intersections, possibilities of diversion routes, as well as analysis of traffic accidents, weather conditions and the existing state of technology systems. Based on these inputs and analysis is then possible to identify critical points and to consider the merits of ITS implementation with determination of a basic framework and concept of technological equipment realisation.

Minimally the first stages of ITS project documentation, i.e. the Technical study and the Functional specification, for all 11 urban agglomerations have to be ready according to the NaTIS project by the end of 2011. In some urban agglomerations works on the Construction project have already started.

Table 1. The minimal range of external conditions analysis

ANALYSIS OF EXTERNAL CONDITIONS
Classification of individual road sections
Constructional properties of roads
Identification of road sections in which capacity is reduced (according to TP 10/2010) because of objective or subjective reasons
Identification of critical locations from traffic point of view
Identification of critical locations from meteorological point of view
Determination of sections from which traffic has to be instantly excluded in case of need
Determination of network control need
Constructional properties analysis of tunnels (for each tunnel separately)
Analysis of other important factors

Table 2. The range of a basic framework design infrastructure

RANGE OF TECHNOLOGICAL EQUIPMENT
Power supply infrastructure
Communication infrastructure
Operator workplaces equipment

4. The Traffic Control System in Prešov

In this part of the article the ideological design of Traffic Control System (TCS) in agglomeration Prešov is described in general terms [3]. In compliance with the NaTIS project a Technical study of ITS for the Prešov agglomeration has been elaborated at authors' workplace. There are described in more details the functions and links of each system, their localization within agglomeration town and connection with the NaTIC (National Traffic Information Center) master system. The TCS Prešov itself is designed as an open system which enables integration of other systems, such as navigation system for local parking, urban mass transportation etc.

The TCS Prešov has been designed on the basis of detailed analysis of external conditions. An urban road network of Prešov is presented on Figure 3, where examples of external analysis outputs – critical location from traffic point of view and critical location of traffic accidents are drawn. Urban road sections and intersections, not complying with terms of capacity are drawn in red. Based on the results of external analysis in terms of the Slovak Technical Regulation TP 09/2008 [2] (table 1) it was determined a range of technological equipment to enable centralized complex control and influence of traffic flows in agglomeration.

These are the fundamental functions of designed TCS Prešov:

- acquisition of traffic information and data,
- traffic control and navigation,
- operator monitoring,
- providing of information,
- supervision and repression,
- technological revision of operation.

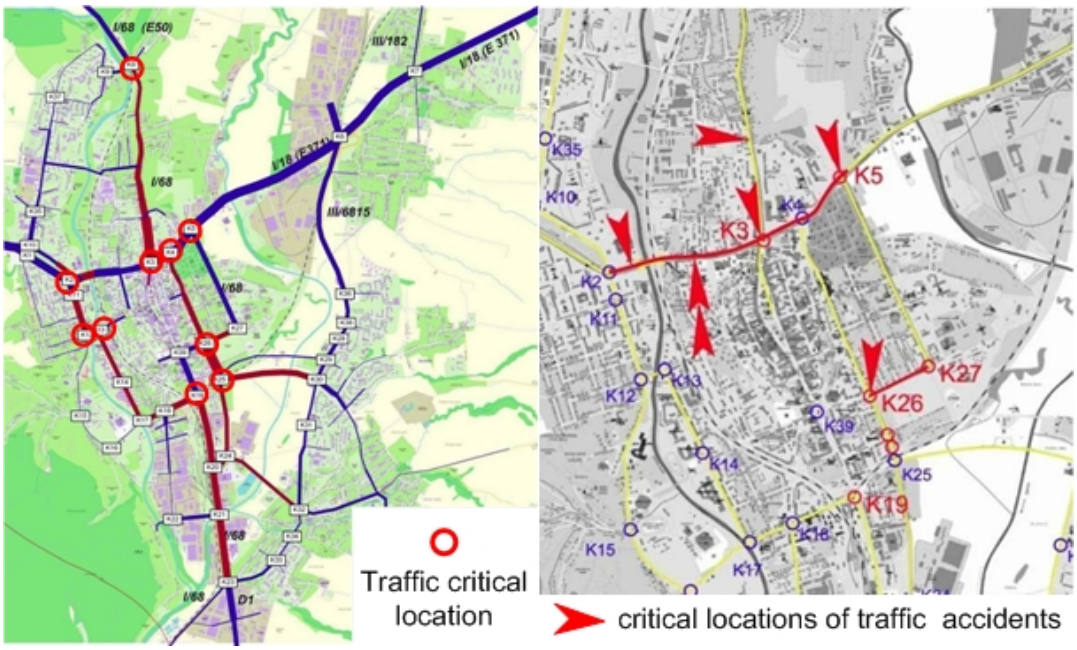

Figure 3. Urban road network of Prešov – critical locations from traffic point of view and critical locations of traffic accidents

4.1. Fundamental subsystems of the TCS Prešov

The main goal of designed TCS Prešov has been to increase capacity of existing road network and to reduce traffic congestions by [3]:

- timely and accurate monitoring of the current traffic situation in a controlled area with optimizing of traffic management,
- increasing the capacity of existing urban roads and intersections for more vehicles,
- reducing the impact and duration of congestion in the controlled area.
- improving of performance and timely problem solving of capacity in emergencies or other emergency states,

- increasing the average speed of vehicles on the roads and reducing the time passing through the city,
- increasing operational efficiency and safety of the travelling public,
- providing sufficient information for road users with a choice of routes,
- cooperating with other transportation management systems (e.g, highway management systems).

To achieve this goal, a complex traffic control system was designed within the frame of Technical Study of ITS Prešov which consists of three basic layers [3]:

- **technological layer**, which consists of technological devices which monitor, inform and control the traffic situation according to directives of the traffic control centre (traffic signal controllers, detectors, variable message signs, monitoring cameras etc.),
- **transmission layer** formed by active transmission and network elements serves for data transmission mediation between the technological and control layer (communication system for data transmission and control from traffic control centre),
- **superior control layer** consisting of the control and visualisation system (components of these systems are concentrated in traffic control centre).

The mentioned three layers – technological, transmission and superior – are for TCS Prešov analytically divided into the following subsystems [3]:

A. Local Traffic Control System – LTCS,
B. Vehicle Detection System (on strategy level) – VDS,
C. Monitoring camera system (Closed Circuit TV) – CCTV,
D. Variable Message Sign System – VMSS,
E. Data Communication Network – DCN,
F. Traffic Control Centre – TCC.

In addition to these systems an Electrical Power Infrastructure (EPI) of all technological devices and meteorological stations were designed in the study.

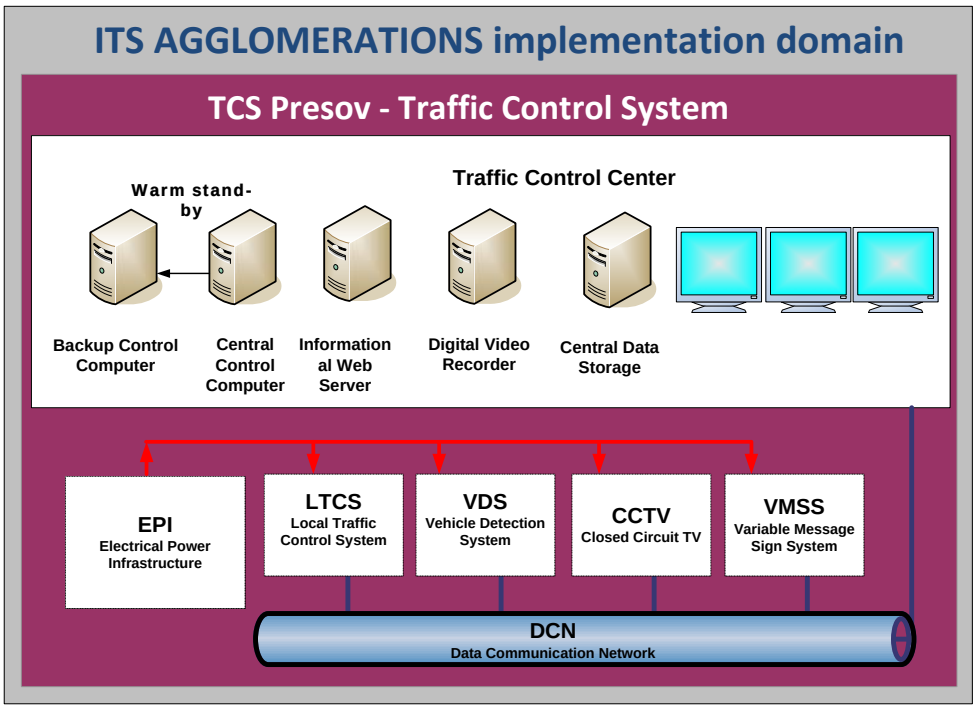

Figure 4. Schematic description of TCS Prešov

The TCS Prešov is schematically shown on Figure 4. Individual components of TCS will be interconnected into a fully functional unit. The TCS Prešov will work on two levels:

- **the operated level** – controlling of traffic flows on local level of traffic node (intersections), eventually several intersections in coordination. The controlling will be optimized on the basis traffic requirements determined by a detection system of intersection traffic controller (Local Traffic Control System – LTCS),

- **the strategic level** – the TCS system will automatically evaluate the current traffic situation on-line detected on detection zones of designed controlled area (Vehicle Detection System on strategy level – VDS). If necessary, a superior system will realize a proper action based on new traffic conditions to optimize control of traffic flows in area. Detection of traffic conditions on this level is realized by a standalone vehicle detection system (independent from the detection system of a traffic light controller) and traffic flows are controlled by traffic light controllers or using variable message signs to redirect traffic flows to alternative routes of urban road network.

Intersections that will be implemented by local traffic control system (LTCS) and also positions where the strategic detectors of traffic detection system (VDS) will be placed within Prešov area are shown on Figure 10.

4.2. Local Traffic Control System – LTCS

The main component of the Local Traffic Control System (LTCS) is a traffic signal controller with its own detection system. Detection system in many cases consists of loop detectors. Detectors are separated from VDS and traffic data are collected in controller for efficiently control signals. LTCS operates traffic signals by optimizing signal display and signal time according to the traffic data in each direction on the road – dynamic (on-line) traffic controlling on the basis traffic demands in real time. Fundamental function LTCS will be to control traffic flow on the road and mitigate traffic congestion by properly controlling signals. There are traffic signal controllers designed on 17 intersections in Prešov – 2 existing traffic lights, 8 reconstructed traffic lights and 7 new traffic lights.

All local traffic signal controllers installed in town will be checked and operated from Traffic Control Centre automatically.

4.3. Vehicle Detection System – VDS

A necessary foundation for traffic control is traffic data acquired from traffic detectors which mediates an image of traffic behaviour in a location requiring traffic-flow control. Primarily the input data for evaluation are the traffic volume, speed and traffic-flow composition. Detected data are evaluated in such a way that they do not only provide information about the actual traffic volume but also predict formation of impulse waves of vehicles or identify traffic accidents.

VDS (Vehicle Detection System) Prešov is a system to collect traffic data on strategy level and consists of traffic survey detectors. These devices are divided according to function:

- Traffic Flow Analyzer (TFA) – traffic survey detector, which function is detecting of immediate characteristics of traffic flow to monitoring and traffic controlling in real time (such as traffic volume, speed, share, time gap, etc.),
- Traffic Incident Detection Device (TIDD) – traffic survey detector, which function is in real time to identify of specified incidents in traffic flow.

The traffic data collected via VDS from traffic detectors TFA or TIDD are provided to the Traffic Control Centre for the purpose of traffic strategy management. There are video detectors designed on 32 locations in Prešov (Figure 10) and this type of detectors cover both functions – traffic flow analysis and traffic incident detection, too.

In addition to TFA and TIDD traffic detectors a Railway Crossing Occupancy Detection (RCOD) has also been proposed within VDS system in Prešov on strategic level.

4.3.1 Railway Level Crossing Occupancy Detection

Within the Prešov town two problematic level crossings of railway and primary road have been identified whose traffic has a direct impact on adjacent road nodes (intersections) and significantly influence the performance of urban road network. The first railway level crossing is located on major road line belonging to the most loaded roads of urban road network not only by internal traffic but also by external traffic (origin, destination and transit traffic). Already in recent times the road sections and intersections on this road are overloaded. The railway level crossing is located between traffic lights controlled intersections and during barriers activation intersects the coordinated set line of controllers. Considering the high frequency of barriers activation mainly during the traffic peak hours long queues of vehicles are formed before railway level crossing with long waiting time. The second railway level crossing is located on an important alternate route to major road line, on which vehicle queue over 1 km long is formed during traffic peak hours. The Figure 5 shows schematic localisation of these railway level crossings.

In both cases from the view of effective traffic control it is desirable on TCS level to provide acquisition, processing and evaluation of data related to occupancy of these railway level crossings. Based on the information from detectors it will be possible using LTCS (Local Traffic Control System) to modify the control on neighbouring intersections and on the intersections of coordinated traffic line. By changing the signal programs with direction preference on intersections directing apart from the railway crossing the queue formation will be avoided and the secondary intersections directions will be depleted. Moreover the VMSS (Variable Message Signs System) enables information of drivers together with the option to redirect the traffic onto alternate routes.

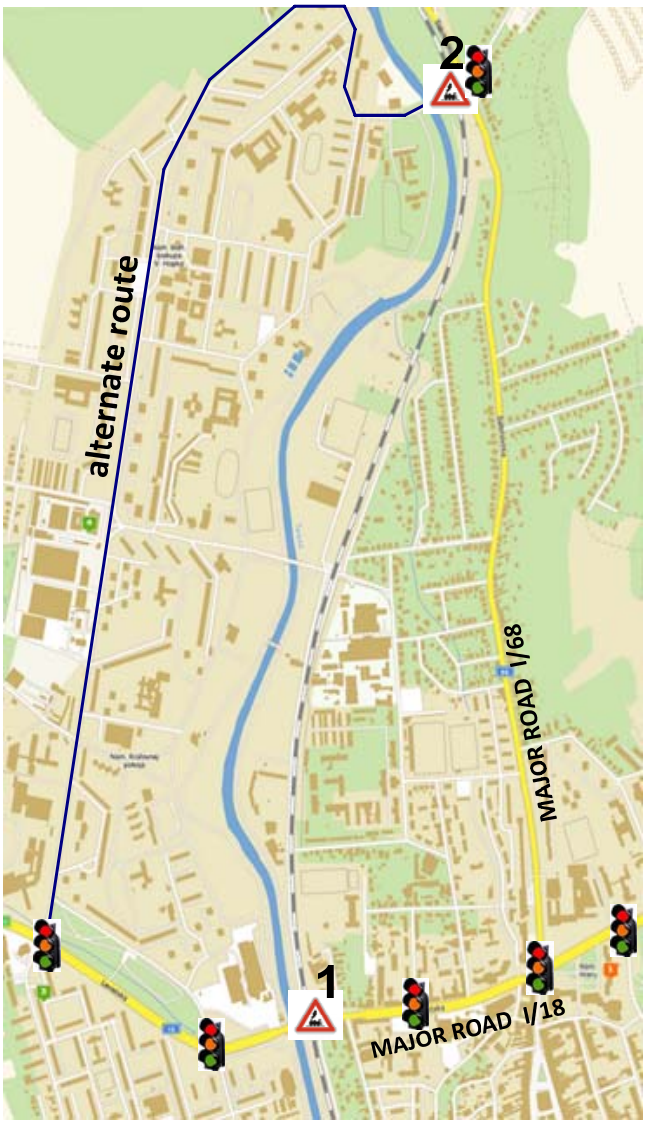

Figure 5. Schematic localisation of railway level crossings in Prešov

During the Technical Study elaboration three possible concepts of railway level crossing occupancy by a railway vehicle have been proposed. In principle two alternatives have been considered: detection of actual barriers activation and indirect detection of road sections in front of the railway level crossing (steady vehicle, queue formation).

Concept 1

The first concept assumes detection of barriers activation using direct linkage to the Railway Level Crossing Device – RCD (Figure 6). The advantage of this solution is high reliability not only from the point of view of safety RCD operation but also from the point of view of information provided. However such a configuration emerged as problematic on the score of direct linkage to the RCD because of valid technical regulations of the Slovak Railways.

Concept 2

The second concept is based on detection of barriers activation, too. However in this case some of the non-invasive detectors are used (Figure 7). This way of detection based on video-detection of actual barriers position (lowered – raised) without affecting the railway crossing device has been evaluated as unsuitable for the given environment because of reduced reliability.

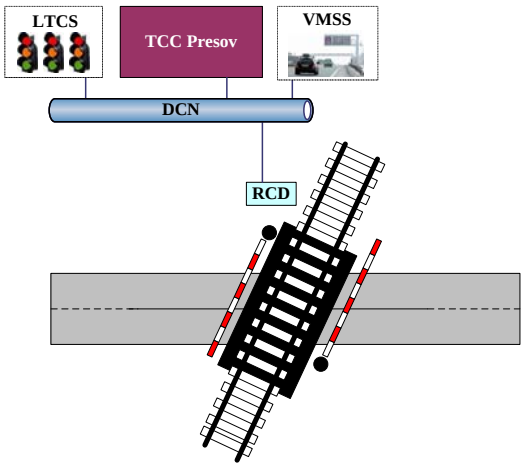

Figure 6. Concept1 – detection using direct linkage to the RCD

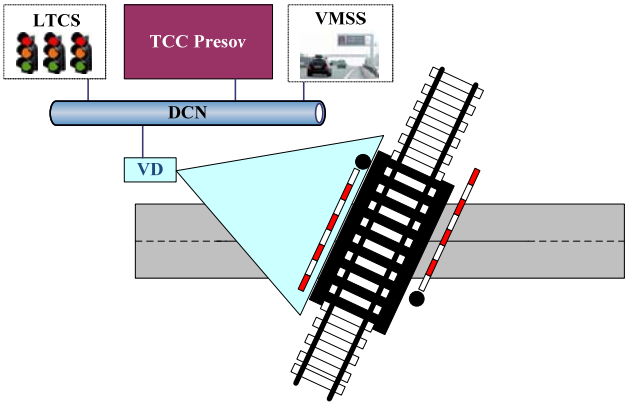

Figure 7. Concept 2 – barrier activation video-detection

TCC Presov – Traffic Control Center, DCN – Data Communication Network, LTCS - Local Traffic Control System, VMSS – Variable Message Sign System, RCD – Railway Crossing Device, VD – Videodetector

Concept 3

The third concept is based on monitoring of traffic situation on the road sections in front of the railway level crossing by an indirect detection using. Non-invasive traffic detectors have been proposed to detecting steady vehicle, vehicle speed, queue formation, etc. (Figure 8). A steady vehicle in coincidence with other fulfilled assumptions means lowered barriers. The advantage of this solution is besides detection of railway crossing occupancy also the possibility of additional utilisation of measured traffic data in the TCS Prešov system. At the same time such a detector becomes a push-forward element of neighbouring intersections.

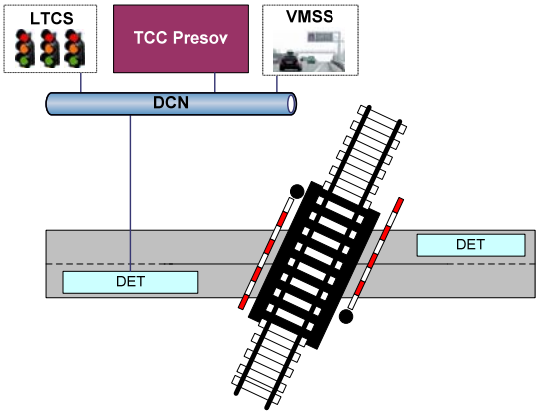

Figure 8. Concept 3 – indirect detection by non-invasive traffic detectors using

TCC Presov – Traffic Control Center, DCN – Data Communication Network, LTCS – Local Traffic Control System, VMSS – Variable Message Sign System, DET – Non-invasive Traffic Detector

In principle all concepts include the Railway Crossing Occupancy Detector (RCOD) from which data is sent by the proposed Data Communication Network (DCN) to Traffic Control Centre Prešov. After processing and evaluation data the control commands are automatically sent to the controllers of adjacent intersections. Moreover information about permanent crossing occupancy can be sent to the system of Variable Message Signs in order to increase the awareness of drivers about the traffic situation in town or to redirect them to the alternate routes.

Regarding the timeliness of the provided information the detection of actual barriers activation is preferable. Of course, a mutual combination of the proposed solutions is possible, which would include the information about lowered barriers complemented by traffic information on the road sections in front of the railway crossing.

4.4. Monitoring camera system – CCTV

Monitoring camera system is created by Closed Circuit TV (CCTV). CCTV is a system for monitoring traffic situation of selected roads and intersections, for visually and simultaneously checking it at traffic information centres when incident or emergency happens, for helping road-users and for performing a road safety function. Considering this, CCTV is designed on 17 locations and there are rotary DOME cameras designed (Figure 10).

4.5. Variable Message Sign System – VMSS

Variable Message Sign System (VMSS) is a system to inform road users about road and traffic states, car accidents, closed roads or road construction information in real time. Variable message signs are applied for reroute traffic flow to alternative routes from overloaded roads, too. VMSS is designed for three purposes in Prešov:

- to regulate traffic flow – reroute traffic to alternative routes,
- to control traffic flow and
- to inform road users.

The informing drivers, the warning about existing congestions and diverting traffic on alternative routes is possible by change of certain symbols or messages on VMSS. There are VMSS (prismatic or LED) designed at 5 locations in Prešov (Figure 10).

4.6. Data Communication Network – DCN

The created communication network infrastructure formed by optical network (Figure 9) will serve for network transmission of data between traffic (operator) centre and technological devices (TD) combined into technological nodes [4, 5]. The technological node is according to configuration able to support several TDs like vehicle detector, variable traffic sign, traffic controller, surveillance CCTV camera, etc.

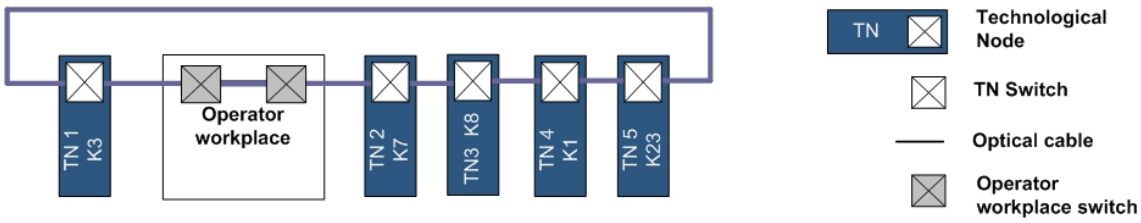

Figure 9. Private backbone network (L1 type) TCS Prešov

4.7. Traffic Control Centre – TCC

The Traffic Control Centre is a place concentrating the initial care of traffic controlled area. It is intended for application domains for traffic data processing, traffic control and monitoring of the entire traffic control system. It operates all technological devices and ensures archiving of all events by a record system. In this location the momentary technical conditions of all devices in traffic controlled area are monitored and where necessary an intervention is decided. The central control system inputs within its competitions actively into traffic control in the controlled area in full-automatic mode. The competent dispatching worker – operator can perform, based on supporting systems results, an adequate intervention to traffic control by either inputting the necessary data (for example about a traffic accident) into the automatic control system, or by a direct manual action. A direct manual intervention into control has to be limited by access rights so that it could be performed only by operators disposed of the corresponding legislative authority (Slovak Police Forces members).

From practical perspective within traffic control in a town a main function is examined – optimisation of traffic flows in controlled area together with control of critical or emergency states. For on-line control it is necessary to ensure that the Traffic Control Centre in Prešov has actual information not only from TCS subsystems (LTCS, VDS, eventually CCTV), but also from the superior National Traffic Information Centre. Traffic data and information from TCS subsystems will directly form the picture of traffic situation in town or send information about critical or emergency state (occurrence of congestions, traffic accident or other emergency situation). The superior NTIC will provide to TCS information primarily about traffic situation on main roads entering town and also on the adjacent superior road network (D1 highway and R4 motor way), on which the town communication system is connected. This way the TCS Prešov will be able to react on time on traffic problems on these roads and optimise the traffic control in town with respect on traffic situation or traffic problems outside town. It also holds in the opposite case when based on traffic data from TCS Prešov enables the superior NaTIS to effectively control and regulate traffic on adjacent and superior road network outside town with respect to current traffic situation in town. Besides traffic control and regulation itself it is necessary to ensure informing of drivers either from position of TCS Prešov or NaTIS by the available ways (VMSS, RDS-TMS, radio, cell-phone, internet).

4.8. Localization of Technological Devices within Prešov Agglomeration

Based on TCS Prešov proposal on the controlled road network of town Prešov it is possible to generate a final location plan of designed technological devices (Figure 10). This way deployed technological devices after completion by another ITS devices (like meteorological-stations of RWIS system, etc.) complexly cover the controlled area and accomplish the goals summarised in the conclusion of this paper.

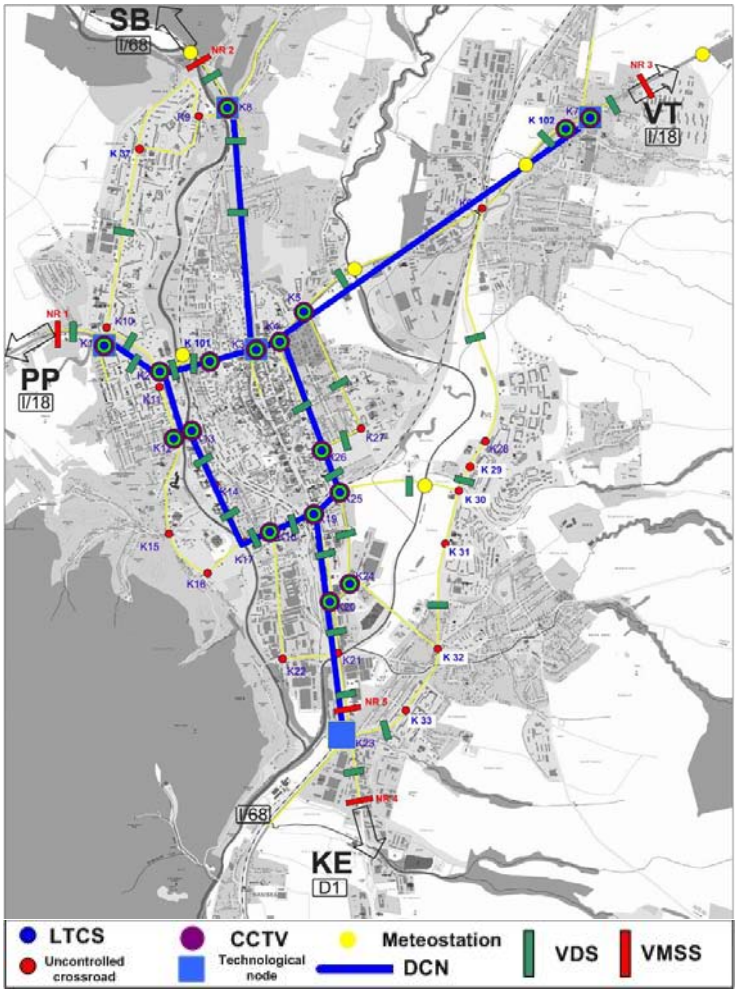

Figure 10. The proposed deployment of technological devices in Prešov

5. Conclusions

The urban ITS proposal of TCS Prešov significantly contributes to reduction of congestions formation and high traffic volumes on by overloaded urban roads within the town Prešov. At the same time it creates a background for a significant operational effectiveness increase of authorities, organisations and institutions in the area of administration and maintenance of roads, their components and accessories, in the area of economy of pavements and other property, in the area of traffic supervision on roads. The real output of the TCS Prešov project is implementation of procedures within the area of traffic control and optimisation and within the area of analytical operation targeting towards permanent removal of traffic problems which impair safety or traffic continuity within the Prešov town territory. Collected data from TCC can then be used for planning long-term outages, for the creation of urban plan or developing new or existing urban road network.

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ESTIMATION OF TRANSPORT SERVICE QUALITY LEVEL USING ECONOMETRIC MODELS

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Regression for polytomous data and ordinal logit model have been used for estimation the overall service quality under the influence of partial quality attributes. The numerical examples were done on the basis of results of questionnaire of transport experts about quality of service in Riga Coach Terminal. Short description of each method of model development is provided.

To compare the suggested approaches the paper discussed three variants of models: with complete set of factors, model with most significant factors and model with grouped factors.

The advantages and disadvantages of using each method and also practical recommendations on the application are provided in the investigation.

Keywords: mathematical model, estimation, quality service, polytomous data, ordinal data, regression, logit model

1. Introduction

Investigation of the transport service quality includes identification the particular quality factors and evaluation of their significance. One of the mostly used approaches is measurement of the passenger satisfaction with public transport on the basis of questionnaire.

The overall quality is presented as a linear function from several particular attributes – variables $Q = f(X_1, ..., X_k)$ and the most complicated question consists in definition of weight of each attribute [1].

The problems of the service quality provided by a Riga Coach Terminal have been considered by the authors for many times already [2–5]. In previous researches [2, 3] the theory of linear composite indicator constructing and statistical methods are being used, namely, linear regression model with constraints on parameters' sign and value. The model constructed for a scalar quality indicator allows estimating influence of particular quality indicators on the overall quality estimation and to simplify monitoring of quality indicators. But the models presented in these papers are based on a number of assumptions. Most critical one is that the overall estimations are continuous variables when in estimation and to simplify model development.

In the paper [4] the new improved approach for the first time offered by Professor Alexander Andronov, where the above mentioned assumption is dismissed; and besides helps to estimate not only parameters (weights) of particular attributes of quality, but also intervals of categories to which values of the overall indicator of quality are offered.

2. Task Setting

The models are constructed on the basis of results of questionnaire of 44 transport experts about service quality in Riga Coach Terminal that has been performed in spring 2009. Respondents were the high-qualified transport specialists. The questionnaire included 7 groups of questions concerned the following groups of quality particular attribute:

– Accessibility (availability)

X1 – Accessibility for external participants of traffic;
X2 – Accessibility for terminal passengers;
X3 – Ticket booking.

– Information

X4 – General information in terminal;
X5 – Information about trips in positive aspect;
X6 – Information about trips in negative aspect.

– Time characteristics of service

X7 – Duration of trip;
X8 – Punctuality;
X9 – Reliability/trust;
X10 – Bus time schedule.

– Customer service

X11 – Customer trust to terminal employees;
X12 – Communication with customer;
X13 – Requirements to employees;
X14 – Physical services providing;
X15 – Process of ticket booking;
X16 – Services provided by bus crews during boarding/debarkation.

– Comfort

X17 – Cleanness and comfort in terminal premises and on terminal square;
X18 – Additional opportunities/services providing in coach terminal.

– Safety

X19 – Protection from crimes;
X20 – Protection from accidents.

– Infrastructure and environment

X21 – Dirtying, its prevention;
X22 – Infrastructure

Different statistical methods were used to model the relationship between the outcome variable, e.g. estimates of overall quality of service – Y_i (all estimates were made on the basis (1–5) scale), and the 22 particular attributes of quality and the explanatory variables in previous researches [2, 5, 6], namely, classical regression, restricted regression, regression for polytomous data. Since outcome variable is ordinal, more reasonable is to apply appropriated methods, that's why the main goal of this investigation is to compare two methods called *regression for polytomous data* and *ordinal logit regression*. There are no unchallenged (proofed) criteria for comparing quality of each model, but since both methods provide probability assessment of each category, that's why the accuracy of the classification for response categories is going to be the main criterion for comparing results. Two next subsections provide short introduction of each method.

3. Offered Approaches

3.1. Regression for Polytomous Data (Model Type I)

The response Y_i of a concrete individual or item *i* (*i* = 1, …,*n*) is one of the fixed set of possible values, let {1, 2, …, *k*}. These values are called *categories.* It is supposed that the categories are ordered: the category *j* is "better" than *i* if *i* <*j*. The response probabilities $\pi = (\pi_1, \pi_2, ..., \pi_k)$ are function of vector of covariates or explanatory variables $x_i = (x_{i,1}, x_{i,2}, ..., x_{i,d})$ associated with the *i*-th individual: $\pi = \pi(x_i)$. The matrix of the covariates *X* and a vector of responses *Y* are given:

$$X = \begin{pmatrix} x_1 \\ \dots \\ x_n \end{pmatrix}_{n \times d}, \; Y = \begin{pmatrix} Y_1 \\ \dots \\ Y_n \end{pmatrix}.$$

Suggested relationship between the response probability $\pi = \pi(x_i)$ and the explanatory variables $x_i = (x_{i,1}, x_{i,2}, ..., x_{i,d})$ is using an unobserved continuous random variable Z_i for the *i*-th individual:

$$Z_i = \sum_{j=1}^{d} \beta_j x_{i,j} + \zeta_i = x_i \beta + \zeta_i, \tag{1}$$

where $\{\zeta_i\}$ are independent and identically normally distributed random variables with zero expectation and unknown variance σ^2, $\{\beta_j\}$ are unknown regression coefficients, $(\beta_1,...,\beta_d)^T = \beta$.

Unknown parameters are $\theta_1 < \theta_2 < ... < \theta_{k-1}$. If the unobserved variable Z_i lies in the interval $(\theta_{j-1}, \theta_j]$ then $y_i = j$ is recorded. Here $j = 1,\ldots,k$, $\theta_0 = -\infty, \theta_k = \infty$.

Maximal likelihood estimation is applied to get the next unknown parameters:

$\beta = (\beta_1,...,\beta_d)^T$, $\theta = (\theta_1,...,\theta_{k-1})^T$ and σ.

For that there are n observations with fixed values $\{Y_i\}$ and $x_i = (x_{i,1},..., x_{i,d})$.

Note that

$$\pi_j(x_i) = P\{Y_i = j\} = P\{\theta_{j-1} < Z_i \le \theta_j\} = \Phi\left(\frac{\theta_j - x_i\beta}{\sigma}\right) - \Phi\left(\frac{\theta_{j-1} - x_i\beta}{\sigma}\right). \quad (2)$$

When parameters are estimated $\tilde{\theta}^* = (\tilde{\theta}_1^*,..., \tilde{\theta}_{k-1}^*)^T$ and $\tilde{\beta}^* = (\tilde{\beta}_1^*,..., \tilde{\beta}_d^*)^T$ it is possible to estimate the probability of interest (2):

$$\pi^*_j(x_i) = P^*\{Y_i = j\} = P\{\tilde{\theta}^*_{j-1} < Z_i \le \tilde{\theta}^*_j\} = \Phi(\tilde{\theta}^*_j - x_i\tilde{\beta}^*) - \Phi(\tilde{\theta}^*_{j-1} - x_i\tilde{\beta}^*). \quad (3)$$

More detailed description can be found in [4].

3.2. Ordinal Logit Model (Model Type II)

Many variants of regression model for analysing ordinal response variables have been developed and described during the past years [7]. Ordinal regression model is embedded in the general framework of generalized linear models. Different models result from the use of different link functions.

In ordinal regression analysis, the two major link functions, e.g., *logit* and complementary log-log (*cloglog*) links, are used to build specific models. There is no clear-cut method to distinguish the preference of using different link functions. However, the *logit* link is generally suitable for analysing the ordered categorical data evenly distributed among all categories. The *cloglog* link may be used to analyse the ordered categorical data when higher categories are more probable [8].

The ordinal regression model may be written in the form as follows if the *logit* link is applied

$$f(\gamma_j(X)) = \log\left(\frac{\gamma_j(X)}{1-\gamma_j(X)}\right) = \log\left(\frac{P\{Y \le y_j / X\}}{P\{Y > y_j / X\}}\right) = \alpha_j + \beta X, \quad j = 1, 2, ..., k-1$$

$$\gamma_j(x) = \frac{e^{\alpha_j + \beta X}}{1 + e^{\alpha_j + \beta X}},$$

where j indexes the cut-off points for all categories (k) of the outcome variable (this model is the well-known proportional odds (PO) model. The number of different names for the same models causes unnecessarily much confusion about ordinal regression models). It is assumed that for the considered link function f the corresponding regression coefficients are equal for each cut-off point j. The adequacy of this 'equal slopes assumption' has to be evaluated carefully before this model can be applied [7]. If multiple explanatory variables are applied to the ordinal regression model, βX is replaced by the linear combination of $\beta_1 X_1 + \beta_2 X_2 + ... + \beta_p X_p$. The function $f(\gamma_j(X))$ is called the link function that connects the systematic components (i.e. $\alpha_j + \beta X$) of the linear model. The alpha α_j represents a separate intercept or threshold for each cumulative probability. The threshold (α_j) and the regression coefficient (β) are unknown parameters to be estimated by means of the maximum likelihood method [6].

4. Comparing Results

The investigation, e.g., the process of comparing two suggested approaches included 3 different variants:

1) Model with complete set of factors (constructing model with all 22 particular quality attributes – 22 factors);

2) Model with most significant factors (constructing model with reduced number of particular quality attributes – 5 factors);

3) Model with grouped factors (constructing model with 7 grouped particular attributes – 7 factors).

The first suggested method, e.g., *regression for polytomous data* was applied using Build-in optimisation block in MathCAD (functions *Given* and *Find*) and optimal values of estimated parameters $\beta = (\beta_1,...,\beta_5)^T$, $\theta = (\theta_1,...,\theta_4)^T$ were found in each variant of investigation.

The second method, e.g., *ordinal logit regression* was applied using SPSS PC version 17.0 software.

4.1. Variant 1. Model with Complete Set of Factors

Let's consider full factor set, e.g., 22 particular quality attributes.

Optimisation part of the regression for polytomous data in MathCAD showed that the optimum value of likelihood function is $l(\tilde{\beta}*, \tilde{\theta}*) = -19.86$ and correctness checking was executed successfully because all partial derivatives were equal to zero. Applying previously described procedure (Model type I) we get the following estimations of unknown parameters:

$$\beta_1 = 0.567,\ \beta_2 = 0.269,\ \beta_3 = 0.101,\ \beta_4 = -0.174,\ \beta_5 = -0.543,\ \beta_6 = 0.567,\ \beta_7 = -0.28,\ \beta_8 = 1.55,$$
$$\beta_9 = -1.481,\ \beta_{10} = -1.112,\ \beta_{11} = 0.606,\ \beta_{12} = 0.113,\ \beta_{13} = 0.084,\ \beta_{14} = 0.177,\ \beta_{15} = 0.31,\ \beta_{16} = -0.641,$$
$$\beta_{17} = 0.253,\ \beta_{18} = -0.227,\ \beta_{19} = 1.198,\ \beta_{20} = -0.826,\ \beta_{21} = 0.13,\ \beta_{22} = 0.642.$$

The cross-tabulating method was used to categorize the classified and the actual responses into a 3 by 3 classification table. Table 2 contains accuracy of the classification for response category according to formula (3) with estimated parameters for regression model for polytomous data. There are only two observations (in category $y_i = 5$) where the estimated value is not equal to the observed value. The model demonstrated very high prediction accuracy (93.2%) for all three categories combined.

Table 1. Accuracy of the Classification for Response Categories Based on the Regression Model Type I with Complete Set of Factors

Actual Response Category (Observed Y)	Accuracy	Classified Response Category		
		3	**4**	**5**
3	**100%**	**11**	0	0
4	**100%**	0	**29**	0
5	**50%**	0	2	**2**
Total	**93.2%**	11	31	2

The classification results of the model type II with the complete set of factors did not need to be presented in this paper because it was unable to perform the evidence of satisfying the test of parallel lines. Complete model containing all 22 explanatory variables were too complex, it could result in inaccurate estimation of the parameters and instability of the model structure, the sample size is too small to yield the high power of the statistical test given that many explanatory variables entered the equation for analysis.

4.2. Variant 2. Model with Most Significant Factors

Similar to linear and logistic regression modelling techniques, the principle of parsimony was applicable to the construction of both regression models (for polytomous data and ordinal *logit* model).

Since the *logit* link in the ordinal regression analysis and regression for polytomous data were not capable of selecting a subset of significant explanatory variables by automatic model building methods such as stepwise and back elimination procedures in SPSS command language, therefore, the selection of explanatory variables in the model was done according to previous investigations [5]. *LeastSquares Method (LSE) for a classical linear regression* model was applied and because of partial quality attributes could correlate between each other, that's why the stepwise regression model definition procedure was used (Forward Stepwise Algorithm in SPSS package). Due to stepwise procedure five factors were selected as significant ones – X3 (Ticket booking), X8 (Punctuality), X11 (Customer trust to terminal employees), X13 (Requirements to employees), X22 (Infrastructure). Thus number of factors is $d = 5$. Table 3 contains values of estimated parameters by both suggested approaches.

Table 2. Values of Estimated Parameters Based on the Model Type I and II with Most Significant Factors

Factors	Values of Estimated Parameters	
	Regression for Polytomous Data	Ordinal Logit Model
X3 (Ticket booking),	0.358	1.004 (sig.=0.283)
X8 (Punctuality)	-0.203	1.752
X11 (Customer trust to terminal employees)	0.776	3.465
X13 (Requirements to employees)	-0.24	0.89 (sig.=0.300)
X22 (Infrastructure)	0.655	1.591

Optimisation part of the regression for polytomous data in MathCAD showed that the optimum value of likelihood function is $l(\tilde{\beta}^*, \tilde{\theta}^*) = -21.125$ and correctness checking was executed successfully because all partial derivatives were equal to zero.

Ordinal Logit Model was tested for accuracy and adequacy, too. The model assumption of parallel lines in the model with 5 factors was not violated (e.g., $\chi^2 = 26.651$ with d.f. = 59 and p = 1.000), the results of the Pearson's chi-square test (e.g., $\chi^2 = 29.822$ with d.f = 5 and p = 0.000) indicated in the reduced model that the observed data were consistent with the estimated values in the fitted model. The three pseudo R squares – McFadden (0.548), Cox and Shell (0.601), and Nagelkerke (0.739) were high. Hence, the reduced model in *logit* link was a good model.

Table 4 contains accuracy of the classification for response category according to formula (3) with estimated parameters for regression model type I.

Table 3. Accuracy of the Classification for Response Categories Based on the Type I Regression Model with 5 Factors

Actual Response Category (Observed Y)	Accuracy	Classified Response Category		
		3	**4**	**5**
3	**54.5%**	**6**	5	0
4	**100%**	0	**29**	0
5	**25%**	0	3	**1**
Total	**73.9%**	6	37	1

As we can see from Table 4 the predicted values are close to real response vector *Y*. We have eight observations, where the estimated value is not equal to the observed value. The considerable quantity of deviations is observed in categories with small amount of observations. It can be connected with sample imperfection. The model demonstrated fairly prediction accuracy (73.9%) for all three categories combined.

Table 5 displays the accuracy of the classification results for the overall quality of service categories based on the Reduced Model with the *logit* link.

Table 4. Accuracy of the Classification for Response Categories Based on Model Type II with 5 Factors

Actual Response Category (Observed Y)	Accuracy	Classified Response Category		
		3	**4**	**5**
3	**72.7%**	**8**	3	0
4	**93.1%**	2	**27**	0
5	**0%**	0	4	**0**
Total	**70.3%**	10	34	0

Table 5 shows that the predicted values are close to real response vector *Y* too, but with lower accuracy (we have nine observations, where the estimated value is not equal to the observed value). The model demonstrated fairly prediction accuracy (70.3%) for all three categories combined.

4.3. Variant 3. Model with Grouped Factors

Now let's consider the next method of forming the independent variables for regression models, in particular: we will form 7 new variables corresponding to 7 groups of attributes (categories of questions). Grouping of the initial attributes and calculation of new values on the basis of a arithmetic mean leads to a replacement of categorical variable x_i (i = 1,..,22) by interval w_l(l = 1,..,7).

Let's use methods described above.

After optimisation part we get the following estimations of unknown parameters:

$$\beta = (1.18 \quad -0.639 \quad -0.719 \quad -0.48 \quad 0.522 \quad 1.002 \quad 0.51)^T .$$

The optimum value of likelihood function is $l(\tilde{\beta}*, \tilde{\theta}*) = -20.384$.

Checking gives correct results because all partial derivatives are equal to zero.

Table 6 contains accuracy of the classification for response category according to formula (3) with estimated parameters for regression model for polytomous data.

Table 5. Accuracy of the Classification for Response Categories Based on the Regression Model Type I with Grouped Factors

Actual Response Category (Observed Y)	Accuracy	Classified Response Category		
		3	**4**	**5**
3	**72.7%**	**8**	3	0
4	**96.6%**	1	**28**	0
5	**0%**	0	4	**0**
Total	**74.7%**	9	35	0

As we can see from Table 6 the most significant difference in real and predicted estimates is followed up in those categories which are in minority, namely $y = 3, y = 5$. But still the model demonstrated fairly high prediction accuracy (74.7%) for all three categories combined.

The classification results of the type II model with the grouped factors did not need to be presented in this paper the same as for complete model because it was unable to perform the evidence of satisfying the test of parallel lines (because of 86 (66.7%) cells (i.e., dependent variable levels by combinations of predictor variable values) with zero frequencies). Model containing 7 continuous explanatory variables were too complex, it could result in inaccurate estimation of the parameters and instability of the model structure, the sample size is too small.

4.4. Summary Results

1) Ordinal Logit model has a serious constraint from application point of view: it cannot be used for any dimension of a problem; researches should have reasonable proportion between number of predictors and number of observations. Regression for polytomous data can be applied for any dimension of a problem. Ordinal *logit* regression should be used or on huge samples or together with the principle of parsimony. According to definition of parsimony if fewer explanatory variables are sufficient to explain the effect of the explanatory variables, the regression model does not need to include unnecessary variables. However, the selection of "few" "important" explanatory variables remain a challenging task for researchers.

2) In this concrete case ordinal logit regression provides less accuracy, regression for polytomous data shows higher level of accuracy.

3) For this particular case in terms of identifying significant sub-indicators affecting the overall quality Model type II has the advantage.

4) Regression for polytomous data is not available in some known statistical package that makes applying of this method more complicated. Ordinal logit regression is available in SPSS and other statistical software (for example, SAS) that greatly facilitates the application of this method in practice.

5) Obviously for getting higher precision of conclusions it would be necessary to test these methods on other different samples.

5. Conclusions

The paper discusses models of two types that are embedded in the general framework of generalized linear models, namely regression for polytomous data and ordinal logit regression. The purpose of the study is to examine and compare for particular case the two methods, to identify the advantages and disadvantages of each method and to achieve practical recommendations on the application of methods.

Regression for polytomous data and ordinal logit model were used for estimation of the overall quality of service under the influence of partial quality attributes in Riga Coach Terminal. As for the terminal management there is not only an assessment of the overall service quality that is important but also knowledge of the factors that have the most significant impact on this assessment; the regression for polytomous data is insufficient, although it shows a high prediction accuracy. Further development of this method is necessary.

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DETERMINED MODEL AND SCALE DIAGRAMS TO INVESTIGATE PROBLEM OF TRANSPORT DELAYS

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In the paper the following question is investigated: what are the reasons of transport delays besides the diffusion of platoons? To answer the question a determined model is developed. It has a number of restrictions. A scale diagram of the highway state in discrete time points is created and described in details. The paper examines certain parameters of the determined model and its response to changes in these parameters with the help of scale diagrams. To be more precise all the places of delays can be detected according to the highway state diagram. Some of these delays can be substantially reduced by using phase offset of green traffic light from the side directions. So the paper contains proposals for the optimization of the developed model, aimed to reduce motor vehicle delays in front of the in-traffic light stop line along the main highway direction. Besides, the density of vehicles on the highway is considered.

Keywords: determined model, platoon, highway, intersection, traffic

1. Introduction

Constant and continuous growth of motor vehicles among the population, traffic growth leads to transport problems: appearance of traffic jams, traffic delay increase, increasing of accident number, environmental pollution, etc. These problems become apparent in the nodal points of the road network most tangibly.

Coordinated regulation makes it possible to smooth over these problems in part. The purpose of coordinated regulation is to ensure safe motor transport movement along a street or a highway. Coordination of traffic signals at adjacent intersections would reduce number of stops, braking and acceleration in the flow, and transport delays.

However coordinated regulation effectiveness often is low. Stochastic nature of speeds and accelerations in traffic flow leads to the diffusion of platoons causing serious difficulties for traffic management. Platoon edges significantly dilute during progression between two traffic lights. Only permanent platoon forms and platoon constant speeds would enable to predict the moment of intersection passage accurately, and make optimal program for traffic lights [1].

A question appears: what are the reasons of transport delays besides the diffusion of platoons? To answer the question, let ignore diffusion in the proposed model. All platoons of equal size, formed by a traffic light, travel with the same constant speed. This is the first position (postulate) of the model.

The object of study is a highway, along which $z+1$ T-type intersections are located at different distances (Figure 1). The highway and all cross roads have one-way traffic. The direction of movement is indicated by arrows (Figure 1). Distances between intersections 0, 1, ..., Z are equal to L_1, L_2, ..., L_z correspondingly. Intersections controlled by traffic lights working with two-phase cycle.

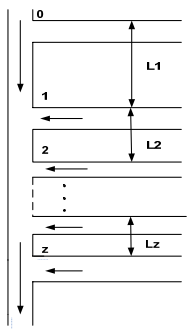

Figure 1. Highway plan with the adjacent T-type, controlled intersections

Let relate yellow times t_{y1} and t_{y2} of traffic light to the red signal (RS) in cycle length. Let take time duration of green signal (GS) of a crossing road, as a minimum time discrete $t_g=\Delta t$. Let make red time duration RS (with yellow) multiple of t_g, i. e. $t_g = k\, t_r$, where k – factor of multiplicity (integer). Thus the duration of the cycle C is:

$$C = t_g + t_r = (k+1)\, t_g\,. \tag{1}$$

Similarly, we introduce a distance discrete Δl. Let take $\Delta l = v\Delta t = v\, t_g$, where v is permissible speed on a highway. Let us assume that all the distances between intersections are multiples of the distance discrete Δl. Then the distance l_i between two intersections $I - 1$ and i $(i = 1, ..., Z)$ will be as follows:

$$l_i = p\Delta\, l = p\, v\, t_g\,, \tag{2}$$

where p is integer.

2. Structural Diagram

A structural diagram of discrete control of traffic lights is showed on Figure 2. The traffic light at the i-th intersection $(i = 0, ..., Z)$ can be represented by two keys K_{i1} and K_{i2}. The key K_{i1} opens or closes traffic on $(i, i+1)$ link. Key K_{i2} opens or closes transport flow into the highway from the crossing road (R_i).

Key management is carried out with register – a word of a highway state. Binary vector $P_j= (\delta_0, \delta_1, \ldots \delta_i, \ldots ,\delta_z)$, $j = 1, \ldots ,2^{Z+1}$, $\delta_i \in 0, 1$, $(i = 0, \ldots ,Z)$ is putted into the register. Each vector's bit controls the corresponding crossroads. Management is carried out with paraphase signal, i.e. if one of the key pair, for example K_{i1} is opened, then key K_{i2} is closed, and vice versa. The combination of opened and closed keys defines the highway state. The state is uniquely determined by the vector P_j. Change of the vector P_j in the register with a command from the control computer changes the state and movement mode of highway and secondary roads R_0 - R_z.

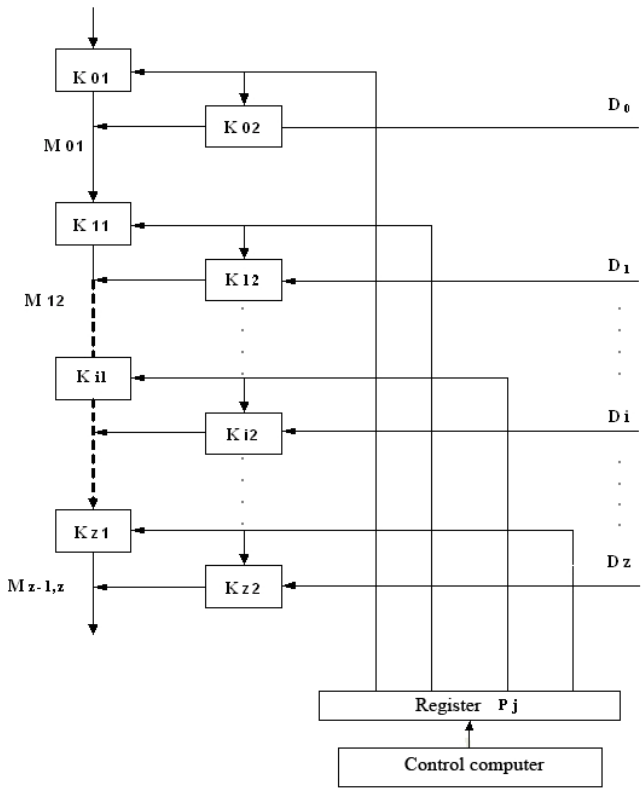

Figure 2. Structural diagram of discrete control of traffic lights

If rank i of vector P_j equals 1 ($\delta_i = 1$) then key K_{i1} state is opened, i.e. the passage through the *i*-th intersection is opened, otherwise ($\delta i = 0$) the intersection is closed for highway and opened for secondary road R_i.

Let consider the process of filling the highway with transport in the morning. The initial state of the highway is the state S_0 – the absence of motor transport. At the same time there are enough vehicles on crossing-roads to ensure that at the opening time, when $\Delta t = t_g$, n units of motor transport would enter the highway from any cross-road. Let us assume that platoon of n vehicles, that came in highway, will travel along it for a distance equal one distance discrete $\Delta l = v\Delta t = vt_g$ during discrete time $\Delta t = t_g$.

3. Scale Diagram

Let create a scale diagram of the highway state in discrete time points. To do this, time intervals of duration $\Delta t = t_g$ are plotted on the horizontal axis, distance intervals are plotted on the vertical axis. The scale for Δt and Δl is chosen so that they have equal length (e.g. a cell) on the diagram of states.

Figure 3 shows the state diagram for five intersections (with different distances between them) during 17 time discretes where $k = 2$. Only two control vectors are used P_j $(j = 1, 2)$. The first vector consists of all zeros and is in register P_j during t_r. Z +1 platoons enter the highway during this time. These platoons manage to pass distance of Δl along the highway. Then the highway goes from state S_0 to state S_1, characterized with the presence of five platoons of *n* cars (the first column in Figure 3). Here and in the future, highway state S_r means the number of platoons at the time t_r, and their composition, i.e. numbers of intersections from which they came. The darker vertical bars indicate red signals for all highway traffic lights, and vehicle emission into the highway. There are platoons numbered from 0 to 4 that came from the corresponding intersections in column 1. One platoon of *n* vehicles is from each intersection. Then the register P_j is filled with vector P_2, consisting of all ones. This vector set green signals for all highway traffic lights, and red signals for cross-roads. This is a phase of transit pass of platoons along the highway.

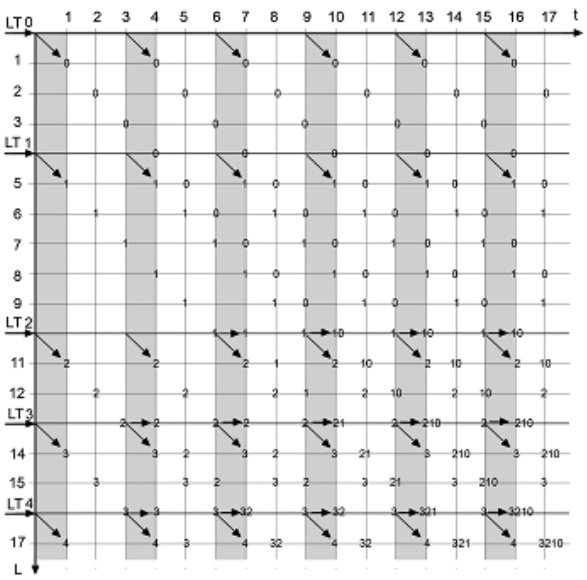

Figure 3. State diagram of highway with two control vectors P_1 and P_2

In the literature, e.g. [2], motor cars moving along the highway are of two types: transit and out of platoon. All motor cars are transit in the determined model. The process of platoon movement control is clearly determined. The effect of platoon "blurring" [2] on the links is not considered in the model.

Thus motor cars enter the highway from side directions in the time intervals 0 – 1, 3 – 4, 6 – 7, etc. as noted in Figure 3 with oblique arrows. All traffic lights on the highway have green phase in the time intervals 1 – 3, 4 – 6, 7 – 9 and so on. The flow crosses the highway without difficulties.

States S_1, S_2 and S_3 are equivalent, because they have equal and constant number of platoons (five). State S_4 is characterized by ten platoons of *n* vehicles in each platoon, because emission of motor cars occurred from side directions at time t_4. It should be noticed that emission is not done simultaneously, but

in the interval between t_3 (start) and t_4 (finish). That is, green phase turns on for the side directions at the moment t_3 and turns off at the moment t_4.

Any platoon P_i *(t, l), (I = 1, ..., z)* is determined uniquely with two coordinates – time t and the distance *l* from the reference point – on the state diagram (Figure 3). The number of platoon in a column shows their number on the highway at the concrete moment of time , as well as the number of platoons on any link, and their structure, i.e. the number of source intersection and start time.

The actual end of the highway is the last traffic light. Platoon P_i moves bias within the next square. Increment of Δt corresponds to Δl. So, for example, platoon P_1 (1, 5) at the moment of time $t = 6$ (Figure 3) will face the traffic light number 2, which will be closed, as it is opened for secondary roads in the time interval 6–7. Platoon P_2 (7, 11) is being formed in this moment. Transit platoon P_1 (6, 10) will delay at the traffic light during Δt and goes into a state of P_1 (7, 10).

Later platoon P_1 (7, 10) moves without delays to the end of highway. It is joined with P_2 (9, 13) at the traffic light number 3. P_2 (9, 13) was forced to wait for the time Δt because of red light of traffic light number 3. Two fused platoons of P_1 (10, 13) and P_2 (10, 13) move to the traffic light number 4, where they are joined with platoon P_3 (13, 16). Then all three platoons reach the end of the highway.

Thus, all the places of delays can be detected according to the highway state diagram. For example, there are 14 such places in the Figure 3, and total delay is $14\Delta t$.

This delay can be substantially reduced by using phase offset of green traffic light from the side directions. This process should start with the last traffic light, gradually moving to the beginning of the highway, will produce phase offset with control vectors P_j, i.e. the number of control vectors will be greater than two.

Let us show phase offset to the left of one time unit Δt for traffic light number 4 (see Figure 4). The offset is performed on the free diagonal. This ensures the passage of the platoons through the traffic light without delays. Since the empty diagonal was used (last row of the state diagram is completely filled), then the delays at traffic lights number 2 and number 3 persist. The number of delayed platoons has reduced from 14 to 9.

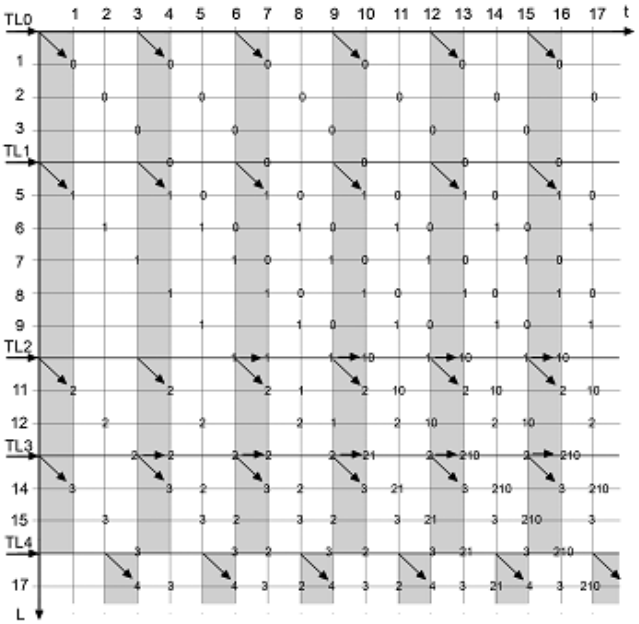

Figure 4. Highway state diagram with an increase in the number of control vectors

4. The Density of Vehicles on the Highway

Flow density of motor cars is a parameter characterizing traffic flow on the number of vehicles at any given time on a given section of road. In our case, the density will be called the number of platoons on a given section of road, not the number of individual vehicles.

Let us construct a density diagram of vehicles on the whole highway at every second for the developed model (see Figure 5).

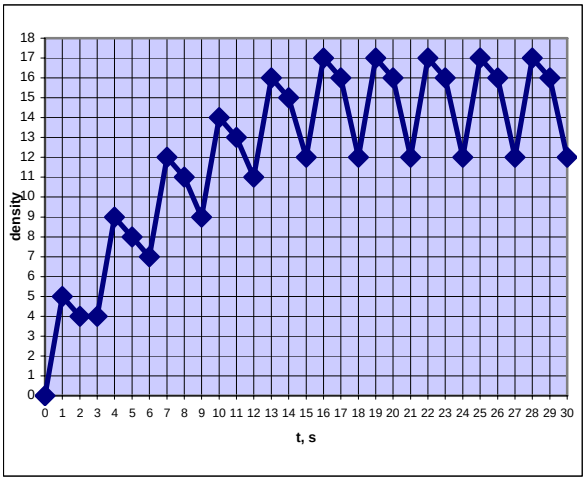

Figure 5. Density diagram

Figure 5 shows that the number of platoons increases jerkily during the highway is filling. After the 16th second condition is stabilized, the density on the highway is no longer changing. Thus, the highway state diagram line (Figure 3, 4), as well as all the highway state diagrams below, have the property that their state no longer change after the first platoon will have been travelled from the start to the end traffic lights on the highway.

5. The Optimal Choice of *k*

Let us create diagrams with different *k* using the same determined model, to find out how to choose the optimal *k* or how to change *k* to eliminate delays.

The highway state diagrams with *k* equals to 1, 2, 3 and 4 are showed on Figure 6. To calculate correctly the number of delays, the counting will be performed after the 20th second, when all the models will work in a stable mode. Also, the counting will be performed during a time interval equal to one cycle.

It is seen that:

- when $k = 1$, taking into account that one horizontal arrow can mean several platoon delays, there are 5 delay at the diagram, and the offset to reduce the number of delays is not possible;
- when $k = 2$, there are 3 delay, a free diagonal presents to make the phase offset in one discrete of time to the left for traffic light number 4. Then the number of delays will be equal to 2;
- when $k = 3$ we have 2 delay, there will be one delay after the phase offset in one discrete of time to the right for traffic light number 0;
- when $k = 4$ we have 1 delay, and there will not any delay after the phase offset in two discretes of time to the left for traffic light number 0.

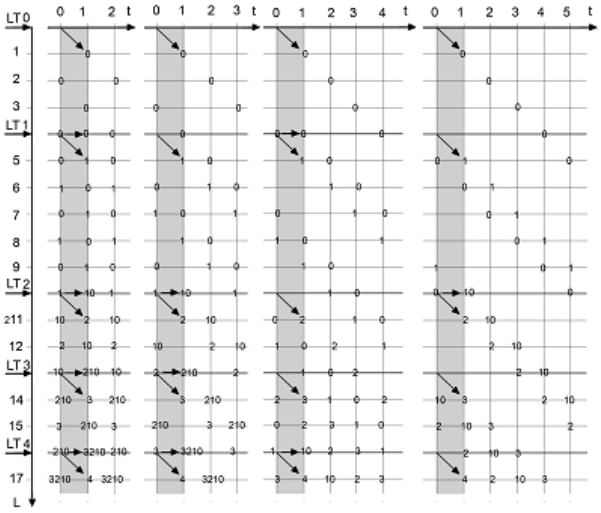

Figure 6. Determined models for 1) $k = 1$, 2) $k = 2$, 3) $k = 3$, 4) $k = 4$ in the stable mode

Diagram of the number of delays dependence on the coefficient k will illustrate the above (see Figure 7).

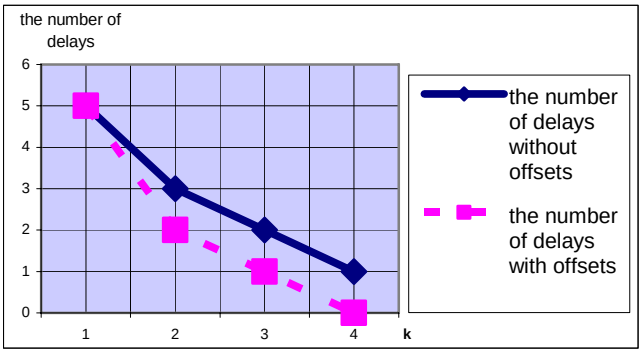

Figure 7. Diagram of the number of delays dependence on the coefficient k

Thus, Figure 7 shows that the smaller k, the greater delays, and vice versa. When $k = 4$, all delays can be eliminated. Phase offsets allow reducing the number of delays.

However, it should be noted that for large k there is little time for the passage from the side streets. And also a great cycle time may provoke massive violations of rules of the road. Therefore, when choosing k, reasonable ratio should be observed between the duration of green signal on the highway and on the cross-streets. [2] gives a formula for calculating the length of green signal for the transport of cross roads:

$$t_z = \frac{q \cdot C\,min}{q_s \cdot x_{lim}} \geq 14s, \tag{3}$$

where q – movement intensity for a secondary direction for given band, veh / s;
q_s – the flow of saturation for a given traffic flow, veh / s;
C_{min} – the minimum duration of the cycle;
x_{lim} – limit (recommended) value of the load factor of a band for a secondary direction (≈ 0,6).

Equation (3) has approximate and recommended character, but you can use it to find the upper limit of k. For more detailed information about the formula and its parameters see the source [2].

In the determined model it should be taken into account that the appearance of delays may depend not only on k, but also on the relations presented below.

There is a delay at intersection b if

$$\left(\sum_{i=a+1}^{b} p_i + \mu\right) mod(k+1) = 0, \tag{4}$$

There is not a delay at intersection b if

$$\left(\sum_{i=a+1}^{b} p_i + \mu\right) mod(k+1) \neq 0, \tag{5}$$

where *mod* is a remainder of the division;
a – number of the intersection, from which a platoon came;
b – number of the intersection, which is tested for presence / absence of delay;
μ – the number of delays has already happened for this platoon;
p_i – the distance between $(i-1)$-th and the i-th intersections (in distance discretes).

With the help of formulas 4 and 5 it is possible not to build a determined model to define the presence or absence of delays at the intersection for a platoon. For example in Figure 6 when $k = 1$, let us check presence of delay at the first traffic light (TL1). The second summand in the numerator is not included, as just one cycle is considered. Thus $a = 0$, $b = 1$. Then we calculate the sum of discretes between the traffic light number 0 and the traffic light number 1. The sum is equal to 4. The denominator is equal to 2. There is no remainder after division of the numerator by the denominator. Therefore, the delay is present.

The same pack when k = 2 will pass TL1 without delay, because the sum of discretes still equal to 4, while the denominator is equal to 3. There is remainder after the division. When k = 1 lets check the delay for the 1st platoon at LT2. a = 1, b = 2, the sum is 6, denominator is 2. There will be delay for the first platoon. While there will not be delay for the platoon number 0, because sum is 6, denominator is 2, but μ = 1 (for the platoon number 0 there has been delay at TL1), so the numerator is equal to 7, and the denominator is 2. I.e. division is with a remainder, no delay. And so on.

6. A Determined Model for Bidirectional Movement

Let's extend the model.

Now the highway and all cross-roads have two-way traffic, and intersections are of X-shaped type (Figure 8).

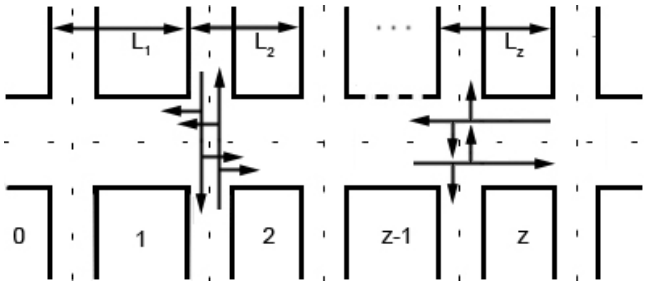

Figure 8. Highway plan with the adjacent X-shaped, controlled intersections

On Figure 8 distances between the intersections 0, 1, ..., Z are equal to L_1, L_2, ..., L_z. Possible for all the intersections, movement directions from the cross-roads are shown with the arrows at the intersection number 1. Possible for all the intersections, movement directions from the highway are shown with the arrows at the intersection number $Z - 1$. All the intersections are equipped with traffic lights. We assume that all traffic lights are working with two-phase traffic light cycle. Then the structural diagram of a discrete control of traffic lights (see Figure 2) is also suitable for the case.

Let's create a scale diagram of the highway state in discrete time points for bidirectional movement (Figure 9). As before k = 2, two control vectors are used: P_1 consists of all zeros and is in register P_j during t_r, P_2 consists of all ones. This vector set green signals for all highway traffic lights, and red signals for cross-roads.

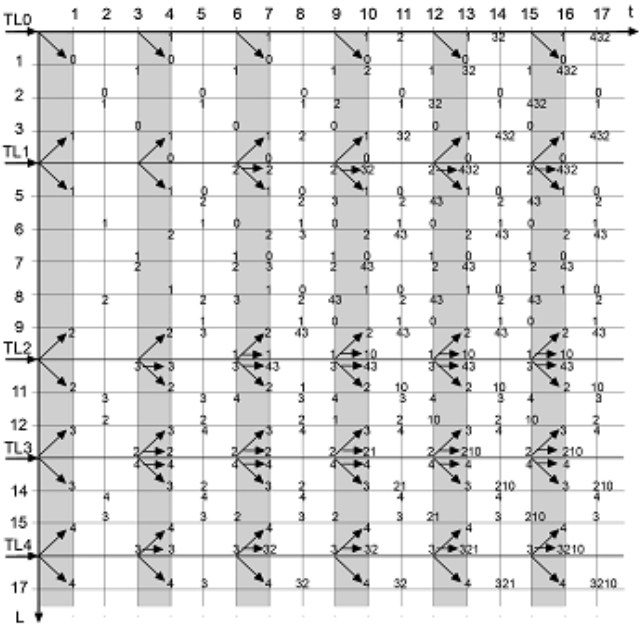

Figure 9. Highway state diagram

Figure 9 shows the 5 traffic lights with 17 distance discretes for 17 time discretes. Arrows pointing down mean the next emission of platoons into one side of the highway (direction I) from the side streets. These platoons are placed above the horizontal lines. Arrows pointing upward mean the next emission of platoons into the other side of the highway (direction II). These platoons are placed under horizontal lines in the diagram. Horizontal arrows indicate platoon delay, because their state is changed only on the time axis and the axis of the distance remains the same. All platoons are numbered in accordance with the number of traffic lights, from which they entered the highway. Several consecutive numbers mean that the packets from different traffic lights merged into one.

Analysing the chart shown on Figure 9, we can conclude that, it is not possible to avoid delays at any intersection for a given location of traffic lights and $k = 2$. And traffic lights 2 and 3 create delays in both directions.

Solutions to this situation are:

- to increase the duration of green phase (k),
- to make phase offset.

Let us set our choice on the latter. Let us find out what changes are possible to minimize the number of delays, if we consider both directions independently of each other. In the direction I it is possible to make phase offset in one time discrete Δt to the left for traffic light number 4. There is no alternative, because there are not free diagonals. In the direction II it is admissible to make phase offset in one time discrete Δt to the left for traffic light number 1 and to the right for traffic light number 4. Now you have to track how these changes are coordinate with each other. Offset in the direction I at the fourth traffic light will lead to the fact that traffic lights will operate asynchronously in the direction I and II. In our case, this situation is not possible, because there are only 3 time discretes in the cycle. If the traffic light is asynchronous, then at least one discrete would be dedicated to the green signal in the direction I, another discrete of green would be dedicated in the direction II. If the third discrete dedicate to the green signal, it would mean that the green light does not ever light up for the cross road. If the third discrete dedicate to the red light, it would mean that the greater part of time the red signal will be turned on at this intersection on the highway. That is also unacceptable. Therefore, phase moving in one direction require phase moving into another one. At the same time we should check if such an offset is possible in the direction II with the diagram. There is a free diagonal. But, having taken it, we no longer have the possibility to shift the phase at the traffic light number 1. As a result, we obtain a new diagram shown in Figure 10. 3 control vectors are needed to manage it. The number of delays has decreased after the phase offset.

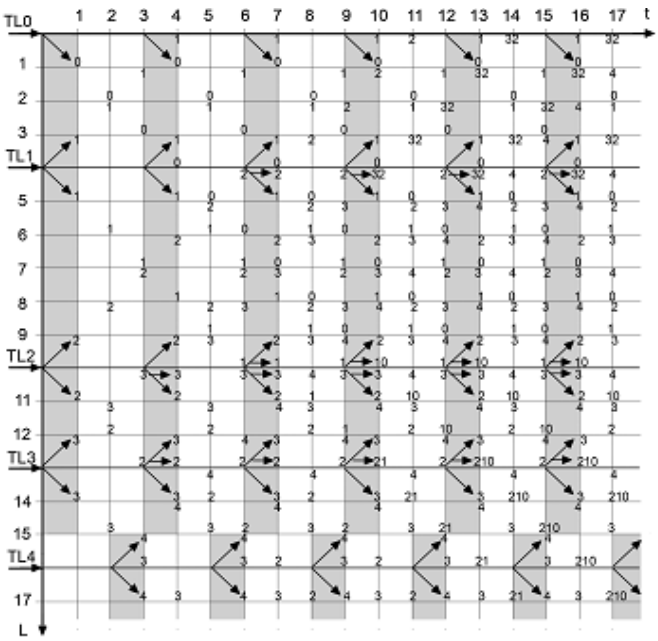

Figure 10. State diagram of highway after the control vectors number increase

7. Conclusions

Diffusion of platoons is not the only a reason of transport delays and probably is not one of the main reasons in the coordinated regulation. The revealed reason for delays is platoon competition from different lateral directions when crossing highway traffic lights. Further research should evaluate the impact of each factor over delays of vehicles. For this it is necessary to introduce an element of chance in the deterministic model, which would dither platoons.

The highway state diagrams in the idealized case move in a stable mode some time after the start. In the real life, such stable modes may exist only for some limited period of time, because traffic flow has stochastic nature. When choosing the coefficient k a balance should be observed. The absence of delays can be achieved in the highway deterministic model with increasing of k, but it should be considered what length of the green signal for the side streets will turn out. It is much more difficult to avoid delays of vehicles with bidirectional movement. Ways to struggle against delays are the following: phase offset, increase of k, phase offset with the asynchronous operation of traffic lights.

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CUMULATIVE INDEX

TRANSPORT and TELECOMMUNICATION, Volume 12, No 4, 2011 (Abstracts)

Krainyukov, A., Kutev, V. Problems of Road Coverage Quality Estimation by GPR Probing Method, *Transport and Telecommunication*, Vol. 12, No 4, 2011, pp. 4–13.

This work deals with problems of flexible pavement structure quality estimation with help of ground-penetrating radars (GPR). Forward and inverse problems of flexible pavement structure GPR probing are discussed. Iterative procedure to solve the inverse problem in frequency domain is used on the base of aim function minimization by using the genetic algorithm. The results of reconstruction of electro-physical characteristics for model of flexible pavement structure are presented.

Keywords: radar probing, inverse problem, genetic algorithm, reconstruction of electro-physical characteristics

Nowak, K., Mazurkiewicz, J. Multiagent Modeling and XML-Like Description of Discrete Transport System, *Transport and Telecommunication*, Vol. 12, No 4, 2011, pp. 14–26.

The paper describes a novel idea to monitoring and modeling of Discrete Transport System (*DTS*). We propose the formal model of the transport system with the approach to its modelling based on the system behaviour observation. The proposed method is based on specified description languages that can be seen as a bridge between the system description (as a mathematical or expert specification) and the analysis tools. The *DTS* is a simplified case of the Polish Post. Using a multilevel-agent based architecture the realistic data are collected. Described architecture can be found as a basis for a tool that can visualize and analyze data, with respect to the real parameters. Absence of any restrictions on the system structure and on the kind of distribution describing the system functional and reliability parameters is the main advantage of the approach. The paper presents some exemplar system modeling based on a case study. The proposed approach can be used as a helpful tool to administrate the system.

Keywords: Discrete Transport System, reliability, agent management system

Batenko, A., Grakovski, A., Kabashkin, I., Petersons, E., Sikerzhicki, Yu. Weight-In-Motion (WIM) Measurements by Fiber Optic Sensor: Problems and Solutions, *Transport and Telecommunication*, Vol. 12, No 4, 2011, pp. 27–33.

In the present study the authors are discussing the possibility of fibre optic sensor application for weighing road vehicles in motion (WIM – weight-in-motion). The various factors affecting the accuracy of fibre optic sensors measurement are considered to be: features of the installation in the roadway, the nonlinearity and inertia of the sensor, the thermal effect, the inertial force of the vibrating vehicle and the extremely short time of the load standing on the sensor. The examples of the record signals, transferring to a fibre optic sensor, are made. The analysis of the causes of measurement error and possible ways to improve the accuracy of weighing for the solution of the pre-selection of road vehicles in motion upon the dynamic load on the axis is submitted.

Keywords: intelligent transport system, vehicle detection, weight-in-motion, fibre optic sensors, dynamic measurement, digital signal processing

Gavulová, A., Pirník, R. Basic Concept of the Technical Study of the Traffic Control System in Prešov, *Transport and Telecommunication*, Vol. 12, No 4, 2011, pp. 34–44.

The project „Support Programme for the development of intelligent transport systems – National Traffic Information System for Slovakia“ also includes implementation of ITS of 11 chosen Slovak urban agglomerations. For the purposes of this project Technical study document for each town was elaborated in the first phase. The Technical study analyses existing and expected situation, defines critical localities on the basis of this analysis, which is necessary to solve and defines a framework for solution and its technical characteristics, respectively different alternatives of solutions. The article describes the current state of the ITS in the Slovak Republic, the scope of the Technical study of urban ITS and an ideological proposal of the Traffic Control System (TCS) in Prešov town, which has been elaborated at the author's' workplace. The urban ITS with respect to main goal – capacity

increasing of existing urban road network and traffic congestion reducing – has been designed. In the article, functions and connections of all subsystems of TCS Prešov, their location within the town and connection to the NTIC (National Traffic Information Centre) master system are described in more details.

Keywords*:* intelligent transport system, ITS, traffic control system, detection system, traffic control centre

Spiridovska, N., Yatskiv, I. Estimation of Transport Service Quality Level Using Econometric Models, *Transport and Telecommunication*, Vol. 12, No 4, 2011, pp. 45–51.

Regression for polytomous data and ordinal logit model have been used for estimation the overall service quality under the influence of partial quality attributes. The numerical examples were done on the basis of results of questionnaire of transport experts about quality of service in Riga Coach Terminal. Short description of each method of model development is provided.

To compare the suggested approaches the paper discussed three variants of models: with complete set of factors, model with most significant factors and model with grouped factors.

The advantages and disadvantages of using each method and also practical recommendations on the application are provided in the investigation.

Keywords: mathematical model, estimation, quality service, polytomous data, ordinal data, regression, logit model

Shuts, V., Vaitsekhovitch, A. Determined Model and Scale Diagrams to Investigate Problem of Transport Delays, *Transport and Telecommunication*, Vol. 12, No 4, 2011, pp. 52–60.

In the paper the following question is investigated: what are the reasons of transport delays besides the diffusion of platoons? To answer the question a determined model is developed. It has a number of restrictions. A scale diagram of the highway state in discrete time points is created and described in details. The paper examines certain parameters of the determined model and its response to changes in these parameters with the help of scale diagrams. To be more precise all the places of delays can be detected according to the highway state diagram. Some of these delays can be substantially reduced by using phase offset of green traffic light from the side directions. So the paper contains proposals for the optimization of the developed model, aimed to reduce motor vehicle delays in front of the in-traffic light stop line along the main highway direction. Besides, the density of vehicles on the highway is considered.

Keywords: determined model, platoon, highway, intersection, traffic

TRANSPORT and TELECOMMUNICATION, 12.sējums, Nr.4, 2011 (Anotācijas)

Kraiņukovs, A., Kutevs, V. Autoceļu pārklājuma kvalitātes novērtēšanas ar GPR zondēšanas metodi problēmas, *Transport and Telecommunication,* 12.sēj., Nr.4, 2011, 4.–13. lpp.

Šajā darbā tiek risinātas problēmas elastīgas ceļa seguma struktūras kvalitātes novērtēšanā ar zemē iestrādātu radaru (angl. *ground-penetrating radars – GPR*) palīdzību. Rakstā tiek diskutētas turpmākas un inversas elastīga ceļa seguma struktūras ar *GPR* zondēšanu problēmas. Kā arī tiek parādīti elektro-fizikālu īpašību rekonstrukcijas rezultāti elastīgas ceļa seguma struktūras modeļiem.

Atslēgvārdi: radara zondēšana, inversā problēma, ģenētisks algoritms, elektro-fizikālas īpašības

Novaks, K., Mazurkevičs, J. Multi-aģentu modelēšana un XML-veida apraksts diskrētās transporta sistēmās, *Transport and Telecommunication,* 12.sēj., Nr.4, 2011, 14.–26. lpp.

Rakstā tiek dotas jaunas idejas monitoringam un diskrētu transporta sistēmu (*DTS*) modelēšanai. Autori ierosina transporta sistēmas formālu modeli ar tās modelēšanas pieeju, balstītu uz sistēmas uzvedības novērošanu. Piedāvātā metode pamatojas uz norādīto aprakstu valodām, ko var uzskatīt kā tiltu starp sistēmas aprakstu (kā matemātisku vai eksperta specifikāciju) un analīzes rīkiem. *DTS* ir vienkāršots Polijas pasta veids. Reāli dati tiek savākti, pielietojot daudzlīmeņu-aģentu balstītu arhitektūru. Aprakstītā arhitektūru var tikt uzskatīta kā bāze rīkam, kas var vizualizēt un analizēt datus, saistītus ar reāliem parametriem. Rakstā tiek sniegti daži paraugi sistēmu modelēšanai, pamatojoties uz gadījumu izpēti. Ierosinātā pieeja var tikt izmantota kā noderīgs līdzeklis, lai administrētu sistēmu.

Atslēgvārdi: diskrēta transporta sistēma, uzticamība, aģentu vadības sistēma

Batenko, A., Grakovskis, A., Kabaškins, I., Pētersons, E., Sikeržickis, J. Svars-kustībā mērījumi ar šķiedru optiskā sensora palīdzību: problēmas un risinājumi, *Transport and Telecommunication,* 12.sēj., Nr.4, 2011, 27.–33. lpp.

Dotajā pētījumā autori izskata šķiedru optiskā sensora pielietojamību transporta līdzekļu nosvēršanu kustībā. Tiek izskatīti daudzie faktori, kas ietekmē šķiedru optisko sensoru mērījumu precizitāti, un tie ir šādi: ceļu instalāciju iezīmes, sensoru nelinearitāte un inertums, termālais efekts, vibrējošā transporta līdzekļa inerces spēks, un slodzes atrašanās uz sensora ārkārtīgi īsais laika periods. Tiek veikti ierakstu signālu piemēri, nododot uz šķiedru optisko sensoru. Rakstā tiek apskatīta mērījumu kļūdas cēloņu analīze un iespējamie veidi, lai uzlabotu svēršanas precizitāti iepriekšējas atlases autotransporta līdzekļu kustībā uz dinamisko slodzi uz ass risināšanai.

Atslēgvārdi: viedā transporta sistēma, svars-kustībā, transporta līdzekļa uztveršana, šķiedru optiskais sensors, dinamiskais mērījums, digitālā signāla apstrāde

Gavulova, A., Pirniks, R. Trafika kontroles sistēmas Prešovā tehniskās izpētes pamata koncepts, *Transport and Telecommunication,* 12.sēj., Nr.4, 2011, 34.–44. lpp.

Projekts "Atbalsta programma automatizēto transporta sistēmu attīstībai – Nacionālā trafika informācijas sistēma Slovākijai" arī ietver 11 izvēlēto Slovākijas pilsētu aglomerācijas *ITS* ieviešanu. Tehniskās izpētes analīžu esamība un paredzētā situācija nosaka kritiskās vietas pēc šīm analīzēm, kuras ir nepieciešams risināt un nosaka risinājuma ietvaru un tā tehniskos raksturojumus, atbilstoši atšķirīgas risinājuma alternatīvas. Rakstā tiek parādīts pašreizējais ITS stāvoklis Slovākijā, pilsētas ITS Tehniskās izpētes redzesloks un Trafika kontroles sistēmas ideoloģiskais piedāvājums Prešovas pilsētā, ko ir izstrādājusi autore savā darba vietā.

Atslēgvārdi: viedā transporta sistēma, ITS, trafika kontroles sistēma, trafika kontroles centrs

Spiridovska, N., Jackiva, I. Transporta pakalpojumu kvalitātes līmeņa novērtēšana, izmantojot ekonometriskos modeļus, *Transport and Telecommunication,* 12.sēj., Nr.4, 2011, 45.–51. lpp.

Regresijas polinomiskie dati un kārtas logit modelis ir pielietoti vispārēju pakalpojumu kvalitātes novērtēšanai, ko ietekmē daļējas kvalitātes atribūti. Skaitliskie piemēri tika veikti, pamatojoties uz transporta ekspertu aptaujas rezultātiem par sniegto pakalpojumu kvalitāti Rīgas autobusu terminālī. Rakstā ir dots katras modeļa uzbūves metodes īss apraksts.

Lai salīdzinātu piedāvātās pieejas, rakstā ir apskatīti trīs modeļu varianti ar faktoru komplektu, – modelis ar vissvarīgākajiem faktoriem un modelis ar grupētiem faktoriem.

Šajā pētījumā tiek parādītas priekšrocības un trūkumi, izmantojot katru metodi, kā arī tiek doti praktiski ieteikumi pielietošanai.

Atslēgvārdi: matemātiskais modelis, novērtēšana, kvalitātes pakalpojums, polinomiskie dati, kārtas dati, regresija, logit modelis

Šuts, V., Vaitsehovičs, A. Noteiktais modelis un mēroga diagrammas transporta kavēšanās problēmas pētīšanai, *Transport and Telecommunication,* 12.sēj., Nr.4, 2011, 52.–60. lpp.

Rakstā tiek izskatīti šādi jautājumi, kādi ir transporta kavēšanās iemesli bez cilvēku grupas izkliedēšanas. Lai atbildētu šo jautājumu tika izveidots determinētais modelis. Tam ir vesela rinda ierobežojumu. Ir izveidota un aprakstīta sīkāk mēroga diagramma šosejas stāvoklim diskrēta laika punktos. Rakstā tiek pētīti determinētā modeļa noteikti parametri un šī modeļa atbilde šo parametru izmaiņām ar mēroga diagrammas palīdzību. Precīzāk, visas kavēšanās vietas var būt atklātas saskaņā ar šosejas stāvokļa diagrammu. Dažas no šim kavēšanās var būt būtiski samazinātas, izmantojot zaļā luksofora fāzes nobīdi no sānu virzieniem. Tādējādi, rakstā tiek doti priekšlikumi uzbūvētā modeļa optimizācijai, kas samazinātu auto transporta kavēšanās. Bez tam rakstā tiek izskatīts arī transportlīdzekļu blīvums uz šosejas.

Atslēgvārdi: determinētais modelis, cilvēku grupa, šoseja, krustojums, satiksme

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