ISSN 1407-6160

TRANSPORT AND TELECOMMUNICATION

Volume 9. No 2

2008

Transporta un sakaru institūts
(Transport and Telecommunication Institute)

Transport and Telecommunication

Volume 9, No 2 - 2008

ISSN 1407-6160
ISSN 1407-6179
(On-line: www.tsi.lv)

Riga – 2008

Host Organizations:
Transport and Telecommunication Institute, Latvia – Eugene Kopytov, Rector
Telematics and Logistics Institute, Latvia – Igor Kabashkin, Director

Co-Sponsor Organization:
PAREX Bank, Latvia

Supporting Organizations:
Latvian Transport Development and Education Association
Latvian Academy of Sciences
Latvian Operations Research Society
International Transport Academy
Telecommunication Association of Latvia

All articles are reviewed.
Articles can be presented in the journal in English.

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TRANSPORT and TELECOMMUNICATION, 2008, Vol. 9, No 2
ISSN 1407-6160
The journal of Transport and Telecommunication Institute (Riga, Latvia).
The journal is being published since 2000.

The papers published in Journal "Transport and Telecommunication" are included in
SCOPUS (since 2008, Vol. 9, No 2), **Elsevier Database**
www.info.scopus.com
www.elsevier.com

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RESULTS OF INVERSE PROBLEM SOLUTION FOR RADAR MONITORING OF ROADWAY COVERAGE

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This work has been focused on the development of approach to the inverse problem of subsurface radar sounding solution in frequency domain. We propose to use an Ultra Wide Band pulse radar combined with a line transmitter and receiver antennas.

Forward modelling is based on using of three-component mixing formula for estimation of soil electromagnetic properties in frequency domain, as well as on linear system response functions for the radar antenna system, and on the equations for wave propagation in a horizontally multi-layered medium representing the subsurface.

Model inversion, realized by numerically, uses results of forward modelling simulation in limited range of the soil electromagnetic properties changing. For realization of model inversion data the genetic algorithm of calculations has been chosen.

Keywords: *radar, soil dielectric properties, radar monitoring, forward modelling, inverse modelling*

1. Introduction

The importance of roadways considerably increases in the modern terms of life. The better is the technical state of roadways, the more efficient and economical is the exploitation of the car transport usage.

The state of roadway coverage has determined its structural features. However it is obviously that the state changes under act of the car loadings and under influencing of environment factors (Fig. 1). There are the so-called calculated periods of the year (spring, autumn), when durability of the structural layers of roadway coverage falls down from geological processes, what is going on in foundation of roadway coverage and covering soils. Counteraction of roadway coverage to the car loadings diminishes as a result.

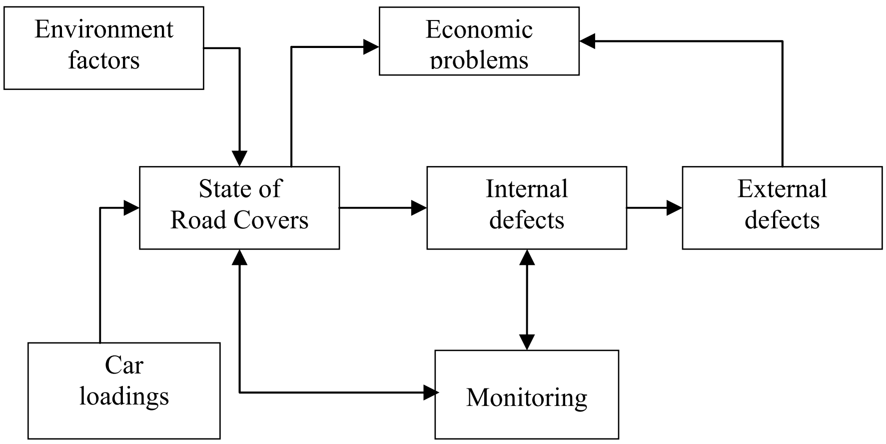

Figure 1. *Monitoring of road covers state*

Before appearance of visible destructions (external defects) of roadway coverage the hidden processes flow into roadway coverage or in its foundation (in laying soils). The hidden processes are characterized the internal defects of roadway coverage (formation of emptiness, multiplying humidity of layers of roadway coverage, infiltration of soil waters, etc.). The timely exposure of internal defects allows in time to take proper measures.

Because the monitoring supervisions of the internal state of road coverage, for instance, monitoring of change humidity and density of laying soils, monitoring the change of thickness of structural layers of roadway coverage, finding out emptiness in roadway coverage are required. Information of monitoring can be used at planning of repair works of and for limitation of the car loadings.

The used usually methods do not allow getting continuous information about structural layers state of roadway coverage, they do not possess the high informing and operativeness. The methods of radar probing of different financial semi-conducting environments are widely used presently, including laying surfaces, such as: soils, mountain breeds, build materials and constructions, etc.

2. Radar Monitoring of Roadway Coverage

Radar monitoring of roadway coverage is an electromagnetic (EM) method for quality estimation of road covers, which is the most efficient for natural soil roads. System of radar monitoring executes the two kinds of processing: primary signal processing, which gives continuous subsurface profile of probing subject, and secondary signal processing, which gives estimation of a roadway physical properties.

The main problem in the secondary signal processing is an interpretation of radar measurements. The interpretation of radar measurements in form estimation of electrical properties of a probed subject is an inverse problem of radar probing, which is in general ill-posed and non unique [5]. The most commonly used analysis methods utilize comparison of direct solutions for assumed subsurface structure with the measured data in time domain [6, 7]. Modern techniques utilize personal computer to perform comparison in frequency domain and iterate the assumed model until the best fit in some since is achieved.

Simplified flow diagram of calculation procedure for this case is shown on Figure 2.

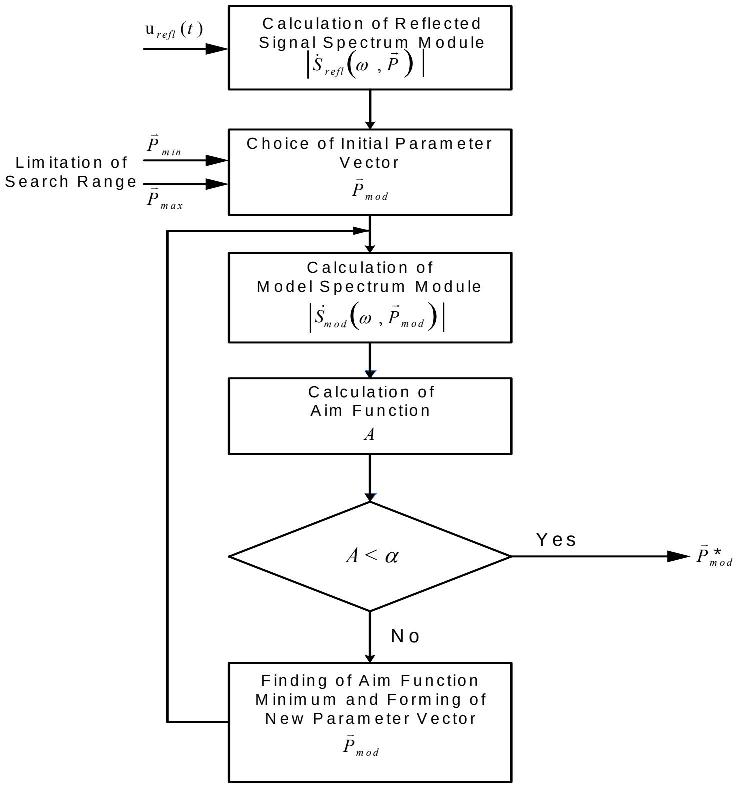

Figure 2. *Simplified flow diagram of procedure to solve radar inverse problem in the frequency-domain*

For formalization of inverse problem vector of parameters $\vec{P} = \{p_1, p_2, ..., p_n\}$ is entered, which components p_i determines a great number of legitimate values of parameters for model vector $\vec{P}_{mod} \subseteq \vec{P}_{lim}$.

Results of the reflected signal spectrum calculations compare with these for model signal spectrum, which calculated for all search range of data on electrical properties of probing object. The end of the calculations will be by meeting the condition [1]:

$$A = \sum_{i=1}^{L}\left(\left|\dot{S}_{refl}\left(\omega_i, \vec{P}\right)\right| - \left|\dot{S}_{mod}\left(\omega_i, \vec{P}_{mod}\right)\right|\right)^2 < \alpha, \tag{1}$$

where: $\left|\dot{S}_{refl}\left(\omega_i, \vec{P}\right)\right|$ – a module of the reflected signal spectral density for estimated vector $\vec{P}$;

$\left|\dot{S}_{mod}\left(\omega_i, \vec{P}_{mod}\right)\right|$ – a module of the model signal spectral density for model vector;

α – mean of threshold, which limited by a permissible absolute error of the parameter estimations.

3. Modelling Electromagnetic Properties of Natural Soils

Moisture content and bulk density largely characterizes physical and mechanical soil status and behaviour. A non-destructive determination of these soil properties is essential.

The electromagnetic properties of two-phase mixture of soil and water can be analysed by using many empirical or theoretical formulas. Among them, Maxwell-Garnett mixing formula

$$\dot{\varepsilon}_{eff} = \dot{\varepsilon}_s \left[1 + \frac{3W\left(\dot{\varepsilon}_w - \dot{\varepsilon}_s\right)}{\dot{\varepsilon}_w + 2\dot{\varepsilon}_s - W\left(\dot{\varepsilon}_w - \dot{\varepsilon}_s\right)} \right] \qquad (2)$$

and Odelevsky mixing formula

$$\dot{\varepsilon}_{eff} = \dot{\varepsilon}_w \left[1 + \frac{1 - W}{\dfrac{W}{3} + \dfrac{\dot{\varepsilon}_w}{\dot{\varepsilon}_s - \dot{\varepsilon}_w}} \right] \qquad (3)$$

are well-known in literature [2, 3]. If soil volumetric water content of soil W%, as well as dielectric permittivities of mixture components $\dot{\varepsilon}_S$ (soil) and $\dot{\varepsilon}_w$ (water) are known, then equivalent dielectric permittivity $\dot{\varepsilon}_{eff}$ of two-phase mixtures soil-pore water may be estimated according to (2) and (3).

Unfortunately, calculation data are not correct in wide frequency range therefore more adequate for practice is three-component mixing formula. This formula has been developed to calculate the equivalent dielectric permittivity of the three-phase mixture air-soil-bulk pore fluid in form:

$$\dot{\varepsilon}_{eff} = \mathrm{Re}\,\dot{\varepsilon}_{eff} - j\,\mathrm{Im}\,\dot{\varepsilon}_{eff} = \left\langle \dot{\varepsilon} \right\rangle + \frac{\sum_{i=1}^{n} P_i \dfrac{\dot{\varepsilon}_i - \left\langle \dot{\varepsilon} \right\rangle}{\dot{\varepsilon}_i + 2\left\langle \dot{\varepsilon} \right\rangle}}{\sum_{i=1}^{n} P_i / (\dot{\varepsilon}_i + 2\left\langle \dot{\varepsilon} \right\rangle)}, \qquad (4)$$

where: i – number of the mixture component; $P_i = V_i/V$ – relative volumetric content of i-th component; $\left\langle \dot{\varepsilon} \right\rangle = \sum_{i=1}^{n} P_i \dot{\varepsilon}_i$ – average mean of mixture complex dielectric permittivity.

If W is volumetric water content of soil with P soil porosity, then one can see that $P_1 = (P - W)$ and $\dot{\varepsilon}_1 = 1$(air); $P_2 = (1 - P)$ and $\dot{\varepsilon}_2 = \varepsilon'_2 - j\varepsilon''_2$ (non-clay dry minerals); $P_3 = W$ and $\dot{\varepsilon}_3 = \dot{\varepsilon}_w$ (pore water). For calculations of real ε'_2 and imaginary ε''_2 parts of the dry mineral complex dielectric permittivity $\dot{\varepsilon}_2$ it is possible to use Krotikov's empirical formulas [3]:

$$\dot{\varepsilon}'_2 = \left(1 + 0.5 \cdot \gamma_m\right)^2 \text{ and } \dot{\varepsilon}''_2 = \dot{\varepsilon}'_2 \cdot \gamma_m \cdot 10^3, \qquad (5)$$

where γ_m – density of soil mineral foundation.

The complex dielectric permittivity of the pore water $\dot{\varepsilon}_w$ can be described by the Debye's relaxation function as:

$$\dot{\varepsilon}_w = \varepsilon(\infty) + \frac{\varepsilon(0) - \varepsilon(\infty)}{1 + j\omega\tau_w} - \mathrm{j}\frac{\sigma_w}{\omega\varepsilon_0}, \qquad (6)$$

where $\varepsilon(0) = \lim_{\omega \to 0} \dot{\varepsilon}_w$ and $\varepsilon(\infty) = \lim_{\omega \to \infty} \dot{\varepsilon}_w$ – are the pre-relaxation and post-relaxation real permittivities of the pore water molecules; τ_w – relaxation time constant; $\varepsilon_O = \dfrac{10^{-9}}{36\pi}$ – electromagnetic constant of free space; ω – angular frequency; σ_w – water DC electrical conductivity.

According to [2], $\varepsilon(\infty)$ is approximately 5.5, and this value is almost unaffected by the temperature and pore fluid salinity. In contrast, $\varepsilon(0)$ and τ_w are affected by the temperature $T^\circ K$. Temperature dependencies of $\varepsilon(0)$ and τ_w may be presented in the form of empirical expressions as:

$$\varepsilon(0) \approx 87.74 - 0.4\mathrm{T} + 9.4 \cdot 10^{-4}\mathrm{T}^2 - 1.4 \cdot 10^{-6}\mathrm{T}^3 , \tag{7}$$

$$\tau_w \approx \frac{1}{2\pi}\left(1.1 \cdot 10^{-10} - 3.8 \cdot 10^{-12}\mathrm{T} + 6.9 \cdot 10^{-14}\mathrm{T}^2\right). \tag{8}$$

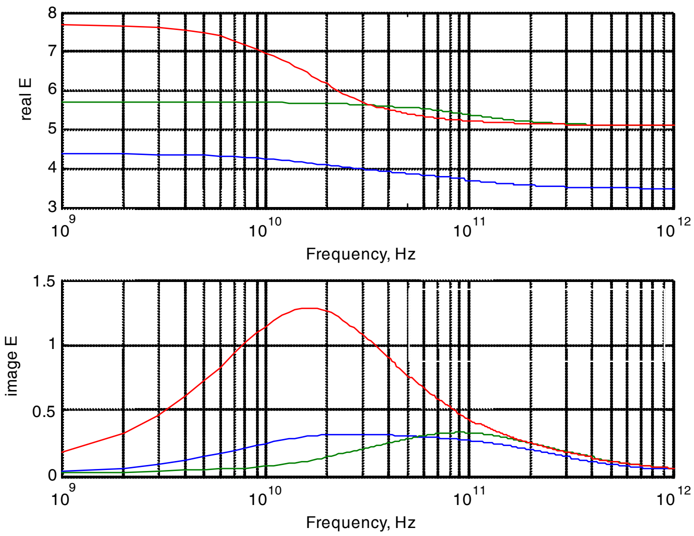

Figure 3. *Frequency dependencies of real* ($\mathrm{Re}\,\dot{\varepsilon}_{eff}$) *and imaginary* ($\mathrm{Im}\,\dot{\varepsilon}_{eff}$) *parts of equivalent dielectric permittivity of sandy soil* ($\gamma_m = 1{,}67 g / cm^3; W = 5\%$)*, calculated for three-phase mixture model* (*3*) *and two-phase mixture formulas: Maxwell-Garnett's* (*1*) *and Odelevsky's* (*2*)

DC electrical conductivity of pore water is affected by pore fluid salinity. The salinity S is defined as the total mass of solid salts in grams dissolved in one kilogram of solution and expressed as parts per thousand (ppt). For $NaCl, NaSO_4, MgCl_2, MgSO_4$ solutions with salt concentration $C \le 10 g/dm^3$ may be used the following empirical expression [3]:

$$\begin{aligned}\sigma_w(T,N) = \sigma_w(25^0 C, N)\{1 - 1.962 * 10^{-2}\Delta + 8.08 * 10^{-5}\Delta^2 \\ - N\Delta[3.02 * 10^{-5} + 3.922 * 10^{-5}\Delta + N(1.721 * 10^{-5} - 6.584 * 10^{-6}\Delta]\},\end{aligned} \tag{9}$$

where: $N = C / M_{salt}$ – normality of soil water; M_{salt} – salt equivalent ($M_{NaCl} = 58.45\ g, M_{Na_2SO_4} = 71\ g, M_{MgCl_2} = 47.45\ g, M_{MgSO_4} = 60\ g$);

$\Delta = (25^0 C, N - T^0 C)$ and $\sigma_w(25^0 C, N) = N(10.394 - 2.38N + 0.683N^2 - 0.135N^3)$.

Using the three-component mixing formula (3), the frequency dependence of theoretical equivalent dielectric permittivity on a soil-water mixture at different volumetric water content W[%] and pore fluid salt concentration $C[g/dm^3]$ are calculated. Some results of such calculations are plotted on Figure 3. For comparison, calculation results for two-phase mixtures in accordance with Maxwell-Garnett's (2) and Odelevsky's (3) formulas are presented on Figure 3 too.

4. Forward Modelling of Subsurface Radar Probing

The possibility to estimate accurately the subsurface electric properties from subsurface radar signals using inverse modelling is obstructed by the appropriateness of the forward model describing the subsurface radar system.

A typical subsurface radar system has three main components: transmitter and receiver that is directly connected to antennas, and display with a timing control unit [3]. The transmitting antenna radiates a short high-frequency 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 scattered back toward the medium surface induce a signal in the receiving antenna, and are recorded as digitised signals for display and further analysis

According to that, a channel of the signal forming for subsurface radar probing in frequency domain may be presented as it is shown on Figure 4 [4]. There $\dot{K}_{ANT}(\omega)$ is a complex transfer function of the antenna system, $\dot{R}_{refl}(\omega)$ is a reflection coefficient of the inspected object, and $\dot{K}_{FW}(\omega)$ is a complex transfer function of antennas direct coupled EM field.

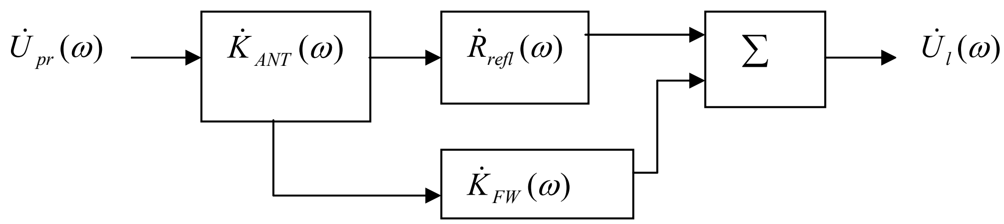

Figure 4. *Channel the signal forming for subsurface radar probing in frequency domain*

As a result, complex transfer function of radar subsurface probing model may be written in the following form:

$$\dot{K}_{RAD}(\omega) = \dot{U}_l(\omega)/\dot{U}_{pr}(\omega) = [\dot{K}_{FW}(\omega) + \dot{K}_{ANT}(\omega)\dot{R}_{refl}(\omega)]. \tag{10}$$

It depends on conditions of the subsurface radar probing, as well as on geometry of antennas location. Now let us consider a forward modelling of the subsurface radar probing for line radar antennas with geometry as it is shown on Figure 5.

If a height of antennas location H over upper medium boundary is sufficiently small ($H \approx 0$), then complex transfer function of the antenna system may be presented as follows [4]:

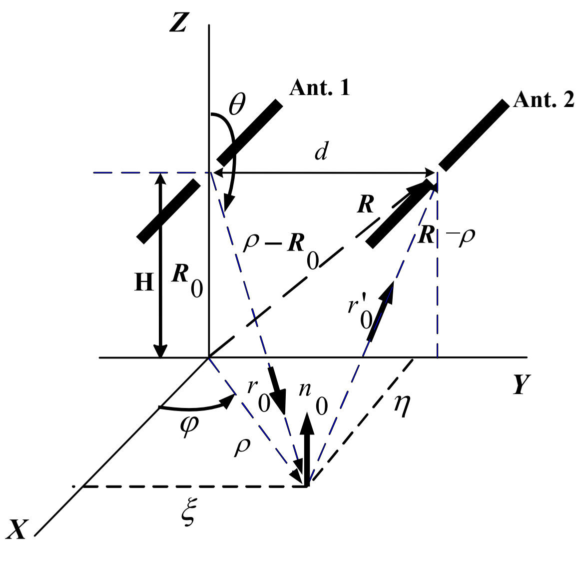

Figure 5. *Geometry of subsurface radar antennas location*

$$\dot{K}_{ANT}(\omega) = -j\frac{60\pi\sqrt{\dot{\varepsilon}_2(\omega)}\,\dot{L}^2_{eff}(\omega)R_L}{l\sqrt{d^2+(2h_2)^2}[R_L+\dot{Z}_{in}(\omega)]^2}\cdot\frac{\cos\theta_0}{\sqrt{\dot{\varepsilon}_2(\omega)\sin^2\theta_0}-\sqrt{\dot{\varepsilon}_2(\omega)}\cos\theta_0}e^{-jk_0\sqrt{\dot{\varepsilon}_2(\omega)}\sqrt{d^2+(2h_2)^2}}, \tag{11}$$

where: $j=\sqrt{-1}$ – image unity; l – half length of liner antennas Ant. 1 and Ant. 2; d – distance between Ant.1 and Ant.2 antennas; $k_0 = \omega/c$ – wave number for free space; $\omega = 2\pi f$ – angular frequency of monochromatic wave with liner frequency f; $\theta_0 = arctg(d/2h_2)$ – incident angle; h_2 and $\dot{\varepsilon}_2$ are thickness and complex permittivity of inspected layer; $\dot{Z}_{in}(\omega)$ – input impedance of transmitting antenna; R_L – load resistor of receiving antenna; $\dot{L}_{eff}(\omega)$ – effective antennas length

$$\dot{L}_{eff}(\omega) = \frac{2}{\dot{k}_L} \cdot \frac{1-\cos\dot{k}_L l}{\sin\dot{k}_L l} \tag{12}$$

for complex wave number [2]

$$\dot{k}_L = k_0 \left\{ 1 + \frac{2}{\ln\frac{2H}{a}} \left[\frac{1}{(2k_0\dot{n}H)^2} - \frac{K_1(2k_0\dot{n}H)}{2k_0\dot{n}H} + j\frac{\pi I_1(2k_0\dot{n}H)}{4k_0\dot{n}H} - j\left(\frac{2k_0\dot{n}H}{3} + \frac{(2k_0\dot{n}H)^3}{45} + \ldots \right) \right] \right\}^{\frac{1}{2}},$$

which depends on antennas diameter – a, antennas high H over upper boundary of inspected medium, and complex refraction coefficient $\dot{n} = \sqrt{\dot{\varepsilon}_2(\omega)}$. There $K_1(.)$ and $I_1(.)$ are modified Bessel's functions of the first order.

Following [4], complex transfer function of antennas direct coupled field we write as

$$\dot{K}_{FW}(\omega) = j\frac{60\pi\dot{L}^2_{eff}(\omega)R_L}{(\sqrt{\dot{\varepsilon}_2(\omega)}-1)ld[R_L + \dot{Z}_{in}(\omega)]^2} \cdot \left[\sqrt{\dot{\varepsilon}_2(\omega)} e^{-jk_0\sqrt{\dot{\varepsilon}_2(\omega)}d} - e^{-jk_0 d} \right] \tag{13}$$

and the model reflection coefficient we write as

$$\dot{R}_{refl}(\omega) = \dot{R}_{2-3}(\omega, \theta_0^{'}) = \frac{\sqrt{\dot{\varepsilon}_3(\omega)}\cos\theta_0 - \sqrt{\dot{\varepsilon}_2(\omega) - \dot{\varepsilon}_3(\omega)\sin^2\theta_0}}{\sqrt{\dot{\varepsilon}_3(\omega)}\cos\theta_0 + \sqrt{\dot{\varepsilon}_2(\omega) - \dot{\varepsilon}_3(\omega)\sin^2\theta_0}} \tag{14}$$

Equations (11), (13), (14) may be used for further modelling of radar subsurface probing of soils in frequency domain. If we want to see signals in time domain, then we must perform transformation

$$u_l(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \dot{K}_{RAD}(\omega)\dot{S}_{probe}(\omega)\, e^{-j\omega t}\, d\omega, \tag{15}$$

where $\dot{S}_{prob}(\omega)$ – the spectrum of probe signal, which used for excitation of the transmitting antenna.

5. Numerical Results of Model Inversion

Model inversion, we realized by numerically in the limited range of the soil electromagnetic properties changing according to equation (1).The probing roadway coverage is modelled by three-layer media with a changing of the primary parameters as it is given in Table 1.

Table 1. The primary parameters changing for model of probing object

N	Primary parameters of model soils	Range of the parameter changing		
		Medium 2	**Medium 3**	**Medium 4**
1	Thickness of layer	$\mathbf{h}_2, \mathbf{m} = (0,1...0,5)$	$\mathbf{h}_3, \mathbf{m} = (0,1...0,5)$	$\mathbf{h}_4 \to \infty$
2	Bulk density	$\gamma_2, gcm^{-3} = (1,35..2,0)$	$\gamma_2, gcm^{-3} = (1,35..2,0)$	$\gamma_3, gcm^{-3} = (1,8..2,5)$
3	Porosity of soils	$P_2, \% = (12...35)$	$P_2, \% = (12...35)$	$P_3, \% = (15...20)$
4	Volumetric moisture content	$W_2, \% = (3...5)$	$W_2, \% = (3...5)$	$W_3, \% = (5...12)$
5	Salt concentration of pore water	$C, gdm^{-3} = (1,0....3,0)$		
6	Type of salt	$NaCl, NaSO_4, MgCl_2, MgSO_4$		

The next secondary parameters of medium of roadway coverage are chosen for investigation of inversion problem:

ε' – real ($\mathrm{Re}\,\varepsilon_{eff}$) part of equivalent dielectric permittivity of media;

σ – DC electrical conductivity of media;

h – thickness of layer of media.

Value of ε' and σ has been received by the help of (4), (5), (6), (7), (8) and (9) equations. Values of these secondary parameters for the model of roadway coverage are presented in Table 2.

Signal on output of receiving antenna, which has been received by the help of (11), (13), (14) and (15) equations and secondary parameters are presented in Table 2, it is shown on Figure 6.

Table 2. The secondary parameter's value is using for model of road coverage

Number of medium	Secondary parameters of medium		
	ε'	σ	**h**
2	2.6	0.0015	0.3
3	7.0	0.001	0.4
4	15.0	0.05	∞

The spectrum of this signal is shown on Figure 7. This spectrum has been used as a model spectrum and it is in expression (1) at investigation of inverse problem.

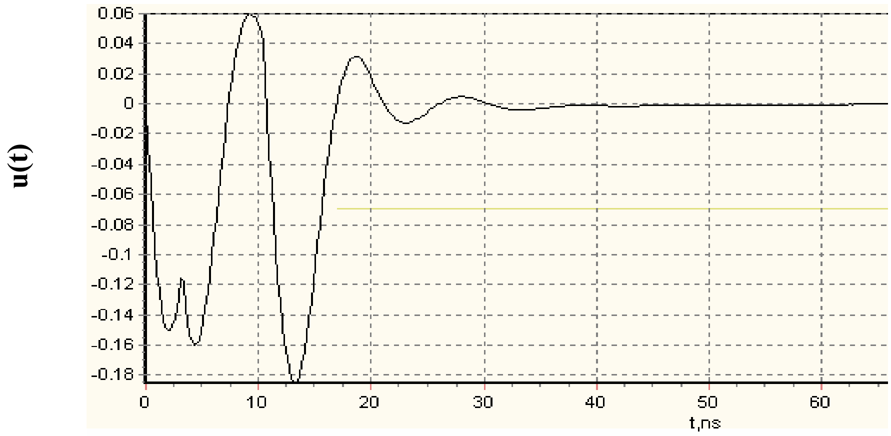

Figure 6. *Model reflected signal on output of receiving antenna for H = 0,01m, l = 0,5 m*

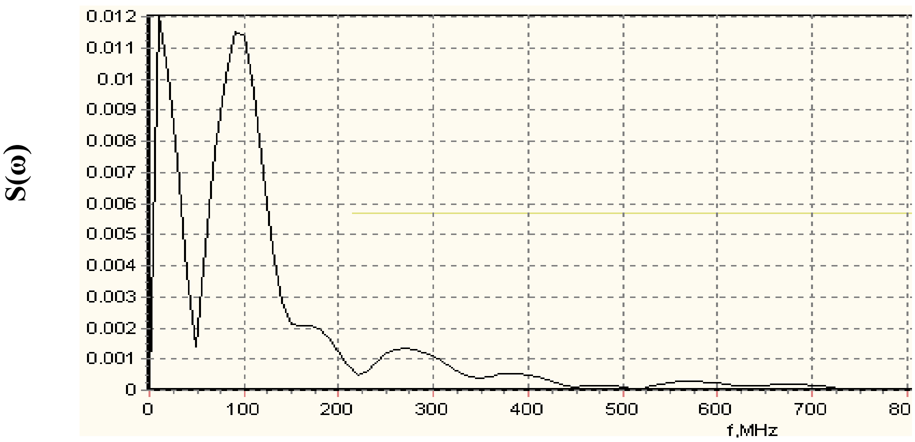

Figure 7. *Model spectrum of reflected signal on output of receiving antenna for H = 0,01 m, l = 0,5 m*

For realization of model inversion data the genetic algorithm of calculations [5] has been chosen with the following characteristics:

- Maximal number of generations.. 50;
- Coding alphabet of an estimated parameters .... binary;
- Number of bit per parameter 6;
- Probability of crossing over.. 0,9;
- Probability of mutation.. 0,05;
- Method of selection .... roulette;
- Admitted number of population into generation for the aim functional means improving .... 500.

As it is known from technical literature [5], one from three conditions is necessary for completing of the data processing by genetic algorithm. These are the following:

- Appropriate quality of solution is received (for radar subsurface inspection of road covers it means that parameters of object are estimated with sufficient accuracy);
- Local extremity has been found but algorithm cannot come out from this state;
- Maximal number of population into generation is formed but appropriate quality of solution is not received.

We investigated these items for our process of the model inversion. For these purposes in all performed estimations of the secondary model parameters we determinate the means of aim functional A, which corresponds to the completion of a computation process. Then the data has been averaged and used for analyses.

In Table 3 are presented averaged means of aim functional A, which corresponds to the completion of a computation process for different relative means of threshold $\delta_\alpha,\%$ and maximal frequency $F_{\max}$.

There have been used 100 meanings of the aim functional A in order to receive its average meaning.

Table 3. Averaged means of aim functional A, which are corresponded to the completion of a computation process

N	Relative mean of threshold $\delta_\alpha,\%$	Maximal frequency of analysis $F_{\max}$, MHz (Relative means of used signal energy E_n)			
		100 (88,0%)	200 (98,4%)	300 (99,6%)	500 (99,9%)
1	0,005	0,056	0,026	0.031	0.031
2	0,025	0.017	0.028	0.031	0.031
3	0,05	0.030	0.039	0.039	0.039
4	0,5	0,062	0,182	0,206	0,191
5	5,0	0.065	0.189	0,244	0,211

For estimation of model secondary parameters we choose a module of effective complex dielectric permittivity of medium 2, average in used frequency range $(F_{\min}...F_{\max})$, as well as, a thickness of this medium. Model inversion has been performed for different relative means of threshold $\delta_\alpha,\%$ and maximal frequency $F_{\max}$ in order to investigate influence of factors on accuracy of the parameter estimations and an efficiency of calculation process. The search range of parameter vector has been limited by the ± 50% changing of parameters. The main results of such estimations are presented in Table 4.

Table 4. The main results of accuracy estimation of model's secondary parameters

N	Relative mean of threshold $\delta_\alpha,\%$	Maximal frequency of analysis $F_{\max}$, MHz (Relative means of used signal energy E_n)							
		100 (88,0%)		200 (98,4%)		300 (99,6%)		500 (99,9%)	
		$\delta_{\varepsilon_2},\%$	$\delta_{h_2},\%$	$\delta_{\varepsilon_2},\%$	$\delta_{h_2},\%$	$\delta_{\varepsilon_2},\%$	$\delta_{h_2},\%$	$\delta_{\varepsilon_2},\%$	$\delta_{h_2},\%$
1	0,005	7,7	4,29	4,19	2,86	3,96	2,39	4,08	2,0
2	0,025	6,73	6,20	4,11	2,61	4,32	2,22	3,72	1,96
3	0,05	7,37	7,49	5,69	3,33	4,67	2,31	4,36	2,85
4	0,5	7,33	7,14	6,4	6,26	6,56	6,5	6,88	5,86
5	5,0	7,23	6,63	6,89	6,72	7,05	6,63	6,39	5,92

As it is seen from the presented data the relative errors of the secondary parameter estimation not exceed 10% both for effective dielectric permittivity and thickness of medium 2. Increasing of relative means of threshold more than $\delta_\alpha ,\% > 0{,}05$ gives essential growing of errors for all used means of maximal frequency of analysis $F_{\max}$.

We investigate the influencing of search range for genetic algorithm on accuracy of the secondary parameter estimations. The results of investigations are presented on Figures 8, 9 and 10. The presented variations have been got by means of statistical treatment 100 decisions of inverse problem.

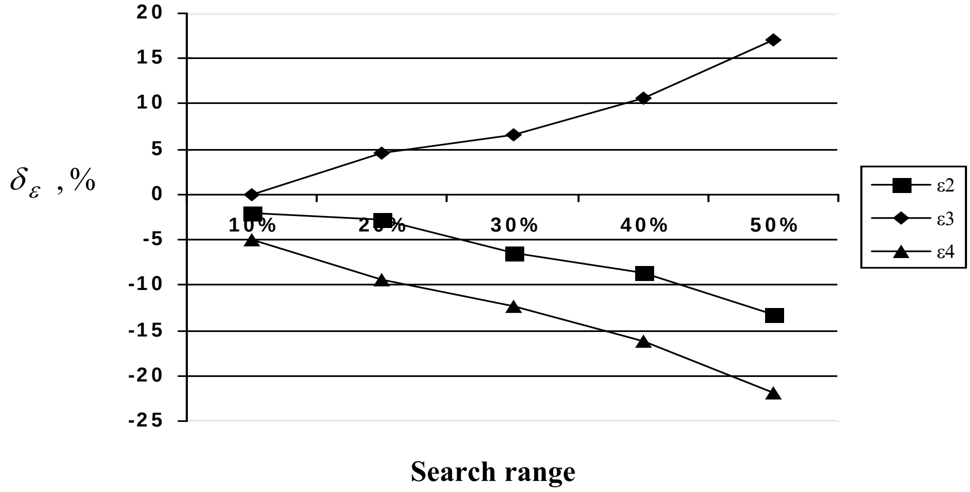

Figure 8. *Variation of relative errors % of the ε' estimations with change of search range for genetic algorithm*

Variations of relative errors of the ε' estimations with change of search range (Fig. 8) show that real part of equivalent dielectric permittivity of layers of model roadway coverage are reconstructed by genetic algorithm with an identical error, but with different signs. Real part of equivalent dielectric permittivity of foundation of model roadway coverage is reconstructed with less accuracy.

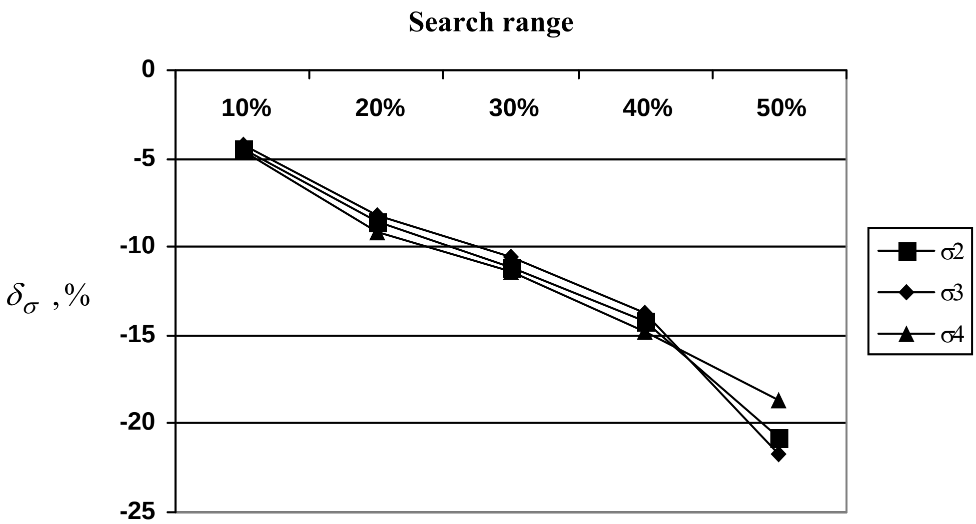

Figure 9. *Variation of relative errors % of the σ estimations with change of search range for genetic algorithm*

Relative errors of the electrical conductivity (σ) estimations do not depend on the model value and from position of layer (medium) in the model roadway coverage (Fig. 9). Relative errors of the electrical conductivity (σ) estimations depend on the search range practically linearly.

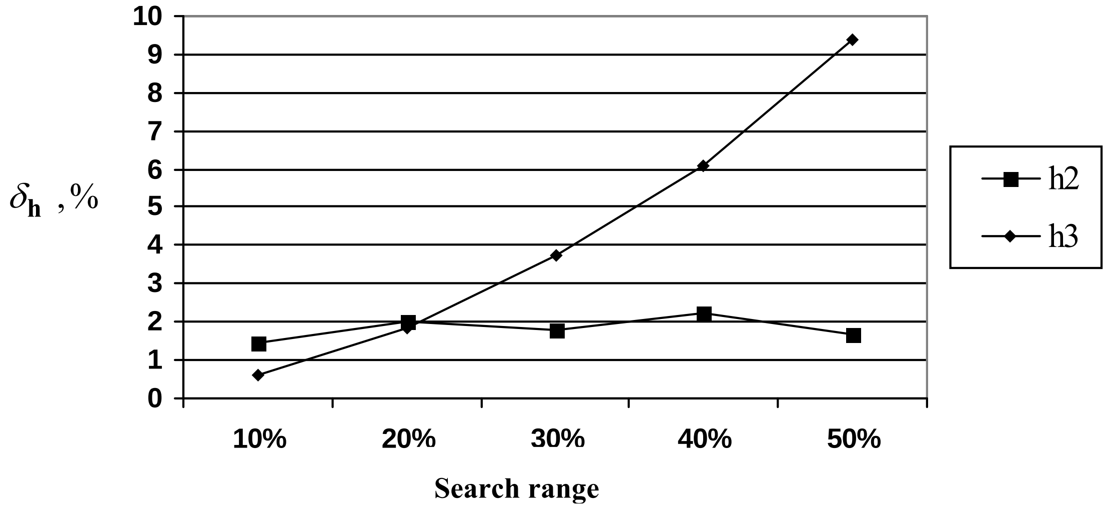

Figure 10. *Variation of relative errors % of the h estimations with change of search range for genetic algorithm*

The relative error of thickness estimation of the first layer (h_2) in roadway coverage (Fig. 10) does not depend on a priori information (the search range). The relative error of thickness estimation of the second layer (h_3) in roadway coverage depends on a priori information substantially.

6. Conclusions

The main results of these model-based experiments are the following:

- The value of threshold α influences on errors of estimation of the model parameters, as well as on the number of population into generation, which must be formed;
- Mean of threshold α must be set in consideration of energy of spectral constituents in the reflected signal, which are used for decision of inverse problem. Such choice of value of threshold allows determining the electrical properties of the roadway coverage with the set error, using the eventual number of generation, and, consequently, substantially reduce a duration of the inverse problem decision
- In our experiments the influences of chromosome length, terms of mating and mutations on the errors of the model parameter determination have been investigated. Finding the dependencies, which are to be found, may be useful to optimise the structure of genetic algorithm for realization of the secondary signal processing in the radar monitoring system.

References

1. Krainyukov, A., Kutev, V. Intelligent system for radar monitoring of transport communications. In: *7th International Conference "Reliability and Statistics in Transportation and Communication (RelStat'07)*, *25–27 October 2007, Riga, Latvia"*. Riga: Transport and Telecommunication Institute, 2007, pp. 312–320.
2. King, R.W.P., Smith, G. S. *Antennas in Matter. Fundamentals, Theory, and Applications*. The MIT Press, 1981. 824 p.
3. Finkelshtein, M. I., Kutev, V. A., Zolotarev, V. P. *Application radar-tracking under superficial sounding in engineering geology.* M.: Nedra, 1986. 128 p. (In Russian)
4. *Krainykov, A. V., Kutev, V. A. Modelling of a path of formation of the reflected signals in problems under superficial radar-locations of layered terrestrial covers. In: Scientific Papers of Riga Aviation University. Riga:* Riga Aviation University*,* 1995, pp. 17–23. (In Russian)
5. Gladkov, L. A., Kureichik, V. M. *Genetic Algorithms* / Edited by V. M. Kureichik. 2nd edition, corrected. M.: Fizmatlit, 2006. 320 p. (In Russian)

Transport and Telecommunication, 2008, Volume 9, No 2, 14–23
Transport and Telecommunication Institute, Lomonosov 1, Riga, LV-1019, Latvia

APPLICATION OF TEMPORAL ELEMENTS IN THE RAILWAY SCHEDULE SYSTEMS

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The paper deals with the issues of building a temporal database for the railway schedule. For the mathematical description of the railway schedule system, we suggest to use set theory and algebra of logics. We define the periodicity parameters and temporal elements and formulate the rules of their calculation. We also consider practical examples on defining the dates on which the set version of the train schedule becomes an actual subject.

Keywords: *railway transportation, schedule, periodicity, temporal database, temporal element*

1. Introduction

The given paper considers the task of supporting the railway schedule in information systems (IS). The main problems of holding the schedule in the database are connected with the great number of its variants conditioned by season changes of the railway changes, different days of the week, planned and unplanned repair works, re-arranging holidays and weekdays and other factors. The schedule-supporting task can be solved by means of a calendar stating the ply of each train on each day of the year. However, the number of entries describing on what day, at what time and at what station each train will be having a stop, will approximately equal the product of the number of trains by the average number of stops and by the number of days covered by the schedule. With this approach we will need about 2 million records to hold the local Latvian railway schedule in the relational database and for larger railway companies the volume of the corresponding database will increase by about ten times. Moreover, holding the schedule for several years will increase the number of records up to hundreds of millions. However, the main problem of the above approach lies not so much in the volume of the stored data but in the trustworthiness of these data and in the operativeness of entering changes in the schedule. When these changes are frequent, the task becomes much more complicated.

The above-mentioned circumstances have served the basis for carrying out the given research, in which we suggest the principle of realizing the schedule system on the basis of the temporal database principles [1, 2]. In the given paper, the authors consider the issues of building a temporal database (TDB) of the railway schedule with the use of the periodicity parameters and temporal elements. The suggested approach is applied in designing the informational system of the inland Latvian railway train schedule.

2. Temporal Database Model in the System of the Railway Schedule

Principles of designing a temporal database assume that the database holds all objects versions and access to all of them is available for the user [1]. The TDB peculiarities are first of all connected with using the stored objects of the temporal database for the VIEW. The main concept in the temporal model is lifespan. It means the duration of time period associated with the existence of the object in a concrete state.

One of the serious problems occurring in the considered IS of the railway schedule is connected with the overlapping of the objects' lifespan, when one schedule overlaps another (see Fig. 1). The peculiarity of the given situation is that, the object when changed cannot lose the actuality of its state either in the past or in the future – for a certain period only it is substituted by another version. As a result, more than one actual tuple describing different versions of the same object's property can exist at one time.

The latter contradicts the very idea of TDB, therefore it is necessary to trace and settle such situations by making special data queries.

To explain the considered case we refer to example shown on Figure 1. We assume that the variable t_n means the moment of reviewing. The season railway schedule is fixed in February for the period from the moment t_1 to t_6. Later on in March, the schedule is changed for the period from the moment t_2 to t_4, and then in April, we make one more change for the period from t_3 to t_5. For the inquiry of the train traffic at the moment t_{n1}, we'll get the schedule fixed in February for $[t_{1,} t_6]$, at the moment t_{n2} – the schedule fixed in April for $[t_3, t_5]$, and at the moment t_{n3} we again have the schedule for $[t_{1,} t_6]$.

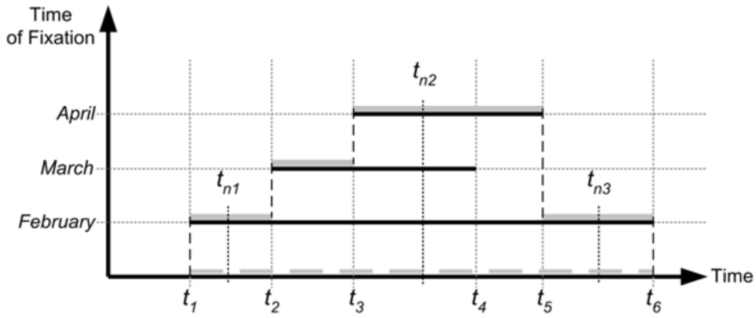

Figure 1. *Crossing of object lifespan in DB of the railway schedule system*

In practice, the train may have simultaneously several valid schedules for a long period. In this situation, every schedule is fixed with the account of the days of traffic and with the use of different periodicity characteristics, for example: on the weekdays, on the rest-days, on the particular rest-days, on the first weekday, on the last day of the weekend (which sometimes may be Monday), on the even, on the odd days, etc.

Let us take as an example a multi-variant train schedule presented on Figure 2. And we can see, for the train numbered *n* there are two basic schedules, one for the weekdays – *wd*, the second one for the rest-days – *rd*. Both schedules are actual in the time period $[t_1, t_4]$, but in different weekdays. Then, for repair works we make a change in the schedule of the given train on Tuesdays and Thursdays for the time period from t_2 to t_3. Thus, in the time period $[t_2, t_3]$ we already have three actual schedule versions valid for the days, which correspond to the characteristics *wd*, *rd* and *Tue, Thu*, with only one schedule version *wd* or *rd*, or *Tue, Thu* valid for one day.

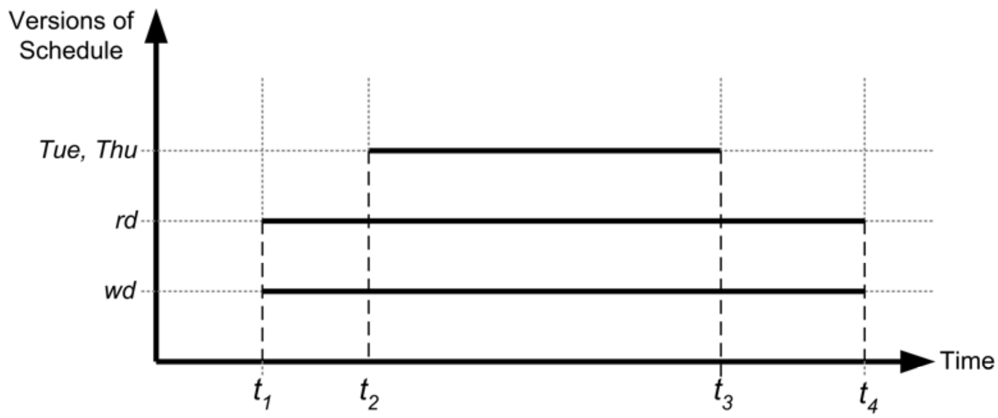

Figure 2. *Variety of the train schedule's valid versions: wd, rd and Tue, Thu*

We shall illustrate the former statement with the diagram on Figure 3, in which the axis "Day of Week" shows the weekdays in the following sequence: 1 – Monday, 2 – Tuesday, etc. The granularity level of this schedule equals one day; therefore, we can state that time in our system has a discrete character and the versions possess the property of periodicity. As we can see on the figure, on different weekdays, one version from the three ones is the actual train schedule, and the other two are in the "shadow zone" at the moment [1]. Here, the train schedule for Tuesdays and Thursdays (characteristic *Tue,Thu*) overlaps the weekday schedule with the characteristic *rd* (see Fig. 3).

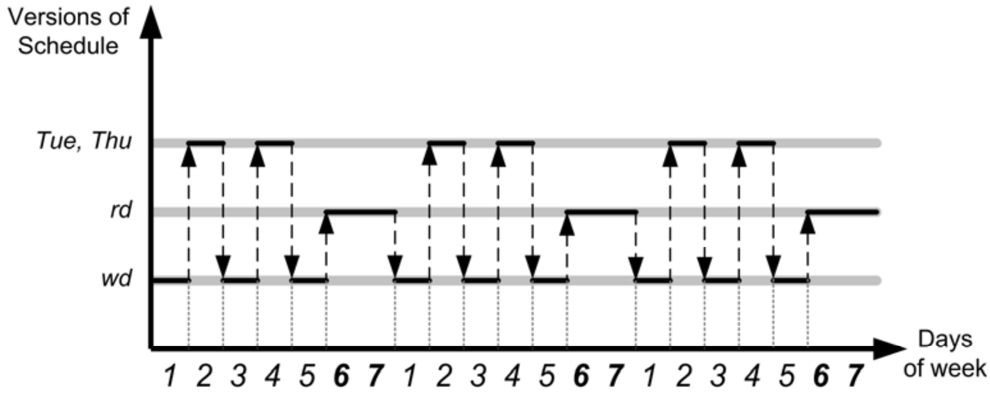

Figure 3. *Periodicity in the train schedule*

However, with the exception of the periodical versions of the train schedule, there may be one-time schedule changes. These are referred to holidays and additionally fixed holidays or cancelled holidays. Point out such case of the schedule change when a weekday changes place with a rest-day. Thus, for example, in 2007, in Latvia, Monday April 30 (weekday) changed place with Saturday April 14 (rest-day). As a result, the trains of the April 30 schedule pursued according to the April 14 (rest-day) schedule and vice versa. Such changes or special fixations sometimes cause paradoxes. For example, in 2007 Monday November 19 was fixed as an additional rest-day and all trains on this day plied according to the November 18 (rest-day) schedule, which caused the periodicity failure as it is shown on Figure 4. It should be added that some trains with the periodicity of the Sunday day were cancelled on November 18 due to the fact that a regular Sunday day is also the last rest-day of the week and additional Sunday day trains are fixed to carry passengers from traditional places of rest on these days.

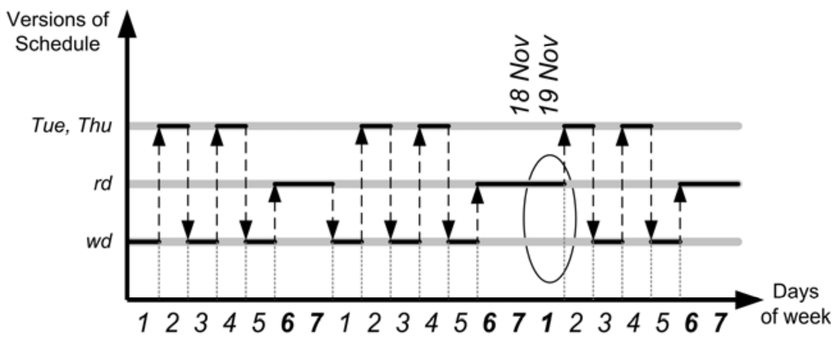

Figure 4. *Failure in the periodicity of the train schedule*

For the correct work of the schedule system with the account of all the above non-trivial rules, we need a clear formalization of the task setting and describing the schedule temporal model. For this, we will take a group of sets characterizing the rules of forming the trains' traffic periodicity, the railway objects and the schedule system as a whole.

3. Formalization of the Schedule Model

3.1. Mathematical Description of the Railway Schedule System

To describe the objects and the rules we will take a number of basic sets:

$S = \{s_1, s_2, ..., s_k\}$ is a set of all railway stations, where k is the power of set *S*;

$N = \{n_1, n_2, ..., n_m\}$ is a set of the railway trains where m is the power of set N ;

We will define the train with number $n \in N$ by the vector of the following type: $v = \left\{ < s_1^{(n)}, T_1 >, < s_2^{(n)}, T_2 >, ..., < s_\alpha^{(n)}, T_\alpha > \right\}$, where the couple $< s_j^{(n)}, T_j >$ defines the *j*-th train stop, in particular, the name of the station $s_j^{(n)} \in S$ and the time of the train departure T_j ; α is the number of the train stops on the schedule v .

For the train numbered n, we can keep several schedule versions characterized by the validity period, time of fixation and periodicity. Correspondingly, we take the following schedule parameters:

t_s is start time when the schedule version comes into action;

t_e is end time when the schedule version expires;

t_{fix} is fixation time, i.e. the moment of entering the given version of the train schedule in the database;

C is the periodicity characteristic used to define the days for which the given schedule will be valid.

Characteristic C presents a logical expression consisting of one or more statements of comparison, which are connected by the logical operations $\vee, \wedge$ and $\neg$ (see [4]). Each statement is an elementary parameter of the p_i periodicity and defines belonging of the day to a particular group, for example, "the day is an even day of the week"; it may be True or False. Elementary periodicity parameters form such a set of attributes on which base we can build logical expressions setting any more complicated periodicity. So, we can write

$$C = f(p_i\,; i = \overline{1,\lambda}) \,, \tag{1}$$

where $p_i \in \mathrm{B} \equiv \{True; False\}$, λ is the number of elementary parameters of the periodicity in characteristic C.

We are going to consider different variants of the periodicity parameter given by the set $P = \{p_1, p_2, ..., p_\pi\}$ where π is the set power; the set elements are the following statements: *ed* is "any weekday" (used in case of daily train ply); *wd* is "work day" (used in case of work days ply); *rd* is "rest-day"; *Mon, Tue, Wed, Thu, Fri, Sat, Sun* are "the corresponding weekday"; *pd* is "the even day of the week"; *nd* is "the odd day of the week"; *lh* is "the last rest-day of the week"; *fw* is "the first work day of the week"; etc.

To identify a concrete version of the schedule for the train with number $n \in N$ we will use the tuple $\left\langle n, C, t_{fix}, t_s, t_e \right\rangle$. Then, the *i*-th version $v_i^{(n)}$ of the schedule for the train number $n \in N$ will be defined by the tuple:

$$v_i^{(n)} = \left\{ \left\langle n, C, t_{fix}, t_s, t_e \right\rangle, \left\langle s_1^{(n)}, T_1 \right\rangle, \left\langle s_2^{(n)}, T_2 \right\rangle, ..., \left\langle s_\alpha^{(n)}, T_\alpha \right\rangle \right\}. \tag{2}$$

Let $V^{(n)} = \left\{ v_1^{(n)}, v_2^{(n)}, ..., v_g^{(n)} \right\}$ be the set of all versions of the schedule for train with number $n \in N$, where g is the set power equal to the number of versions of the *n*-th train schedule; then $V = \left\{ V^{(n_1)}, V^{(n_2)}, ..., V^{(n_m)} \right\}$ is a set of all versions of all trains' schedules.

Then, we introduce the sets characterizing exceptions in the periodicity fixed directly.

$EX(C) = \left\{ ex_1^{(C)}, ex_2^{(C)}, \ldots, ex_\theta^{(C)} \right\}$ is a set of days-exceptions $ex_j^{(C)}$, which are given the C characteristic, where θ is the power of set $EX(C)$. Special example of the set $EX(C)$ are given by the set $EX(wd) = \left\{ ex_1^{(wd)}, ex_2^{(wd)}, ..., ex_w^{(wd)} \right\}$ setting additionally fixed work days by the periodicity characteristic $C = wd$ and the set $EX(rd) = \left\{ ex_1^{(rd)}, ex_2^{(rd)}, ..., ex_q^{(rd)} \right\}$ determining additionally fixed rest-days with the periodicity characteristic $C = rd$;

$EX = \left\{ \left\langle C_1, EX(C_1) \right\rangle, \left\langle C_2, EX(C_2) \right\rangle, \ldots, \left\langle C_l, EX(C_l) \right\rangle \right\}$ is the set of all exceptions for similar periodicity characteristics, where l is the power of the set EX ; the elements of set EX re-define the periodicity attributes for the dates indicated in $EX(C)$.

$Z = \{z_1, z_2, ..., z_\mu\}$ is the set of dates transferred (changed) in the trains' schedule, where z_i is a couple of days $\left\langle d_1, d_2 \right\rangle$ determining that the schedule fixed for d_1 date is now fixed for the d_2 date; μ is the power of set Z .

3.2. Formalization of the Periodicity Model

To define the time in which the version of a particular train schedule becomes urgent for the whole period of its lifespan, we will use the notion of temporal elements TE [3]. Element $TE(C)$ for $C = wd$ is a finite union of intervals t during wd is active: $t_1^{(wd)} \cup ... \cup t_\lambda^{(wd)}$ and $TE(wd)$ also can be denoted by the set $\{t_1^{(wd)},...,t_\lambda^{(wd)}\}$. In this way $TE(C)$ for $C = wd$, $C = rd$ and $C = Tue \vee Thu$ (see Fig. 4 and Fig. 5) can be defined as follows:

$$TE(wd) = \{t_s,...,[64,68],[71,75],...,t_e\}, \tag{3}$$

$$TE(rd) = \{t_s,...,[69,70],[76,77],[83,84],...,t_e\}, \tag{4}$$

$$TE(Tue \vee Thu) = \{t_s,...,[65,65],[67,67],...,t_e\}, \tag{5}$$

where $[64,68]$ is the time interval expressed in days of the year (64 – Monday, 68 – Friday, t_s and t_e are denoted as the start and end points of the interval $t = [t_s, t_e]$.

Thus, the temporal element represents a calculable multitude of the dates' ranges and serves for determining the time in which the version of a particular train schedule becomes topical for all its life cycle. The TE comprises all the information about the schedule periodicity, takes into account all operative changes, the overlaps of some versions, the replacements.

As it is seen from the formulae (3)–(5), temporal elements TE of the schedule versions possess periodicity, therefore, to get the whole set of the TE values, we introduce the extension function $Ext(C)$ [3]. E.g., if $C = Mon \vee Wed \vee Fri$ is the definition of Monday, Wednesday and Friday, $\mathrm{Ext}(\mathrm{C})$ gives as output the set of all Mondays, Wednesdays and Fridays in the time interval of the following schedule version. The periodic event in the time range $[t_1, t_4]$ will be presented as a pair $\langle [t_1, t_4], C \rangle$, and the set of the $TE(C)$ values in the given time range as the extension function Bounded Extension in the format $BExt([t_1, t_4], C)$. With the employment of the used definitions and functions, we define the temporal element for the periodicity characteristic C in the time range $[t_s, t_e]$ as follows:

$$TE(C) = BExt([t_s, t_e], C) \cup EX([t_s, t_e], C) - EX([t_s, t_e], \neg C), \tag{6}$$

where $EX([t_s, t_e], C) \subseteq EX(C)$ is the set of exceptions of the periodicity characteristic C acting in the period of the schedule version validity: $EX([t_s, t_e], C) = \{ex^{(C)} \mid ex^{(C)} \in [t_s, t_e]\}$;

$\neg C$ is the set of days which are subject to the change of the periodicity attributes except the C characteristic.

Thus, the expressions (3), (4) and (5) will look as follows:

$$TE(wd) = BExt([t_1, t_4], Mon \vee Tue \vee Wed \vee Thu \vee Fri) \cup EX([t_1, t_4], wd) - EX([t_1, t_4], rd); \tag{7}$$

$$TE(rd) = BExt([t_1, t_4], Sat \vee Sun) \cup EX([t_1, t_4], rd) - EX([t_1, t_4], wd); \tag{8}$$

$$TE(Tue \vee Thu) = BExt([t_2, t_3], Tue \vee Thu') - EX([t_2, t_3], Mon \vee Wed \vee Fri \vee Sat \vee Sun). \tag{9}$$

Example. Calculation of the temporal element for even days of the month, except Tuesday, can be presented as follows:

$$TE(pd \wedge \neg Tue) = BExt([t_2, t_3], pd \wedge \neg Tue) - EX([t_2, t_3], nd \vee Tue). \tag{10}$$

For periodicity characteristics we have formulated the given essential ***rule***: coverings of the temporal scale, which correspond to the periodicity characteristics C and $\neg C$ never overlap, in other words $Ext(C) \cap Ext(\neg C) = \varnothing$. Examples of calculating the periodicity characteristic $\neg C$ are illustrated in Table 1.

Table 1. Examples of performing a complement operation on $\neg$ on the C statement

Statement C	Statement $\neg C$
wd	rd
rd	wd
Mon	$Tue \vee Wed \vee Thu \vee Fri \vee Sat \vee Sun$
$Tue \vee Thu$	$Mon \vee Wed \vee Fri \vee Sat \vee Sun$
$pd \wedge \neg Tue$	$nd \vee Tue$

It is significant that we will use temporal elements in order to define actual versions of the trains' schedule. Thus, the version of schedule v_i for train number $n \in N$, defined by expression (2), may be specified using a temporal element:

$$v_i = \left\{ \left\langle n, TE(C, t_{fix}) \right\rangle, \left\langle s_1^{(n)}, T_1 \right\rangle, \left\langle s_2^{(n)}, T_2 \right\rangle, ..., \left\langle s_\alpha^{(n)}, T_\alpha \right\rangle \right\}, \tag{11}$$

where temporal element $TE(C, t_{fix})$ is formed with the account of the fixation time t_{fix} of schedule v_i and defines all the dates for which the given version is actual.

Temporal element $TE(C_i, t_{fix}^{(i)})$, besides periodicity attribute characteristics and date changes, takes into account the cases of the schedules' overlap. When spotting such conflicts, similar dates are excluded in that of the two temporal elements, which finds correspondence with the earlier fixation time t_{fix}. Then, the definition $TE(C_i, t_{fix}^{(i)})$ presents a recursive function. Recursive essence is also found in the fact that in calculating of one temporal element there are used the temporal elements of later versions, which elements, in turn, are defined in the same way:

$$TE(C_i, t_{fix}^{(i)}) = TE(C_i) - \bigcup_{v_j \in V(v_i)} TE(C_j, t_{fix}^{(j)}), \tag{12}$$

where $V(v_i)$ is the set of versions of the schedule for n-th train, which time periods cover partly the period of version v_i and elements of $V(v_i)$ are fixed later than version v_i; the set $V(v_i)$ can be found by formula:

$$V(v_i) = \left\{ v_j \mid v_j \in V^{(n)}; [t_s^{(i)}, t_e^{(i)}] \cap [t_s^{(j)}, t_e^{(j)}] \neq \varnothing \wedge t_{fix}^{(j)} > t_{fix}^{(i)} \right\}; \tag{13}$$

$\bigcup_{v_j \in V(v_i)} TE(C_j, t_{fix}^{(j)})$ defines the set of dates, for which versions of the schedule $v_j \in V(v_i)$ are actual and which overlap the schedule v_i and have higher priority.

The condition of recursion termination is fulfilled when such a version of the schedule $v_{last} \in V^{(n)}$ for train with number n is reached for which we will not spot any other version of this train schedule $v_j \in V^{(n)}$, satisfying the condition: $[t_s^{(last)}, t_e^{(last)}] \cap [t_s^{(j)}, t_e^{(j)}] \neq \varnothing \wedge t_{fix}^{(j)} > t_{fix}^{(last)}$, here $j \neq last$. Then, from (13) we have $V(v_{last}) = \varnothing$.

Let us note that after the correction of $TE(C)$ according to the formula (12), temporal elements of different schedule versions for one train never overlap, i.e. we satisfy the rule:

$$TE(C_i, t_{fix}^{(i)}) \cap TE(C_j, t_{fix}^{(j)}) = \varnothing \text{ for } i, j = 1,2,...g; \quad i \neq j.$$

To take into account all date changes, the temporal elements of versions for schedule $v_i \in V^{(n)}$ should be transformed as follows:

$$TE(C_i, t_{fix}^{(i)}) = TE(C_i, t_{fix}^{(i)}) \cup z_i^- - z_i^+; \qquad i = 1,2,..., g, \tag{14}$$

where

$z_i^- = \{d_1 \mid z = < d_1, d_2 >, z \in Z, d_2 \in TE(C_i, t_{fix}^{(i)})\}$ is the set of dates, which should be excluded from the temporal element of version v_i since they subject to change;

$z_i^+ = \{d_1 \mid z = < d_1, d_2 >, z \in Z, d_1 \in TE(C_i, t_{fix}^{(i)})\}$ is the set of dates, which should be included in the temporal element of version v_i since its temporal element $TE(C_i, t_{fix}^{(i)})$ comprises the date which schedule is standard for the date to be updated.

On Figure 5 the schedule change from Friday April 13 to Saturday April 14 is illustrated, which means excluding April 14 from the temporal element of schedule #2 for the rest-days (*rd*) and including it in the temporal element of schedule #1 for the weekdays (*wd*).

Function $BExt([t_s, t_e], C)$ defines the dots of the time period within the diapason $[t_s, t_e]$, responding the periodicity characteristic C. The basis of the function is checking every dot $x \in [t_s, t_e]$ for correspondence to the logical expression C. This check means including the reviewed date x in every statement incorporated into C; as a result, we get a certain complicated statement $C(x)$ built on the base C for day x.

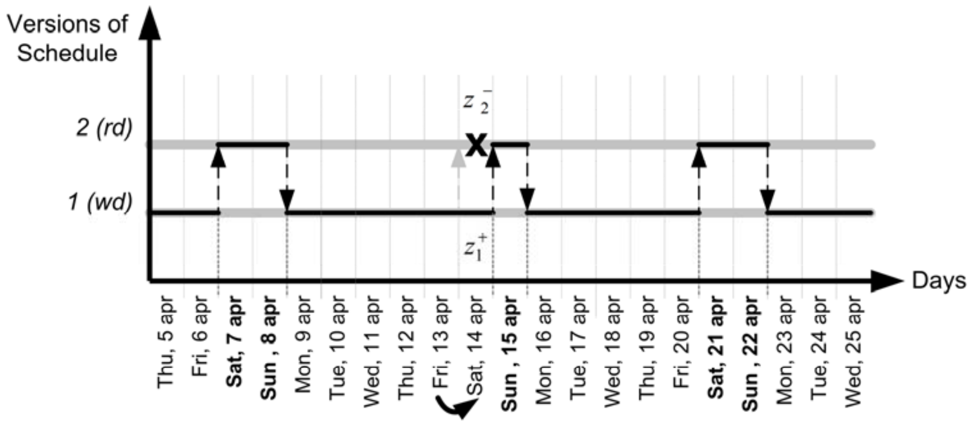

Figure 5. *The schedule of change of one day for another*

The result $C(x) = True$ means that day x satisfies the periodicity characteristic of schedule C, while $C(x) = False$ means that for day x another version of the schedule is actual. Then, the set of dots of the time axis within the diapason $[t_s, t_e]$ corresponding to the periodicity attribute C is calculated in the following way:

$$(\forall x \in [t_s, t_e])C(x) \rightarrow x \in BExt([t_s, t_e], C). \quad (15)$$

For an example of calculating according to formulae (15), we consider the definition of dates in the diapason $[t_s, t_e]$, which are the workdays and the even days of the month. We may put down the solution of this task as follows:

$$(\forall x \in [t_s, t_e])\left[(x \text{ is } pd) \wedge (x \text{ is } wd)\right] \rightarrow x \in BExt([t_s, t_e], pd \wedge wd). \quad (16)$$

Generally, in calculating the expression $C(x)$, we have, at first, to work out all the elementary expressions $p(x)$ constituting it, and then to subject the received results (1 – *True* or 0 – *False*) to the operations $\vee, \wedge$ and $\neg$ forming the expression C. Let us note that $p(x)$ means the expression built on the basis of the periodicity parameter p for day x.

For calculating the expressions $p(x)$ for the majority of possible elements of the set P, it is enough to know the coordinates of the reviewed dot on the time axis. For example, if we know the date, we can calculate out the day of the week and thus, to check it for the correspondence to the periodicity attributes *Mon, Tue, Wed, Thu, Fri, Sat* and *Sun*, and using the rule of correlation of the weekdays to defining the rest days, we can check it for the correspondence to the attributes wd and rd.

Still, there are such attributes for which check up it is not enough to know the coordinates of the reviewed dot, and we need to know periodicity attributes of the other days. The examples of such “complicated” periodicity are the first and the last days of the rest-days’ group. To define them, we need to know the periodicity attributes of the adjacent days: the day before the reviewed date in case of the day of the rest-days’ group and the day after the reviewed date for the last day of that group. Difficulty is added by the fact that for these adjacent days there might have been fixed changes or substitutions, and we need to take into account the periodicity attributes of all these changes.

4. Calculation of Temporal Elements

The procedure of calculating the TE may start with any version and covers those schedule versions which will be entered into the system afterwards. This procedure has two main stages.

The first stage. Calculation of the temporal element $TE(C)$ with the account of the C periodicity and the EX exclusions under the formula (5).

The second stage. Correction of the temporal element under the formula (8): account of the versions’ overlaps and of the days’ replacements in the calendar (multitude Z). From the temporal element calculated at the previous step, we deduct the temporal elements of the versions standing higher in priority (registered in the data base afterwards). That is, from the ranges (scopes) of the version validity (actuality) we exclude the data already captured by other versions. If for some version the temporal element has not been calculated, it will be subjected for a procedure call.

The general scheme of a recursive calculation of the TE for a train schedule version is given on Figure 6.

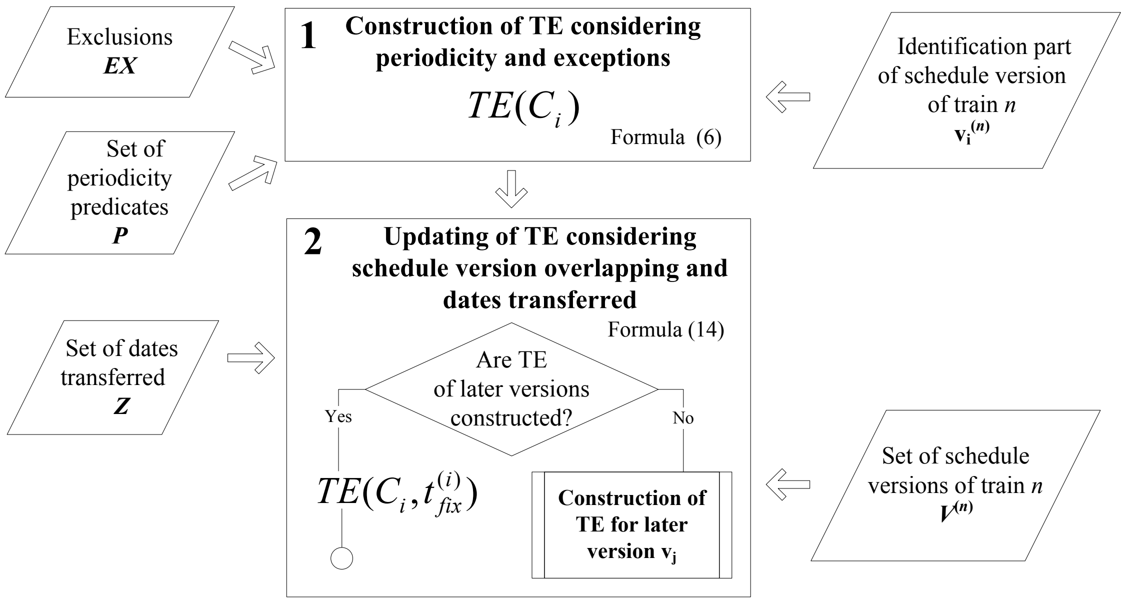

Figure 6. *Algorithm of TE generating*

Presence of the temporal element allows simplifying significantly many of the temporal functions, such as defining an actual object version, defining the dots on the valid time axis when a particular object version comes out of the “shadow zone”.

Thus, to define the actual schedule version for the train with number n we suggest using function $ActVer()$ of the type:

$$ActVer(x, V^{(n)}) = \begin{cases} v_i & \text{if } x \in TE(C_i, t_{fix}^{(i)}); \\ \varnothing & \text{otherwise} \end{cases}, \tag{17}$$

where x is the date, which schedule you have to know.

The resulting of the function $ActVer(x, V^{(n)})$ is the element of the set $v_i \in V^{(n)}$ presenting the sought for actual version. If the train does not ply on the given date x, the function will give back the empty set. The guarantee of only one actual version in action is the condition of non-overlapping *TE* of all versions of the train schedule (see the rule in the section 3.2.).

5. Examples of Calculating Temporal Elements

Let us consider an example of calculating temporal elements for different versions of the schedule for the train numbered n. The set of versions of train schedule with different periodicity is schematically presented on Figure 3 and on Figure 5. As we can see on Figure 3, the train has three schedules v_1, v_2 and v_3. Let us fix two versions of the schedule v_1 and v_2 with the corresponding periodicity attributes *wd* and *rd* on the period from November 1 to November 30, 2007; the time of fixation of these versions is October 10, 2007 correspondingly at hours 12:00 and 14:00, and the third version v_3 with the attribute *Tue, Thu* for the period from November 5 till November 25, 2007 is fixed on November 2, 2007. Then we have: $t_1 =$'01.11.07', $t_2 =$'05.11.07', $t_3 =$'25.11.07' and $t_4 =$'30.11.07'.

Figure 5 shows the time period from November 5 till November 25, 2007, when three schedules v_1, v_2 and v_3 are being in use; here: "1" on the axis "Days of week" corresponds to Monday November 5, 2007; "2" corresponds to Tuesday November 6, 2007, etc. According to formulae (2) we can describe each schedule version:

$$v_1 = \{\langle n, wd, \text{'10.10.07 12:00'}, \text{'01.11.07'}, \text{'30.11.07}\rangle, \langle s_1, \text{'11:05'}\rangle, \ldots, \langle s_{10}, \text{'12:15'}\rangle\};$$

$$v_2 = \{\langle n, rd, \text{'10.10.07 14:00'}, \text{'01.11.07'}, \text{'30.11.07}\rangle, \langle s_1, \text{'11:00'}\rangle, \ldots, \langle s_{10}, \text{'12:12'}\rangle\};$$

$$v_3 = \{\langle n, (Tue \vee Thu), \text{'02.11.07 11:00'}, \text{'05.11.07'}, \text{'25.11.07}\rangle, \langle s_1, \text{'11:10'}\rangle, \ldots, \langle s_{10}, \text{'12:21'}\rangle\}.$$

Note that in the given examples we show only the first and the last stops of the train schedules to simplify the data presentation.

Since November 19, 2007 was announced a rest-day in Latvia, on that day the trains were plying in conformity with the rest-day schedule. Therefore, in our case we have a non-empty set of exceptions for the rest-days; in other words we have $EX(rd) = \{19.11\}$. Note that here and further on, we do not mention the year 2007 to simplify the data presentation. Calculation of the temporal element for the schedule version v_3, fixed after the first two versions, is made pretty simply according to formula (5), since we do not need the temporal elements of the other schedule versions here:

$$TE(C_3, t_{fix}^{(3)}) = TE(C_3) = BExt([t_s^{(3)}), t_e^{(3)}], C_3) \cup EX([t_s^{(3)}, t_e^{(3)}], C_3) - EX([t_s^{(3)}, t_e^{(3)}], \neg C_3) =$$
$$BExt([5.11,\ 29.11], Tue \vee Thu) \cup EX([5.11,\ 29.11], Tue \vee Thu) -$$
$$EX([5.11,\ 29.11], Mon \vee Wed \vee Fri \vee Sat \vee Sun \vee rd) =$$
$$\{6.11, 8.11, 13.11, 15.11, 20.11, 22.11\} \cup \varnothing - \varnothing = \{6.11, 8.11, 13.11, 15.11, 20.11, 22.11\}.$$

To calculate the temporal element of the schedule v_2, we need to know the temporal element of version v_3 – the only version of the schedule, which is fixed further:

$$TE(C_2, \text{'10.10.07 14:00'}) = TE(C_2) - TE(C_3, t_{fix}^{(3)}) =$$
$$BExt([t_s^{(2)}, t_e^{(2)}], C_2) \cup EX([t_s^{(2)}, t_e^{(2)}], C_2) - EX([t_s^{(2)}, t_e^{(2)}], \neg C_2) - TE(C_3) =$$
$$BExt([01.11,\ 30.11], rd) \cup EX([01.11,\ 30.11], rd) - EX([01.11,\ 30.11], wd) - TE(C_3) =$$
$$\{3.11, 4.11, 10.11, 11.11, 17.11, 18.11, 24.11, 25.11\} \cup \{19.11\} - \varnothing -$$
$$\{6.11, 8.11, 13.11, 15.11, 20.11, 22.11\} = \{3.11, 4.11, 10.11, 11.11, 17.11, 18.11, 19.11, 24.11, 25.11\}.$$

The schedule v_1 is the earliest one, and to calculate its temporal element we need the temporal elements of the schedules v_2 and v_3:

$$TE(C_1, t_{fix}^{(1)}) = TE(C_1) - \left(TE(C_2, t_{fix}^{(2)}) \cup TE(C_3, t_{fix}^{(3)})\right) =$$
$$BExt\left([t_s^{(1)}, t_e^{(1)}], C_1\right) \cup EX\left([t_s^{(1)}, t_e^{(1)}], C_1\right) - EX\left([t_s^{(1)}, t_e^{(1)}], \neg C_1\right) - \left(TE(C_2, t_{fix}^{(2)}) \cup TE(C_3)\right) =$$
$$BExt([01.11, 30.11], wd) \cup EX([01.11, 30.11], wd) - EX([01.11, 30.11], rd) -$$
$$\left(TE(C_2, '01.04.2007\ \ 14:00') \cup TE(C_3)\right) =$$

$$\{\,01.11, 2.11,\ 5.11\text{-}9.11,\ 12.11\text{-}16.11,\ 19.11\text{-}23.11, 26.11\text{-}30.11\} \cup \varnothing - \{19.11\} -$$
$$(\{3.11, 4.11, 10.11, 11.11, 17.11, 18.11, 19.11, 24.11, 25.11\} \cup$$
$$\{6.11, 8.11, 13.11, 15.11, 20.11, 22.11, 27.11, 29.11\}) =$$
$$\{01.11, 2.11, 5.11, 7.11, 9.11, 12.11, 14.11, 16.11, 19.11, 21.11, 23.11, 26.11, 28.11, 30.11\}$$

6. Conclusions

In the given paper the authors have shown the possibility of using the theory of sets and the algebra of logics for the description of the railway schedule system. Realization of the mathematical model of railway schedule is performed in the environment of the temporal database, for which the periodicity parameters and temporal elements have been defined and the rules of their calculation have been formulated.

The suggested schedule's support system may serve not only as an informational schedule system but also as a part of the management system making it possible to model the railway schedule by automatically generating changes options in case of announcing an additional rest-day and be suitable also as a part of an analytical system for analysing and predicting passengers' flows.

Further guidelines of the current research will be aimed at reaching efficient solutions for realizing the considered system with the use of modern database technologies.

References

1. Kopytov, E., Demidovs, V., Petoukhova, N. Method of Temporal Databases Design Using Relational Environment. In: *Scientific Proceedings of Riga Technical University – Computer Science: Applied Computer Systems*. Riga: Riga Technical University, 2002, Series 5, Vol. 13, pp. 236–246.
2. Kopytov, E., Demidovs, V., Petoukhova, N. Use of Temporal Databases Principles in Information Systems of the Latvian Railway. In: *Proceedings of VII International Conference "TransBaltica 2002"*. Riga: RMS Forum, 2002, pp. 183–190. (In Russian)
3. Novikov, F. *Discrete Mathematics for Programmers*. St. Petersburg: Piter, 2000. 304 p. (In Russian)
4. Terenziani, P. Symbolic User-defined Periodicity in Temporal Relational Databases, *IEEE Transactions on Knowledge and Data Engineering*, Vol. 15, No 2, 2003, pp. 489–509.

Transport and Telecommunication, 2008, Volume 9, No 2, 24–38
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THE NATIONAL AUTOMATIC TOLL COLLECTION SYSTEM FOR THE REPUBLIC OF POLAND

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The paper refers to some problems of worldwide applications in electronic toll collection systems for motorways and expressways. According to Directive 2004/52/EC, these systems should use one or more of the following technologies: satellite positioning, mobile communications using the GSM-GPRS standard (reference GSM TS 03.60/23.060) and 5, 8 GHz microwave technology. Authors have analysed the systems, which meet these requirements, especially the states as follows: The United States of America, Japan, Taiwan, Australia, Austria, Czech Republic, France, Norway and Germany. As a result of the analysis, it has turned out that only system using satellite positioning technology and mobile communications (GSM/GPRS) is the best toll solution of unique capabilities and this kind of technologically sophisticated system should be implemented in Poland. Author will present the initial structure of GSM/GPS based Toll Collection System for Poland. This type of system has many advantages. The first one is absence of the need for new road infrastructure (gantries); operators can keep using the existing infrastructure. System works without toll booths, extra lanes, speed restrictions or complex structures along toll roads. The second one is much greater flexibility in defining or changing payment by simply redefining the "virtual" toll areas. It means ability to adapt easily and quickly to changes in charge parameters (road classes, vehicle types, emission levels, times slots, etc.). The third advantage is the system's ability to support other value-added services on the same technology platform.

Keywords: *Electronic Toll Collection (ECT), microwave technology, on-board unit (OBU)*

1. Introduction

Electronic Toll Collection (ETC) is a fairly mature technology that allows for electronic payment for motorways and expressways. An ETC system is able to determine if a car is registered in a toll payment program, alerts enforcers of toll payment violations, and debits the participating account. ETC is fast becoming a globally accepted method of toll collection, a trend greatly aided by the growth of interoperable ETC technologies. Some of the benefits of ETC include:

- fuel savings;
- reduced mobile emissions by reducing or eliminating deceleration, waiting times, and acceleration;
- possible reduced drain on public monies, if the system is more self-sustaining or if the system was built/run via a public-private partnership arrangement.

The EC's target is for all vehicles to be equipped with an ETC box, linked to a standard contract for the owner/operator. At the end of each billing period, a single invoice would be issued, covering journeys through any of the member states.

All new electronic toll collection systems brought into service on or after the 1st of January, 2007 shall, for carrying out electronic toll transactions, to use one or more of the following technologies: satellite positioning, mobile communications using the GSM-GPRS standard (reference GSM TS 03.60/23.060) and 5,8 GHz microwave technology.

The above mentioned conditions are included in Directive 2004/52/EC of the European Parliament and of the Council of the 29th of April, 2004 on the interoperability of electronic road toll systems in the Community [4].

The requirements of that directive will be implemented in Poland based on the Act from the 28th of July, 2005 on changing act of public roads and some other acts [11]. It stressed that toll collecting charge institutions should be able to carry out electronic toll transactions from the 1st of January, 2011 – to the carriage of goods where the maximum permissible mass of the vehicle, including any trailer, or semi-trailer, exceeds 3, 5 tons, or of passengers by vehicles which are constructed or permanently adapted for carrying more than nine persons including the driver.

New electronic toll systems brought into service after the adoption of this Directive should use the satellite positioning and mobile communications technologies.

The Working Group No 1 (WG1) of Technical Committee 278 (Road Transport and Traffic Telematics) established in 1991 is responsible for electronic toll collection systems in European Union. ISO/TC 204 is the partner of CEN/TC 278 in ISO, responsible for the international standardisation of transport information, communication and control systems.

It is recommended to implement National Automated Toll System for highways and expressways in Poland. Authors have carried out the analysis of some systems functioning all over the world to choose the best one for Poland.

2. Characterization of Electronic Toll Collection Systems

A toll collection system can be either closed (cordoned) or open. The closed system requires entrances and exits based on toll booth (a booth at a tollgate where the toll collector collects tolls). In an open toll system, toll stations are located along the facility. It is the collection of tolls on toll roads in three or more adjacent lanes without the use of lane dividing barriers or toll-booths. The major advantage to open system is that cars need not stop nor even slow down for payment.

DSRC is typically used as the primary method of charging where a charge is to be applied at one of a discrete number of specific points, such as a toll plaza (an area where tollbooths are located) or a location on the open highway.

DSRC systems were implemented in some countries between 1980 and 1990. These mentioned kinds of the systems equipped with automatic toll gates led to the use of devices intended to ensure that users were making correct toll payments for the type of vehicle they are driving. These included devices, which examine each vehicle before they entered the tollgate and while in the tollgate (for example, vehicle classification systems).

Since 1990's DSRC systems have presented new opportunities for users to make toll payments without the need for any physical contact with a toll collector or roadside equipment and without vehicles having to stop.

The Rationale for Electronic Toll Collection ETC systems take advantage of vehicle-to-roadside communication technologies (traditionally via microwave or infrared communication, more recently via GPS technology) to perform an electronic monetary transaction between a vehicle passing through a toll station and the toll agency.

Electronic Toll Road Systems in USA and some European Member States using microwave technology have functioned independently. The telematics systems are implemented in some states, an example being Hitachi System (Japan), as well as Barouh System (Taiwan), which provide the function of electronic road toll for highways and expressways and additionally function of transferring data from digital Tachograph. Toll Collecting System in Germany is a modern solution for the mentioned scope.

2.1. Electronic Tall Collection Systems Using Microwave Technology – DSRC

Electronic Toll Collection System using microwave technology is an element of Intelligent Transport Systems (ITS) that allows for non-stop toll collection and traffic monitoring. It is to uniquely identify each vehicle, electronically collect the toll, and provide general vehicle/traffic monitoring and data collection. New technologies and infrastructures provide the necessary capabilities for future applications such as incident management, alternate route guidance, and travel demand management. Properly implemented, system can reduce congestion, increase operating efficiency, improve travel time, reduce pollution, and improve safety of the roadway facility and surrounding corridors. All electronic tall systems using microwave technology all over the world have the same structure, which utilizes vehicles equipped with transponders (electronic tags), toll and control gantries, in-road/roadside detection and classification sensors, computerized system (hardware and software) and wireless communication (5,8 GHz nearly all over the world, only 5,9 GHz in USA), as well as enforcement technologies.

The elements of toll system like transponders (tags) mounted on the vehicle's windshield, have got the same dimensions (box of cigarettes), but for every kind of system the vehicle should be equipped with different transponder (Fig. 1), for example Go-Box in Austria, Premid in Czech Republic, Passango in France. The antennas carried by gantries communicate with transponders (On Board Units, OBU). Users can get the OBU at a high number of points of sale 24 hours a day. OBU is equipped with a switch for the change of the vehicle class, for instance, in case of an additional trailer.

In June 2002, ASFINAG (Autobahnen und Schnellstrassen-Finanzierung AG) Austria's national road authority charged with planning, financing, building and maintenance of the highway network, awarded a contract for the installation and operation of a fully electronic nationwide toll system for heavy goods vehicles with a maximum permissible laden weight of 3, 5 tons to Autostrade S.p.A. with Kapsch TrafficCom AG [1] as the turn-key system supplier.

Figure 1. *Electronic transponders mounted on the vehicle's windshield*

The toll system is an open system with one gantry for toll communication in each sector between exit/entry-points (Fig. 2). More than 800 gantries (420 for each driving direction) has been implemented in the entire network. Users who drive on the tolled road network rarely can choose to pay the toll using the pre-pay procedure. This procedure is similar to that of a prepaid telephone card; the user charges the Go-Box with toll credit up to a certain maximum limit and the toll is then deducted from this credit as required by the toll system. According to this procedure, the owner of the vehicle registers with the system and provides an authorized means of payment, which is later used to pay the toll as required. The money is collected by the relevant card issuer (Maestro card, petrol card or credit card).

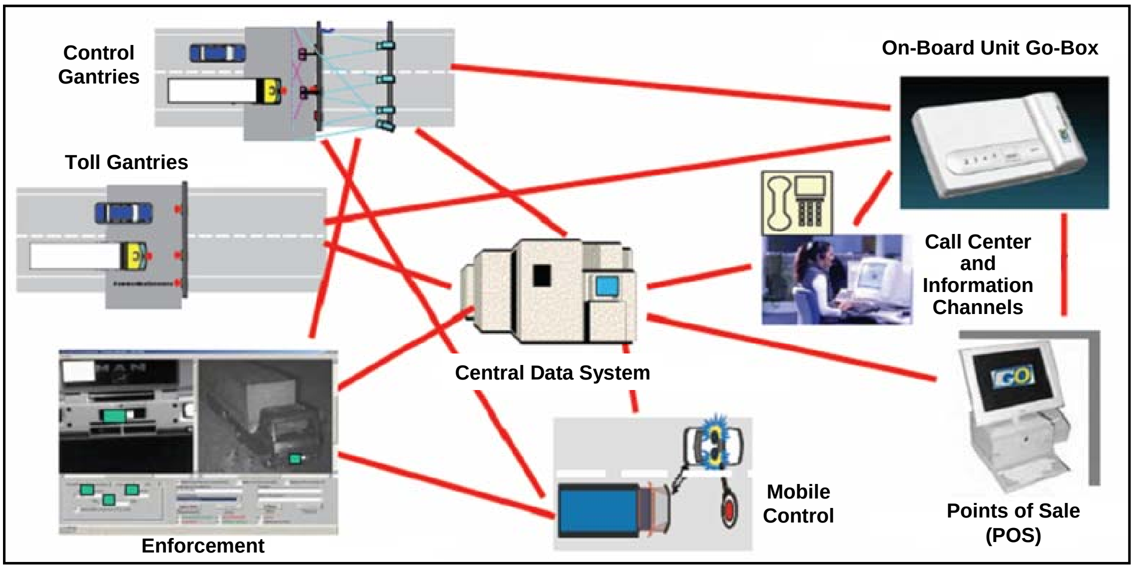

Figure 2*. An example of Electronic Toll System in Austria* [7]

Toll-enforcement which is one of the most important parts of an electronic toll system without barriers executed on the one hand by stationary toll-enforcement-gantries and portable enforcement equipments and on the other hand by a mobile control unit ("toll-enforcement-officers"). 100 permanent enforcement gantries are spread over the network primarily in the parts of higher traffic density. They consist of equipment for automatic vehicle classification by laser scanner. Vehicle class video cameras take a picture of the vehicles front. The license plate is then read by automatic character recognition and sent to the enforcement office.

Electronic toll has been paid by vehicles weighing 12 tons and more on 970 km of motorways and express roads in the Czech Republic as of January 1, 2007. Kapsch TrafficCom AB contracted the system in Czech Republic, but the transponder is different and called Premid. It is the brand name for a product line of microwave-based communication links for dedicated short range communication, DSRC, between fixed Roadside Equipment and mobile units. Kapsch TrafficCom AB has supplied this DSRC Link technology to a large number of traffic applications in over 20 countries all over the world.

The third generation of the system, Premid, is compliant with the current European CEN TC278 standards for Dedicated Short Range Communication, DSRC, as well as to the international ISO standard for Electronic Toll Collection (ETC).

The term TIS-PL refers to the new French electronic toll system for class 3 and 4 HGVs. Modelled on the "Liber-t" system designed for light vehicles in France, the TIS-PL is a badge which is fitted to the windscreen and which simplifies toll payments (motorways, tunnels, bridges etc.). Launched at the beginning of 2007, it has since replaced the CAPLIS toll card as the method of toll payment in France.

AutoPASS is an electronic toll collection system used in Norway. It allows collecting road tolls automatically from cars. It uses electronic radio transmitters and receivers operating at 5.8 GHz (MD5885).

The system involves the installation of a radio transmitter on the windscreen of a vehicle, and signing an agreement with one of the toll collection companies in Norway. Tolls are charged at toll plazas as before, but cars can drive past in up to 80 km/h. The system is administrated by the Norwegian Public Roads Administration. 23 of the 45 toll roads in Norway use the system, in addition to tests for use of the system on some car ferries. The primary reason that some projects don't support AutoPASS is that they charge both for the car and for passengers, which the system cannot support. All projects using AutoPASS can only charge per car. All systems with AutoPASS also have manual payment methods, though not necessarily manned.

The tolls in the United States are typically collected using RFID (Radio Frequency Identification). It is an automatic identification method, relying on storing and remotely retrieving data using devices called RFID tags or transponders. An RFID tag is an object that can be attached to or incorporated into a product, animal, or person for the purpose of identification using radio waves. Chip-based RFID tags contain silicon chips and antennae. Passive tags require no internal power source, whereas active tags require a power source.

Example of mentioned system is the E-ZPass electronic toll collection system used on most toll bridges and toll roads in the eastern U.S. from Virginia to Maine, and recently extended into Illinois; Houston`s EZ Tag, which also works in other parts of the state of Texas, California's FasTrak, Illinois` I-Pass, Florida's SunPuss, and more recently Indiana's I-Zoom (Fig. 3). Traffic in these special lanes can move well with minimal slowing. Toll roads have been only in 26 states as of 2006. The majority of states without any turnpikes are in the West and South [2, 5].

***Figure 3**. Types of ETC Systems in USA*
Based on – http: www.transcore.com

Operation principle of the system is the same in Europe (Fig. 4). As a car approaches a toll plaza, the radio-frequency (RF) field emitted from the antenna activates the transponder. The transponder broadcasts a signal back to the lane antenna with some basic information. That information is transferred from the lane antenna to the central database. If the account is in good standing, a toll is deducted from the driver's prepaid account. If the toll lane has a gate, the gate opens. A green light indicates that the driver can proceed. Some lanes have text messages that inform drivers of the toll just paid and their account balance. If the vehicle does not have a transponder, the system classifies it as a violator and cameras take photos of the vehicle and its license plate for processing. If the license plate is registered as belonging to toll system user, the account is debited only the toll charge, and no penalty is charged.

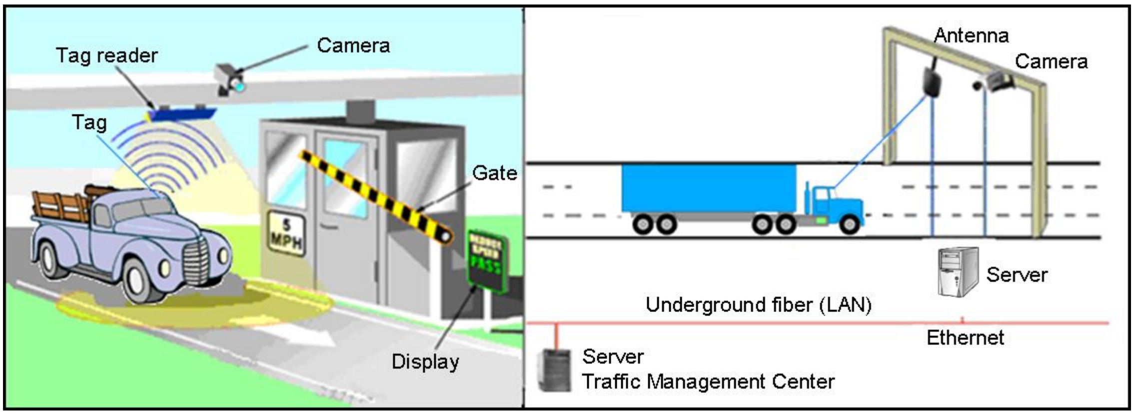

Figure 4. *E-ZPass System* (*on the left – closed road line, on the right – open road line*)
Based on – http://www.garamchai.com/askadesi/ask13.htm; http://www.calccit.org/itsdecision/serv_and_tech/list.html

E-ZPass tags are battery powered RFID transponders; they communicate with reader equipment built into lane-based or open road toll collection lanes. The most common type of tag is mounted on the inside of the vehicle's windshield behind the rear-view mirror. Some vehicles have windshields that block RFID signals. For those vehicles, an externally-mountable tag is offered, typically designed to attach to the vehicle's front license plate mounting points. Most E-ZPass lanes are converted closed toll lanes and must have fairly low speed limits for safety reasons (5 and 15 mph are typical). In some areas, however (typically recently built or retrofitted facilities), there is no need to slow down, as E-ZPass users utilize dedicated traffic lanes ("Express E-ZPass") outside the toll booth (Delaware Route 1, Virginia's Pocahontas Parkway, the Garden State Parkway's express lanes, and the Pennsylvania Turnpike's Warrendale and Mid-County (I-476) Toll Plazas).

The E-ZPass Interagency Group (IAG) was formed in 1990 with three states (NY, NJ & PA) and seven agencies. The first deployment of E-ZPass was on the New York State Thruway at the Spring Valley barrier on August 3, 1993. The IAG currently has over 9 million account holders who utilize more than 16 million transponders operating electronic toll collection for 23 agencies in 12 states. The nine million account holders reside throughout North America with thousands in each state and province including the States of Hawaii and Alaska.

Another system in the USA is FasTrak. It is used state-wide on all of the toll roads and bridges along the California Freeway and Expressway System.

Like other ETC systems, FasTrak is designed to eliminate the need for cars to stop to pay at toll booths, thus decreasing the traffic traditionally associated with toll roads. Its use of technology to improve transit is in line with the U.S. Department of Transportation's Intelligent Transportation Systems initiative.

FasTrak uses RFID technology to read data from a transponder placed in a vehicle (usually mounted by Velcro strips to the windshield) moving at speeds that may exceed 70 mph. The RFID transponder in each vehicle is associated with a prepaid debit account; each time the vehicle passes underneath a toll collection site, the account is debited to pay the toll. If a vehicle does not have a transponder, the system uses automatic number plate recognition to take photos of the vehicle and its license plate for processing.

Anybody with a FasTrak transponder can use it to pay tolls on any California toll road or bridge using the system. But people are encouraged to open their accounts with the local agency in charge of the toll facility that they use the most. Different agencies may offer different discounts and incentives, and people may be charged a fee if the majority of their FasTrak use occurs elsewhere.

SunPass is an electronic toll collection system in use by the State of Florida and has been originally created by the Florida Department of Transportation's Florida's Turnpike Enterprise. The system uses

Amtech active RFID windshield-mounted transponders manufactured by TransCore along with lane equipment designed by several companies including SAIC and TransCore. SunPass is fully interoperable with E-Pass (from the Orlando-Orange County Expressway Authority), O-Pass (from the Osceola Parkway), LeeWay (from Lee County toll bridges) and Miami-Dade Expressway Authority (MDX) toll roads. SunPass may also be used at the Orlando International Airport to pay for parking. There are plans for other major Florida airports to utilize the SunPass system for parking fees.

SunPass-Only toll lanes on most toll roads in Florida allow a vehicle to proceed through the tollbooth at speeds of up to 25 mph (40 km/h). This is a safety guideline, not a technological limitation, and violation may be a subject to a speeding ticket and associated fine. Some mainline toll barriers are being constructed with wider SunPass-Only lanes that can handle speeds up to 50 mph (80 km/h). E-Pass-Only lanes system have a speed limit of 35 mph (60 km/h), though the mainline toll barriers will all have dedicated lanes capable of full-speed automatic toll collection at up to 65 mph (105 km/h) by 2009.

I-PASS is the Illinois Tollway's Electronic Toll Collection Program. Users of the Tollway are encouraged to open an account that allows them to travel through the toll plazas faster, in many cases without having to stop, and to avoid having to handle cash toll payments.

Hitachi has developed creative solutions to roadside communications, traffic operation and payment processing to enhance toll collection system performance (Fig. 5). Capable of high-speed operation to enable free traffic flow, the system incorporates a fully integrated payment processing system, comprising facilities to identify and record illegal passage, efficient management of toll-collection data, system auditing and access management for high security and EDI processing to facilitate smooth fund transfers.

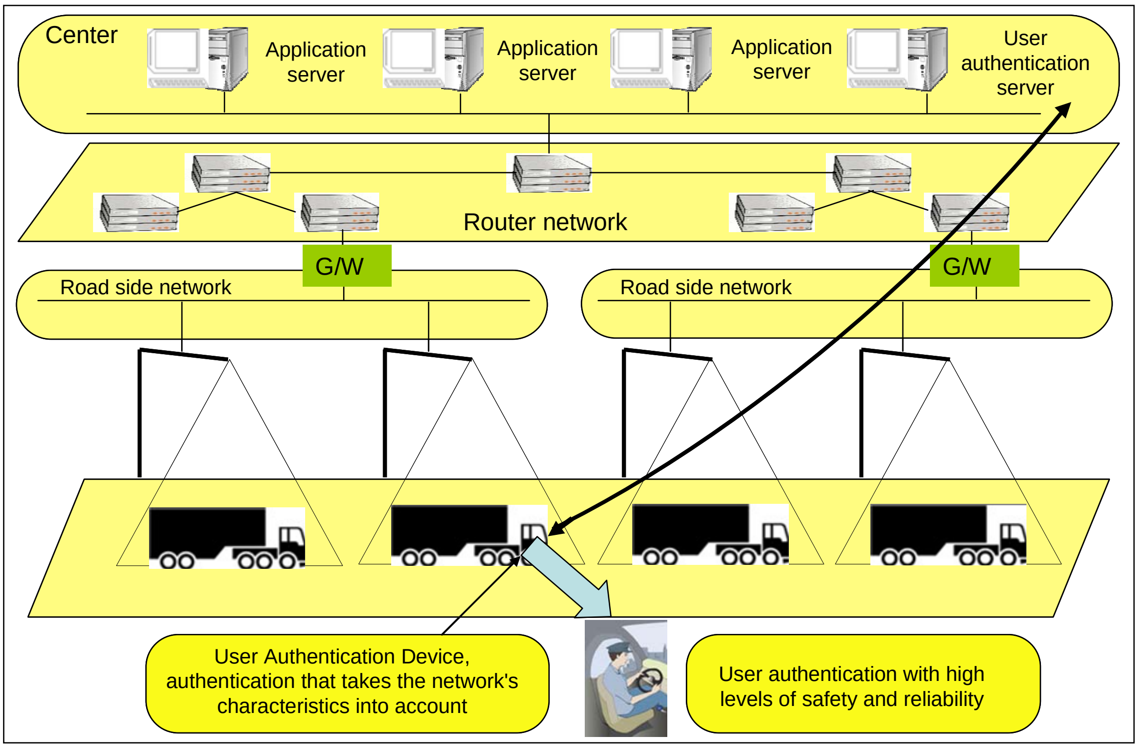

Figure 5. *The project of electronic toll collection system created by Hitachi and supported by Telecommunications Advancement Organization of Japan*
Based on – http://www.hitachi.co.jp/en/products/its/product/solution/2004613_12384.html

Hitachi covers everything from data collection to information delivery. Hitachi has made advanced system concepts a reality, with a complete information system consisting of data collection, information management, on-board equipment, radio beacons and other facilities.

This system, developed to improve both safety and convenience levels, not only provides accident and other travel-related data to cars driving at high speeds, it also uses the Internet to provide music and image streaming, and to reserve and pay for airline tickets.

Fibre-optic cables buried within the road are capable of detecting road surface temperatures and can issue warnings when freezing conditions exist.

An image recognition system monitors your car as you drive to detect possible danger signs. It offers the driver information on the possible existence of dangerous situations, and provides information on safer driving to avert such dangers.

Microwave-based digital short range communication (DSRC) systems need road-side equipment, typically mounted on a gantry, with electronic tags in the vehicles which may be read-only, read–write or smartcard-based. The majority of systems all over the world have tags reading-only, contain a fixed identification code which, when interrogated by a roadside reading device at the charging point, conveys this identity to the roadside system.

China has got currently ETC systems in Guangdong Province, Beijing, and Shanghai [13]. Although several DSRC systems have been developed and used in China, they use different frequency bands and thus are not compatible with each other. To solve this problem, the Chinese Government has determined the domestic standardization of the 5.8 GHz-band (GB/T 20839-2007, GB/T 20851.1, 2, 3, 4, 5. 2007), which indicates that this frequency band will be adopted as the standard for the DSRC systems in China.

Research is underway on a new generation of electronic highway toll collection technology, based on GPS and wireless communication technology to implement such a system in China. For the reason of aforementioned system, China has planned to develop a truly global satellite navigation system, known as Compass or Beidou-2. The current Beidou-1 system (made up of 4 satellites) is experimental and has limited coverage and application. The new system will be a constellation of 35 satellites, which include 5 geo-stationary orbit (GEO) satellites and 30 medium Earth orbit (MEO) satellites that will offer complete coverage of the globe. There will be two levels of service provided; free service for those in China, and licensed service for the military.

The free service will have a 10 meter location-tracking accuracy, will synchronize clocks with an accuracy of 50 ns, and measure speeds within 0.2 m/s.

The licensed service will be more accurate than the free service, can be used for communication, and will supply information about the system status to the users.

Two satellites for Beidou 2 have been launched in early 2007. In the next few years, China plans to continue experimentation and system set-up operations.

By the end of 2020, China will have finished constructing 12 roads and formed the main arteries of state roads with high-grade highways, which will run through capital, cities directly under the jurisdiction of state, the capitals of each provinces and municipalities.

The Taiwanese Electronic Toll Collection System is composed of four subsystems as follows: roadside sub-system, vehicle sub-system, administration sub-system, and external sub-system [3].

The roadside sub-system is composed of several Changeable Message Signs (CMS) and Surveillance Station (SS) – Fig. 6. The primary function of CMSs is to provide travel information to truck drivers, and they are directly controlled by the Central Surveillance Centre (CSC). The SS, which is installed at the main line of highway is controlled by the nearest downstream Vehicle Weigh Control Centre (VWCC).

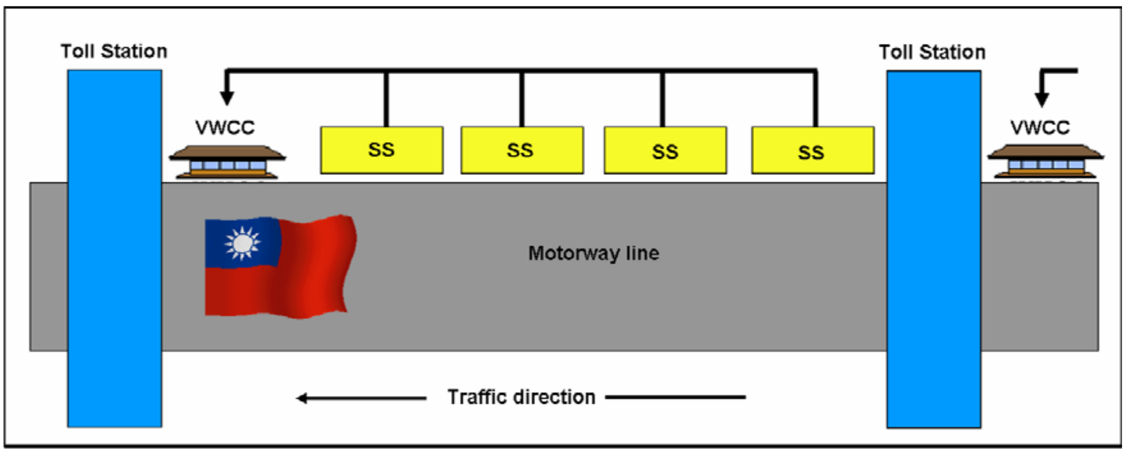

Figure 6. *Roadside sub-system of ETC in Taiwan*

The SS consists of five units as follows:

- Weigh-in-Motion (WIM) system. This system detects the speed, gross vehicle weight, axle number, and axle distances of each passing truck. All WIM collected data are transferred immediately to the Roadside Operation Computer (ROC).
- Roadside Unit (RSU). The main function of this unit is to communicate with the OBU on the vehicle. The communication between the RSU and OBU uses the DSRC to identify each passing truck. The ETC transaction and the notification of the results of weight and safety record check can also be done through the DSRC. Since most of the vehicles pass the WIM and RSU at a relatively high speeds (e.g. 90 to 100 km/h), two RSUs are needed for each MSS. The second RSU is located about 100 m downstream and is used to send the check results back to the driver.
- Automatic Vehicle Classification (AVC). The AVC is designed to detect the classification of each passing truck. The loop detectors of the WIM can be used in AVC. By comparison between data from the AVC and from the RSU, any possibility of miss-using the OBU by truck drivers will be identified and reported immediately.
- Vehicle Enforcement System (VES): The VES will automatically catch the image of any violating vehicle that is reported by the SS. Not only the vehicle weight check but also other vehicle safety related issues, such as inspection and insurance, are checked by the whole system. Although the WIM cannot be used for law enforcement directly, the image is still transmitted to the VWCC for the possible citation latter. However, the driver will then be notified by the OBU through the data transmitted from the second RSU.
- Roadside Operation Computer (ROC): All data and information from the above units are gathered here. The ROC serves as the data processing and transferring bridge between the VWCC and other MSS units.

OBU is the major component of the vehicle sub-system. With the use of OBU, the ETC transaction and truck weight and safety record check can then be processed. The OBU must be capable of displaying “red” and “green” lights on the small LCD screen or providing different sounds to indicate the various checking statuses to drivers.

The administration sub-system is composed of the Vehicle Weigh Control Centre (VWCC) and Central Surveillance Centre (CSC). This system controls all the following sub-systems and the upstream SSs. The computer system controls the static weight pad, truck record checking sub-system, violation citation sub-system, traveller information sub-system, and fleet management sub-system. Under current freeway traffic control regulations in Taiwan, all loaded trucks must enter a weigh station that is located in both sides of each toll station for weight checking. The CSC is comprised of the truck surveillance sub-system, weight analysis sub-system, and traveller information sub-system.

The External Sub-system. The external sub-system is comprised of the truck company’s surveillance computer, the DMV (Department of Motor Vehicles) computer, and the traveller information service provider.

2.2. GPS/GSM Based Tall Collection Systems

Hitachi telematics system was implemented in Japan in 2001 for managing of transport companies [6]. It functions based on GPS, GSM communication and Internet. Each vehicle is equipped with digital tachograph, OBU and telematics terminal, which uses GPS to measure its current position and reports it to an application service provider (ASP) centre at regular intervals (usually every 15 minutes) via a mobile packet transmission network. A PC (personal computer) at the transportation company’s office can be connected to the ASP centre via the Internet, and can be used to display the current position and route of each vehicle superimposed on a map of Japan. Hitachi’s ASP service can be linked to a toll collect system, allowing the fleet managers to respond precisely to enquiries from consignors about their payment for highways and expressways. In Hitachi’s truck fleet management service system, the telematics terminals collect the types of data (speed, time, distance and charge of road), and transmit it to Hitachi’s ASP centre via a mobile packet transmission network. The driving data collected in this way can be freely inspected and amended via the Internet, and can be used to print out documents such as daily driving reports and monthly statistical reports, or downloaded into accounting/payroll systems. It is also possible to identify bad driving habits such excessive acceleration or braking, speeding or prolonged idling, and this information can be used to make the drivers safer and more fuel-efficient by providing them with suitable feedback.

The trucks are fitted with telematics equipment, GPS systems, packet cell phone terminals, etc., and thus have the potential to be used as floating cars. First, the truck positional data is superimposed on a map to infer the route on which the truck is travelling, and then the speed of the truck along this route is calculated. Next, this data is statistically processed to calculate the estimated arrival time. To avoid excessive communication costs, the time intervals at which this positional information is uploaded should be made as long as possible. However, this makes it harder to track the routes travelled by the trucks.

Japan has started a new project of Quasi-Zenith Satellite System (QZSS) in FY2003 [12]. QZSS consists of three satellites and will provide a regional satellite positioning service as well as communication and broadcasting services. Each satellite is in three different orbit planes, which are obtained by inclining the geo-stationary orbit (GEO) by about 45 degree. In this system, at least one satellite stays around the zenith for about eight hours and is visible with a higher elevation angle in mid-latitude area (e.g. at least 80 deg. in Tokyo) than in case of using a satellite in GEO. This characteristic is very beneficial in large cities where there are many tall buildings which block the signal from satellites in GEO. Thus, satellite availability for satellite positioning and mobile communication services is expected to be greatly improved.

The QZSS satellite positioning system is planned to be compatible and interoperable with the civil specifications of modernized GPS except its orbit and some experiments, and will compliment and augment the GPS. The aimed accuracy of GPS-QZSS time offset is less than 3 ns rms over any 24-hour period.

Taiwanese telemtaics system (Fig. 7) has the same structure as Hitachi one. It is capable of calculating and collecting road use charges via OBU and GPS. Furthermore it allows Baoruh Digital Tachograph to send vehicle status and position to the backend server via GSM/GPRS, while the server is capable of issuing commands or system parameters simultaneously. To use GIS technology to provide best route-analysis, distance measurement, route management and restrictive access settings, road speed limit. All types of reports can be directly printed out or transformed into other file formats, such PDF, Excel, html, CSB, text file [10].

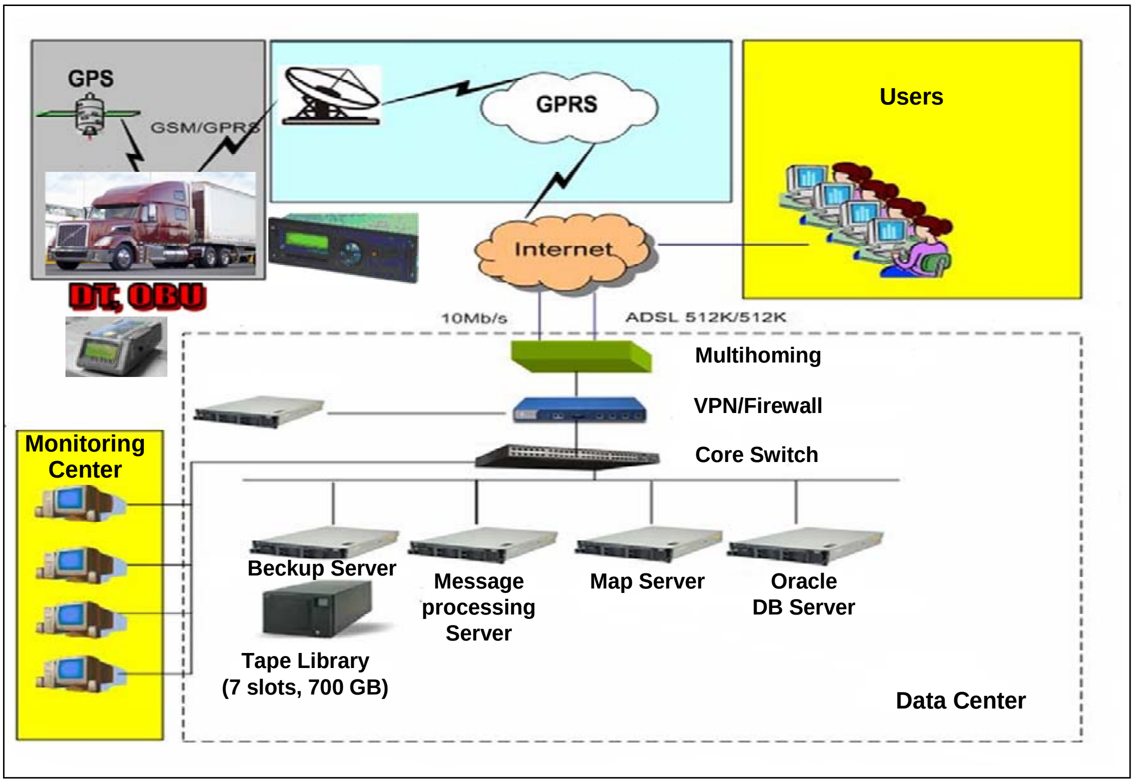

***Figure** 7. The structure of Taiwanese telemtaics system*

In January 2005 the Toll Collect system was introduced on the 12 000 km of German highways for all trucks with a maximum weight of 12t and above. Its technology is based on the GPS, and a web application (GSM). System is capable of calculating and collecting road use charges based on the distance travelled.

In addition, the Toll Collect system ensures that the collection of road tolls does not disrupt traffic flow. In contrast to conventional toll systems, Toll Collect does not require vehicles to slow down or stop, or restrict them to a designated lane [8].

The main element of the automatic log-on system is the On-Board Unit (Fig. 8). OBU is used for positioning, monitoring and billing. With the aid of GPS satellite signals and other positioning sensors, the OBU automatically determines how many kilometres have already been driven on the toll route, calculates the toll based on the vehicle and toll rate information that has been entered, and transmits this information to the Toll Collect computer centre for further processing. Additionally the OBUs have infrared interfaces for communicating with stationary control bridges on the motorways. System has 300 gantries equipped with IR detection equipment and high resolution cameras able to pick out trucks via profiling (and record number plates). These send a DSRC signal to a DSRC transponder (which is a part of the OBU) in the lorry to check on the accuracy of the GPS as a back-up and also alert BAG officers to toll violations.

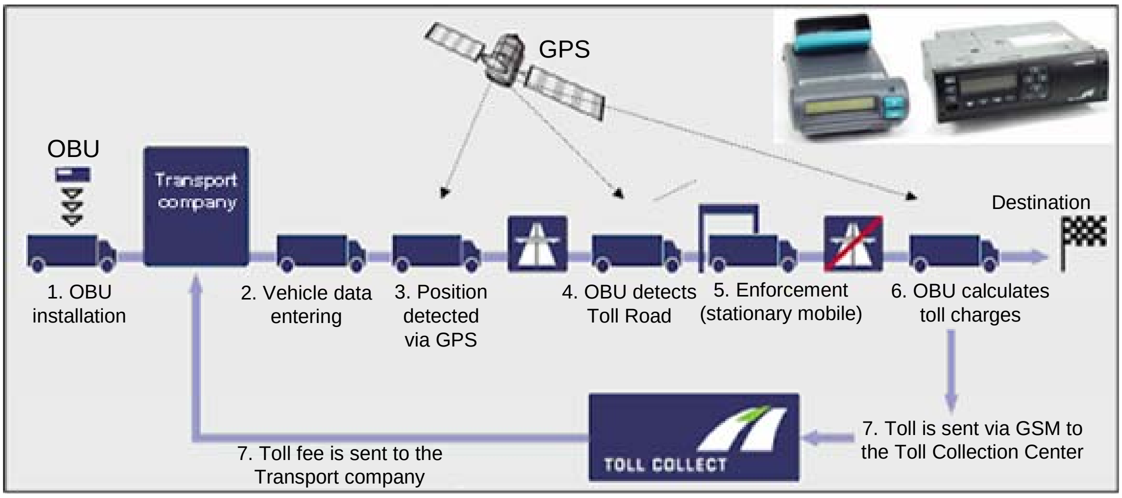

Figure 8. *Toll Collect System in Germany – automated logging* [*9*]

Toll Enforcement will also rely on mobile patrols, consisting of a fleet of 300 vehicles with 540 officers of the Federal Office of Freight (BAG). The officers will patrol the autobahns, checking vehicles and drivers to see if they have paid the toll or have the OBU installed (these vehicles will be equipped with an infrared short range DSRC (Dedicated Short Range Communications) system that can be used to scan and monitor trucks in motion). The BAG will have police powers to request trucks to stop for examination at any point during their journey. The OBU will also be able to work with the new Galileo satellite system for positioning which is being developed in Europe as a more accurate alternative to GPS.

Electronic Toll Collection System was implemented in Australia, especially in Melbourne and Sydney. The company Transurban was awarded the contract to construct two new freeways – labelled the Western and Southern Links – directly linking a number of existing freeways to provide a continuous, high-capacity road route to, and around, the central business district.

When electronic toll collection or ETC was introduced to Australia starting in the mid 1990's there were already several competing technologies world-wide and two incompatible systems were introduced by different operators of toll roads in east coast states of Australia. It was soon apparent that this would limit the take-up of the technology, so in 1998 the governments of Australia decided to adopt the European CEN Standard for all future projects. Despite this, interoperability was not immediately achieved and a standardization committee was formed to examine interoperability between the different suppliers' products. The result was Australian standard AS 4962 published in 2001.

D. Hensher, Director of the Institute of Transport Studies at the University of Sydney (Australia), has offered a new electronic toll collection system, based on distance and axle load (Fig. 9).

Tolls based on axle loads can be used to charge heavy vehicles for road damage. Heavy vehicle operators ignore both road damage and congestion costs, imposed on others. A heavy vehicle also contributes more to congestion than a car, because of its size and slow acceleration in stop start conditions.

Damage to roads rises faster than linearly with payload per axle, yet fuel consumption rises less than linearly with payload, hence, fuel taxes are quite inappropriate for capturing road wear costs and for encouraging efficient practices.

Distance-based charges system may consist of the following.

- Participants in tracking/distance reckoning and road use assessment system: the vehicle, the station (be it a service station or a truck station or other).
- Tracking can be defined spatially with using OBU (on-board unit) and GPS system.
- OBU records distance in jurisdiction.
- Central computer: wirelessly intercommunicating with OBU, calculates road-use charge and applies it at point of sale, once the charge has been paid the system turns OBU back to zero, re-initiating the road-user charge procedure.

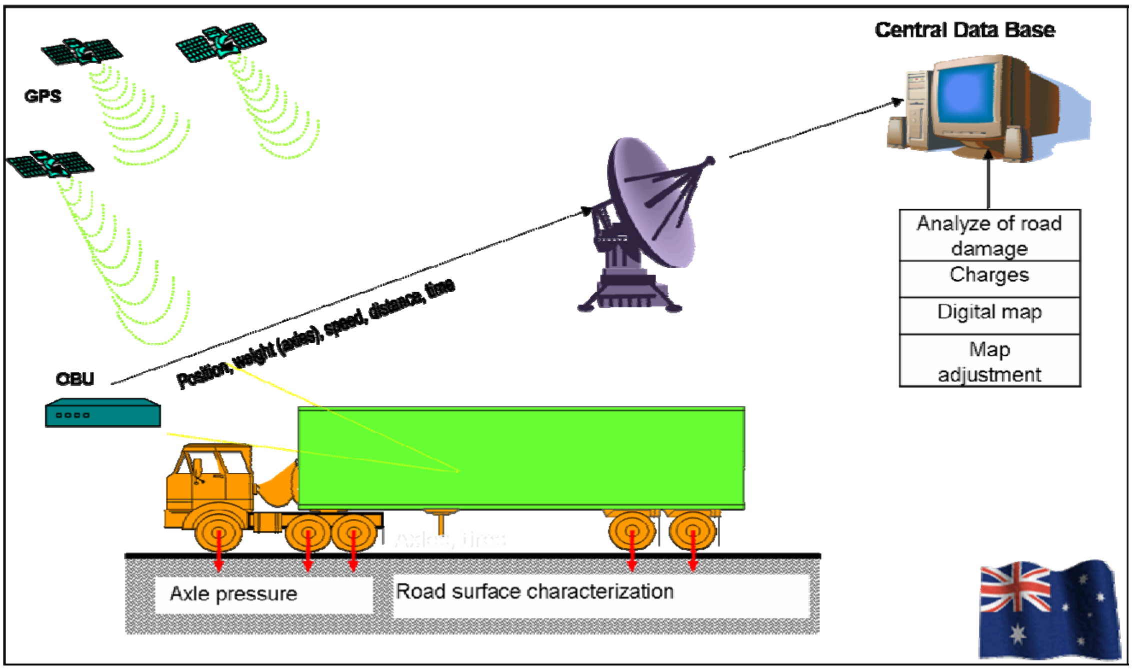

Figure 9. *Proposition of ETC system for Australia*
Based on presentation – Hensher D. A, Road User Charging: Where to Next. ALGA National Local Roads and Transport Congress, Launceston – http://www.alga.asn.au/policy/transport/congress/2005/presentations/hensher.php

In a field test in Melbourne and the New South Wales region, Siemens ITS, Transurban, the toll solutions market leader in Australia, and the largest Australian mobile radio provider, Telstra, have successfully tested a hybrid OBU from Siemens VDO and a new software application with which both microwave-based and satellite-based toll solutions can be used by one single unit.

The hybrid OBU, into which a DSRC microwave module is integrated, makes it possible to detect existing microwave signals from toll gantries in addition to normal satellite operation. Therefore, Siemens is the first manufacturer of a hybrid OBU which detects microwave signals from gantries and processes GPS signals. This is above all important in view of possible migration from DSRC to GPS solutions.

A GSM/GPS system for road charging has been made a long-term government target in the UK. This technology is the only ETC system that can also potentially support telematics services, including the e-call provision that the EC would like to see introduced for all new cars from around 2010.

3. Future Trends of Electronic Toll Collection Systems

Specialist literature study demonstrates that Europe already has a poor record on the interoperability of ETC services between different countries. Each nation has hitherto developed its own system for toll collection, with at present only one example of cross-border co-operation. A future single contract and invoice system would have to take into account the split between public and private toll operators and the national differences in areas such as tariffs, sales tax and legislation.

Electronic Toll Collection (ETC) systems offer the possibility of charging road vehicles in a more flexible way and allow infrastructure charging policies to be implemented. It is vital for such systems to be interoperable across national borders to avoid creating new obstacles to traffic flow in Europe. Interoperability should therefore enable users to travel throughout the Union without charging procedures changing from one country to another and without having to install extra equipment to access other charging zones. This does not mean there would be one single supplier but that there should be sufficient technical compatibility between different systems so that paying charges on different stretches of road in the Union would be a seamless operation. Interoperability is, therefore, an important factor from the viewpoint of the single market, transport policy and the development of the information society.

This Communication examines the obstacles to interoperable electronic fee collection systems and puts forward certain recommendations for arriving at an appropriate level of interoperability on a European scale.

The first major issue studied is technical interoperability. Existing motorway ETC systems make use of Dedicated Short Range Communication (DSRC) between fixed roadside equipment and vehicles. Another type of system is based on satellite location (GPS) and mobile telephone technology (GSM).

The first step towards interoperability should be the definition of a common minimum level of functionality to enable authorized subscribers to pay fees using the same method of payment and the same equipment anywhere on the network of operators belonging to the system.

The second major issue is contractual interoperability. The existence of interoperable equipment needs to be accompanied by contractual agreements between infrastructure operators. The same concept of a common minimum level of functionality should therefore be applied.

The Commission argues that satellite positioning in conjunction with mobile communications is the only solution that allows easy application of ‘zone tolls’ – for instance, within conurbation.

In 2004 the agreement was signed between the United States of America and the European Community. The objective of it is to provide a framework for cooperation between the Parties in the promotion, provision and use of civil GPS and GALILEO navigation and timing signals and services, value-added services, augmentations, and global navigation and timing goods. The Parties intend to work together, both bilaterally and in multilateral for, as provided herein, to promote and facilitate the use of these signals, services, and equipment for peaceful civil, commercial, and scientific uses, consistent with and in furtherance of mutual security interests. This agreement is intended to complement and facilitate agreements in force, or which may be negotiated in the future, between the Parties related to the design and implementation of civil satellite-based navigation and timing signals and services, augmentations, or value-added services. There will be four different navigation services available:

– The Open Service (OS) will be free for anyone to access. The OS signals will be broadcast in two bands, at 1164–1214 MHz and at 1563–1591 MHz. Receivers will achieve an accuracy of < 4 m horizontally and < 8 m vertically if they use both OS bands. Receivers that use only a single band will still achieve < 15 m horizontally and < 35 m vertically, comparable to what the civilian GPS C/A service provides today. It is expected that most future mass market receivers, such as automotive navigation systems will process both the GPS C/A and the Galileo OS signals, for maximum coverage.
– The encrypted Commercial Service (CS) will be available for a fee and will offer an accuracy of better than 1 m. The CS can also be complemented by ground stations to bring the accuracy down to less than 10 cm. This signal will be broadcast in three frequency bands, the two used for the OS signals, as well as at 1260–1300 MHz.

The Transport Council reached historical conclusions at its session of 29/30th November, 2007 on the future developments of Galileo, more specifically on the procurement and governance aspects. Together with the ECOFIN Council and European Parliament decision of 23rd November, 2007 on the financing of the program, the European Commission has now the basis to implement the next phase of the European GNSS programs. As proposed by the Commission on 19 September, this next phase – the deployment of Galileo – will be carried out and financed by the Community. The next phase includes the operational availability of EGNOS within the next 1–2 years as well as the procurement of Galileo and leading to a Galileo operational system by 2013.

The Commission proposes that the use of satellite positioning technology should be compulsory as from 2008 for newly introduced systems, and as from 2012 for all systems. Systems brought into service before 1st January, 2008 will be required to have abandoned the microwave technology by 1st January, 2012.

With a view to the possible migration to systems based on satellite and mobile communications technologies from services based on other technologies, the Commission shall submit a report no later than 31st December, 2009.

4. System Proposition for the Republic of Poland

The Motor Transport Institute with University of Technology in Warsaw and Lublin intend to create the structure of The National Automatic Toll Collection System for Poland (NATCS). System will be consisted of The National Automatic Toll Collection Centre (NATCC), control gates and on-board units (OBU) – Fig. 10. The prototype of control gate and OBU will be carried out by AutoGuard S.A. It is a leading company on Polish market that produces telematics systems since 2000. Its experience is based on long-term cooperation with scientific and research institutes as well as on continuous analysis of new technologies that allow creating new telematics solutions.

The system is based on an innovative combination of mobile telecommunications technology (GSM) and GPS, the satellite-based Global Positioning System. The main element of the automatic log-on system is the On-Board Unit (OBU). With the aid of GPS satellite signals and other positioning sensors, the OBU automatically determines how many kilometres have already been driven on the toll route, calculates the toll based on the vehicle and toll rate information that has been entered, and transmits this information to the NATCS computer centre for further processing.

Software will be support with electronic road maps and data of users registered in as well as data charges of highways and expressways.

Charge counting will be started after highway entrance gate and finished after highway exit gate. Data on vehicle position will be additionally approved by GPS system and delivered to NATCC by GSM net. The toll amount is based on the truck’s emission category and number of axles, as well as on the length of the toll route.

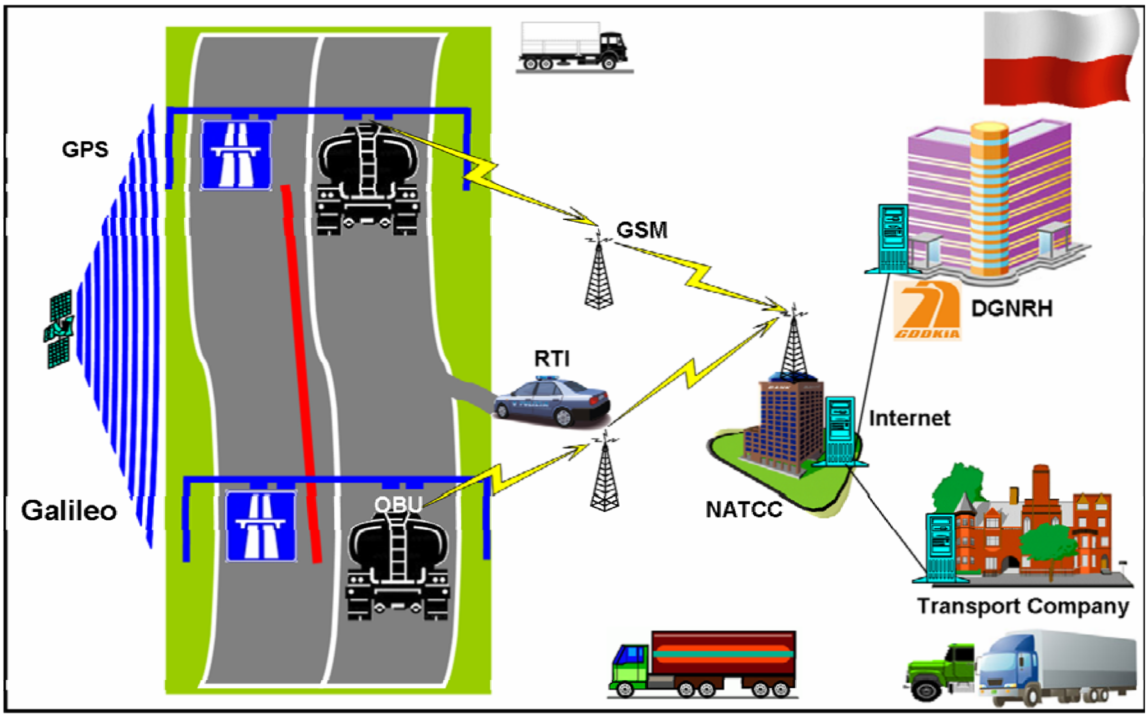

Figure 10. *The structure of the National Automatic Toll Collection System (NATCS)*

Details on Figure 4 to be clarified:

– DGNRH – Directorate-General for National Roads and Highways,
– NATCC – The National Toll Collection Centre,
– RTI – Road Transport Inspection.

For truck drivers, automatic log-on requires the least amount of effort: He is not required to book the route himself. All key data is already stored in the On-Board Unit. The prerequisite for participating in automatic log-on is registration the transport company and the trucks with General Directorate-General for National Roads and Highways (DGNRH) and pay toll to DGNHR. After registration, the company receives a vehicle card for each truck. This card contains the most important vehicle information. With this vehicle card, the user can schedule an appointment with an authorized Toll Collect Service Partner to have an On-Board Unit installed.

The simplest way to pay the truck toll is to register company and vehicles with DGNHR. A registered user can have an On-Board Unit installed and participate in automatic log-on and use all possible means paying the toll (credit account, credit card or fuel card, cash payment). Immediately after registering your company, you will receive a personal user number and a master PIN number for security. After vehicle registration, we will send you a vehicle card for each truck, containing the most important information about the vehicle.

System has control gates equipped with IR detection equipment and high resolution cameras able to pick out trucks via profiling (and record number plates) – Fig. 11.

Toll enforcement and the punishment of violations are the responsibility of the Road Transport Inspection. The RTI has provided with the technology needed for an effective enforcement system so that RTI can enforce correct booking of the toll, thereby ensuring that all toll payers are treated equally. With the aid of this system, RTI can determine if a vehicle is has an obligation to pay toll and if it has met this obligation fully, partially, or not at all.

The control system distinguishes between automatic enforcement through control gates, enforcement by stationary and mobile teams, and company-level enforcement. This combination guarantees comprehensive, continuous enforcement of the requirement to pay toll and allows the control system to be constantly adjusted to meet prevailing circumstances.

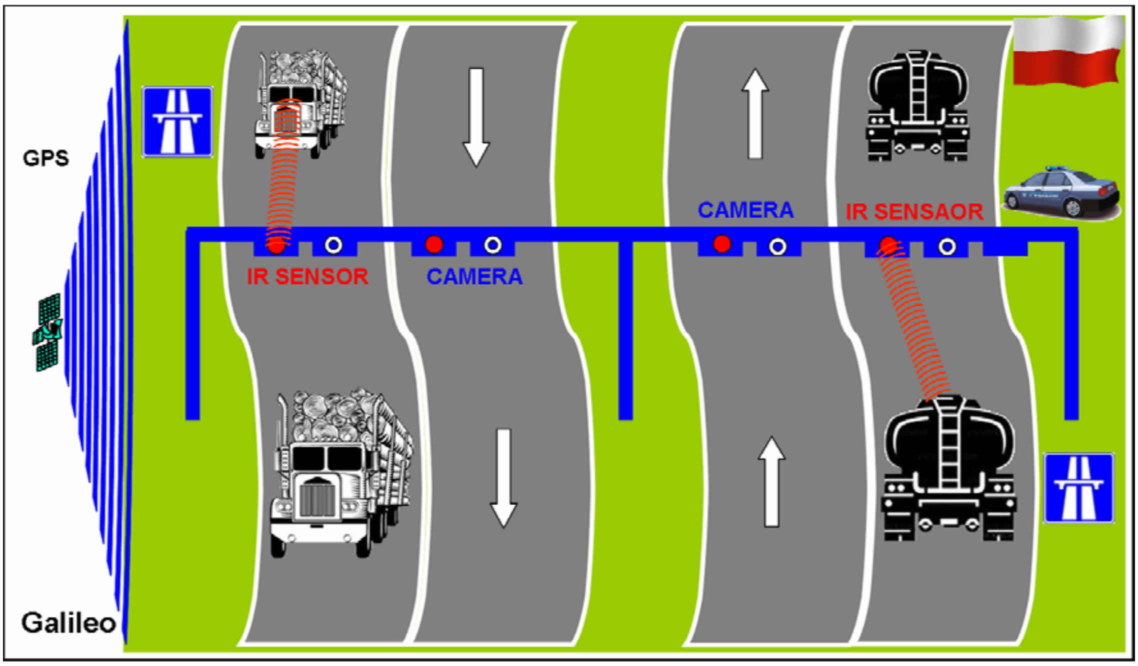

Figure 11. *Control gate with electronic equipment*

5. Conclusions

These mentioned families of technology for future electronic toll collect systems and all have different attributes, advantages and disadvantages. For many years, microwave-based digital short range communication (DSRC) systems have been preferred, due to their simplicity of operation, potential for supporting additional services for vehicle users and, most importantly, because they are easy for users to understand. These systems need road-side equipment, typically mounted on a gantry, with electronic tags in the vehicles which may be read-only, read-write or smartcard-based. The key limiting factor seems to be the processing speed of the smartcard – each charging point has two gantries – one to start communications with the vehicle and a second (further down the road) to complete the transaction and perform enforcement measures, if necessary.

A new class of ETC systems is based on a combination of mobile communications technology (GSM) and the satellite-based global positioning system (GPS). An innovative element of the automatic log-on system is the On-Board Unit (OBU), which automatically calculates the amount of charge due and takes into account the emissions class (ecological aspect) and the number of vehicle axles in calculating this charge.

The first GPS based system advantage is absence of the need for new road infrastructure (gantries), operators can keep using the existing infrastructure. System works without toll booths, extra lanes, speed restrictions or complex structures along toll roads. The second is much greater flexibility in defining or changing payment by simply redefining the "virtual" toll areas. It means ability to adapt easily and quickly to changes in charge parameters (road classes, vehicle types, emission levels, times slots etc). The third is the systems ability to support other value-added services on the same technology platform. These services might include fleet and vehicle engine management systems, emergency response services, pay-as-you-drive insurance services and navigation capabilities.

These systems were implemented in the Germany and Hong Kong and will be implemented in UK, India, USA, China, and Australia. With regard to future expansion and development, the satellite-based toll collection system will be a better solution, especially with regard to flexibility when it comes to extending toll collection to every road category, every category of vehicle and, what's more, in terms of cost efficiency in implementation and operation.

References

1. Beckers T., Brenck, A., Klatt, J. P. *Die ASFINAG und das Österreichische Modell der Fernstrassenfinanzierung Finanzierung des Netzes durch die Autobahnen- und Schnellstrassen-Finanzierungs-AG als privatrechtliches Unternehmen. Internationales Verkehrswesen, Nu 1+2.* Hamburg, 2006.
2. Burris, M. W. *Electronic Toll Collection and Variable Pricing. Chapter 10 in Assessing the Benefits and Costs of Intelligent Transportation Systems. Volume 10 of Transportation Research, Economics, and Policy*. San Antonio: Kluwer Academic Publishers, 2004.
3. Chia-pei, Chou, Yi-hsien, Chen and I-Chang, Chen. Integrating weigh-in-motion and electronic toll collection for commercial vehicle operation in Taiwan, *Journal of the Institution of Engineers*, Vol. 44, Issue 2, Singapore, 2004.
4. Directive 2004/52/EC of the European Parliament and of the Council of 29 April 2004 on the interoperability of electronic road toll systems in the Community. OJ of the EU, L 166/132, 30.04.2004.
5. Electronic Toll Collection/Electronic Screening Interoperability Pilot Project Final Report Synthesis. Department of Transportation, Publication FHWA-OP-03-XXX, USA, July 29, 2005.
6. Gommori, N., Fushiki, T., Ito, A., Nakagawa, H., Nitta, T. Telematics Information Service for Commercial Vehicles (B2B) – Hitachi's ASP Service for Truck Fleet Management, *Hitachi Review*, Vol. 52, No 1, 2003.
7. Hofstetter, H. Electronic Tolling System in Austria. In: *Proceedings of the Conference on Road Charging. Paris, 1st June, 2006.* Paris, 2006.
8. Kossak, A. Road Pricing in Germany. Research and Consulting. Hamburg. In: *TRB 2006 Annual Meeting. Washington D.C. January 22 –26, 2006.* Washington D.C, 2006.
9. LKW-MAUT Electronic Toll Collection System for Heavy Goods Vehicles, Germany – http://www.roadtraffic-technology.com/projects/lkw-maut/lkw-maut4.html**.**
10. Shou-Ren, Hu. Realization of ITS Potentials and Benefits – From the Current to the Future ITS Development and Deployment in Taiwan. In: *Proceedings of the ITS Academia Network Symposium. Keio University, Yokohama, Japan, June 13, 2002.* Yokohama, Japan, 2002.
11. The Act from 28th of July, 2005 on changing act of public roads and some other acts, *Official Journal 2005,* No 172, position 1440.
12. The materials of 16th meeting of the CCTF Quasi-Zenith Satellite System – a new satellite positioning system of Japan – Communications Research Laboratory, Koganei, Tokyo, Japan, 1–2 April 2004.
13. Yang, Xiaoguang; Wu, Zhizhou; Yun, Meiping. *Status and Trend of China ITS Development.* China, Shanghai: Institute of Transportation, Tongji University, 2002.

Transport and Telecommunication, 2008, Volume 9, No 2, 39–45
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INVESTIGATION OF BUS AND COACH SERVICE QUALITY ON THE BASIS OF INFORMATION SYSTEM FOR RIGA COACH TERMINAL

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The objective of the article is to analyse data about quality of bus and coach transportation in Latvia. Regional, intercity and international trips arriving in Riga Coach Terminal are examined. Determination and analysis of punctuality indices for different operators, on the different routes of buses, on day times and days of the week and for terminal as a whole may be a basis for a decision-making on quality improvement of passenger services. A solution of this task is an inalienable part of the quality system supported on a Coach Terminal and will serve as a basis for forming the passenger logistic hub on Riga Coach Terminal base.

Keywords: *bus, information system, reliability, punctuality, descriptive characteristics, analysis*

1. Introduction

Nowadays the process of market regulation principles changing from the direction of the state is going on. Taking into account the EU standards the quality of travel is the important moment in determination for the transport operator or mode of transport.

The role of information system in transport is important from the point of view of the service quality for travellers. The development of the information system is an essential factor for coach terminals as passengers' transport infrastructure objects in their transformation into passengers' logistics centres [1]. The first realization of the coach terminal information system (IS) „Baltic Lines" was implemented in Riga Coach Terminal in 2003. From 2004 the system is being used in other cities of Latvia. Nowadays, plans to introduce it in some EU countries are discussed. The description of information flows, functions, technical decisions of the IS „Baltic Lines" has been described in [2] and the possibilities of using this system at the strategic and operative levels have been analysed in [3]. The current developing task in this system is the development of the quality indicators system on the base of sampled data from the IS „Baltic Lines".

2. Measure of Reliability of Bus and Coach Service

The quality of the rendered service is one of the main characteristics of public transport development, which is the necessary condition of demand for it.

There is the system of measures for the evaluation of city bus service quality in [4]. In this research one of these indices does not make sense, some of them must be calculated on the basis of other algorithms.

Measures of bus intercity, regional and international transportation quality can be classified in 2 groups: providing availability and providing comfort and convenience from the passenger's point of view by this mode of transport. Availability is foremost provided by a network, within the limits of which service is carried out by this mode of transport and time-table (by time and frequency, to the proper queries of users). Comfort and convenience are connected with reliability of service; first of all, it's joining with other modes of transport, passenger seating capacity.

As this mode of transport is in competition with railway (and private cars also) in Latvia the measures that represent comfort and convenience are of great importance. Railway is the mode of transport, which doesn't feel the influence of congestion or weather conditions, and that's why it is more reliable mode of transport and also is the winner in competition with bus by travel time. On the other hand, it yields to bus transportation by the level of availability (absence of network in some districts, foremost). In this competition, multiplying a comfort and service of bus transportation can play a solution role in the choice of this mode of transport. And if time of moving often differs insignificantly (example), reliability can become the problem for a bus travel. The exact observance of time-table becomes the important property.

In this research the main attention has been paid to measure the reliability of coach and bus service. Reliability is a measure determining bus service level from the viewpoint of users as well as operators.

One of the considered in [4] reliability indices is punctuality index. Punctuality of bus operation is a quantitative measure of reliability from the viewpoint of users. This index indicates the magnitude of time gap between actual and scheduled arrival times. Research of this index in combination with different factors influencing on this index and in an ideal development of the model for evaluation of punctuality is a difficult task, possible only at presence of enormous amount of information and its plenitude. The presence of the developed information system of Riga Coach Terminal makes possible the solution of such task in the decision-making designed module.

The task of exposure of different factors influencing this index stronger than others is important for top management first of all. To such factors potentially the following can be referred [4]:

- Traffic conditions,
- Road conditions (weather),
- Road length and number of stops,
- Operation control strategies.

3. Data Collection

The system solution of this task requires fixing of real arrived times at all intermediate stops. It is possible equipping GPS in all busses, that it is planned to carry out by the end of 2009. Information has been collected about times of buses arriving on the final bus stop in Riga bus terminal for July 2005, 2006 and 2007.

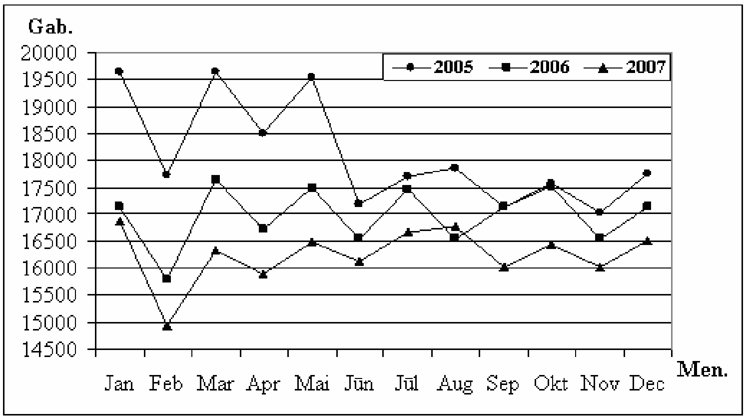


Figure 1. *Time series of the inbounding trips to Riga Coach Terminal*

In this research the data about delays on the last stop – Riga Coach Terminal in July 2005, 2006 and 2007 have been analysed. In 2005, Riga Coach Terminal executed 17703 inbound trips, in 2006 – 17470 trips, and in 2007 – 16680 inbound trips and in more than 70 directions (see Figure 1 and Table 1).

Besides, the decision of this task in relation to Riga Terminal is important also because the space of the terminal is limited and for today dissatisfies the tasks of providing comfort and safety to the passengers. Delay of arrival not only violates the plans of passengers but also often complicates the problems of placing for loading and unloading on platforms.

Assumption is accepted – to fix as a delay only delay for a time more than 10 minutes. On every delay a date, time, operator, trip and reason of delay have been recorded.

4. Results of Statistical Treatment

4.1. Descriptive Characteristics

In Statistica/Win package descriptive characteristics of delays of trips arriving at the Riga Coach Terminal (See Table 1) have been obtained.

Table 1. Descriptive statistics for the sample with trip delay in July 2005, 2006 and 2007

Year	N	Valid N	%	Mean	Median	Mode	Freq.	Min.	Max.	5%	95%	Variance	Std. Dev
2005	17703	1078	6.09	38.01	19.00	10.00	118.00	10.00	646.00	10.00	122.00	3175.82	56.35
2006	17470	1440	8.24	29.64	19.00	10.00	144.00	10.00	411.00	10.00	89.00	958.40	30.96
2007	16680	1129	6.77	27.07	16.00	10.00	159.00	10.00	447.00	10.00	80.00	1731.52	41.61

As it is obvious from the results of treatment of statistics on delays for July 2007:

- the delay of arrival in Riga is established at 1129 trips, that is 6.77% of the common number of trips;
- the mean duration of delay – 27.07 minutes;
- the most widespread delay makes 10 minutes (*mode*) and that delays compile 14% of total amount of delay;
- 50% delays exceed 16 minutes and 5 % delays make compile 80 minutes;
- the expected value of delay is covered by an interval (24.65; 29.50) with the confidence level 0.95;
- a maximal delay in 2007 compiled a bit less than 8 hours (447 minutes) (in 2005 – over 10 and a half of hours);
- deviation of delay – almost 42 minutes.

It is possible to establish a small increase in 2007 of both absolute number of delays and relative number (in %), if to compare these results to the indices for 2005. As a positive tendency it is possible to mark diminishing in 2007, if compared to 2005, average, maximum of delay and a median, and also characteristics of delay scattering. It is possible to establish a tendency to multiplying the number of small delays. Research of distributing of delays by duration also confirms it. On Figure 2 the distribution of delays by duration is presented. Predominance of delays from 10 to 20 minutes is confirmed in 2007. But at that a part of delays of trips for more than 20 minutes is rather large – more than 30%.

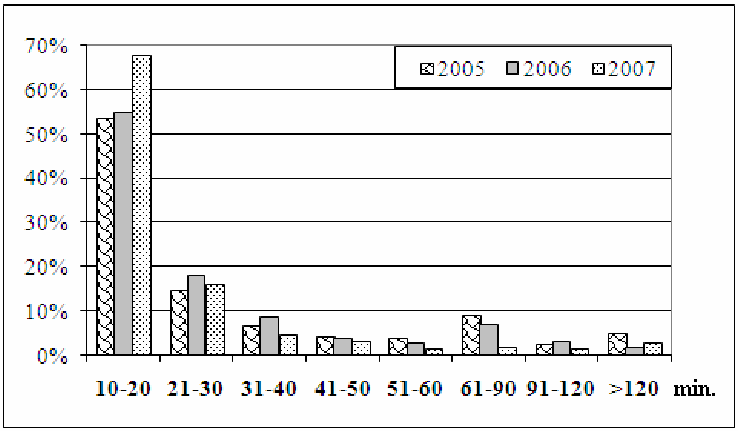
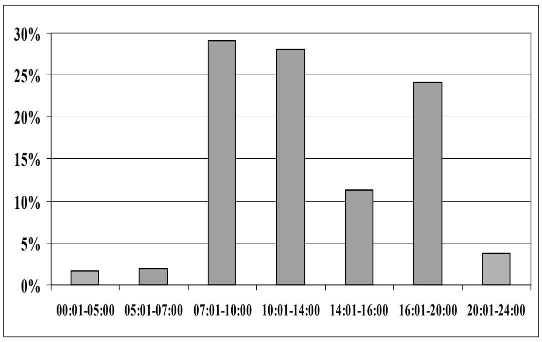
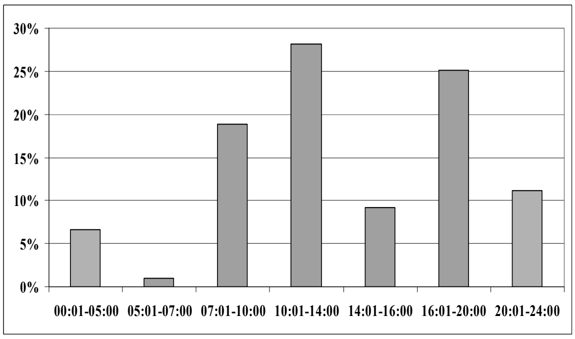


Figure 2. *Distribution of delays by duration (arriving at the Riga Coach Terminal)*

On Figure 3 the distribution of delays on arriving at the Riga Coach Terminal by the time of the day is presented. As it is obvious from the graph in 2007 most of delays is at hours 7.00–14.00 and 16.00–20.00, thus this tendency has become stronger if to compare to 2005. It is possible to suppose that one of the factors, influencing it, is connected to congestions in the streets of Riga during these hours. Certainly, this supposition requires a separate verification.



a) July, 2007



b) July, 2005

Figure 3. *Distribution of delays by time of the day*

We can suppose that the frequency of delays depends on the frequency of trips in these time periods (at hours 7.00–14.00 and 16.00–20.00) but it is known [6] that the amount of trips is approximately uniformly distributed between hours 10.00 and 21.00.

4.2. Analysis of Dependence of Delay on the Day of a Week

Distribution of delays by duration for the different days of a week is showed on Figure 4. Evidently, the most prolonged delays are more frequent at weekends.

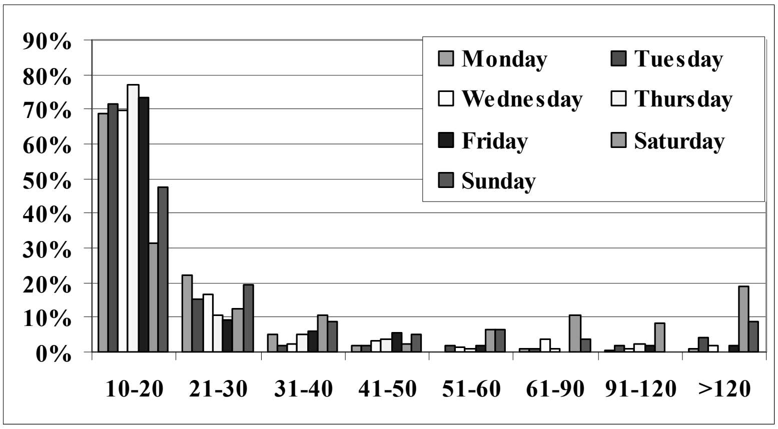


Figure 4. *Distribution of delays by the day of a week (July, 2007)*

In Table 2 the descriptive characteristics of delays by the days of a week for the examined time are presented. Evidently there are considerably less delays at weekends in 2007 if to compare with working days, although the amount of trips does not differ so meaningfully (see Figure 5). However mean value and scattering of delays is considerably greater at weekends.

Table 2. Descriptive statistics for trip delay in different days of a week in July 2005, 2006 and 2007

Day	Delay Time for 2005			Delay Time for 2006			Delay Time for 2007		
	Number	Means	Std. Dev	Number	Means	Std. Dev	Number	Means	Std. Dev
1	146	28.53	31.46	301	26.13	26.40	299	20.70	24.52
2	142	25.28	21.81	226	25.73	23.22	193	26.07	35.05
3	140	32.87	35.52	215	29.19	36.84	211	25.45	37.36
4	151	38.63	55.77	183	30.91	27.60	139	18.74	14.36
5	202	41.88	77.84	211	29.19	25.02	161	24.46	36.27
6	168	54.28	67.17	147	37.65	48.09	48	80.44	102.77
7	129	40.33	63.04	157	34.33	28.93	78	45.71	64.71
Total	1078	38.01	56.35	1440	30.45	31.2	1129	27.07	41.61

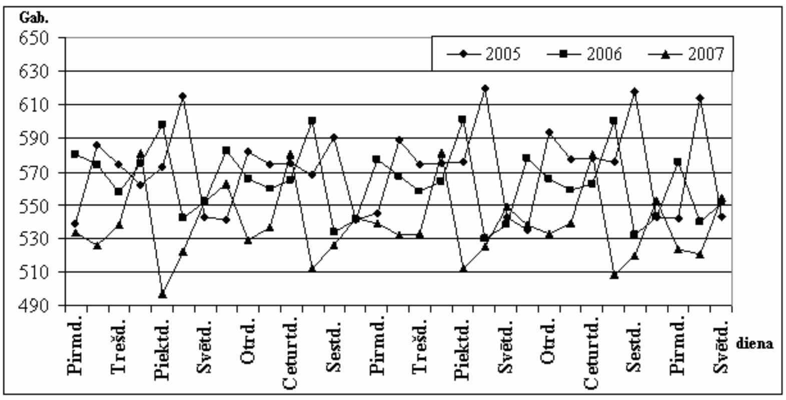


Figure 5. *Distribution of the number of trips by the days of a week (4 weeks, July, 2005 and 2007)*

During testing the hypothesis about insignificance of delay value dependence on the day of a week the value of F criterion is significant and, consequently, the hypothesis about insignificance is rejected for data of 2005, 2006 and 2007 (see Table 3). However, the distinction between delays at weekends and working days had been considerably increased to 2007.

Table 3. Descriptive statistics for delays sampling for July, 2005, 2006 and 2007

	SS	df	MS	SS	df	MS	F	p
2005	88095.83	6	14682.64	3332266	1071	3111.360	4.719	0.000094
2006	20426.35	6	3404.4	1358477	1432	948.66	3.589	0,001553
2007	187406.2	6	31234.37	1765744	1122	1573.746	19.847	4.00E-22

4.3. Analysis of Dependence of Delay on Direction and Trip

The supposition that the number and duration of delays are influenced by congestions in the streets of Riga has been done earlier. All trips have been divided into 4 directions, which determinates the gate of entry to Riga: 1 – Zemgale (Z), 2 – Latgale (L), 3 – Kurzeme (K), 4 – Vidzeme (V) (see Figure 6).

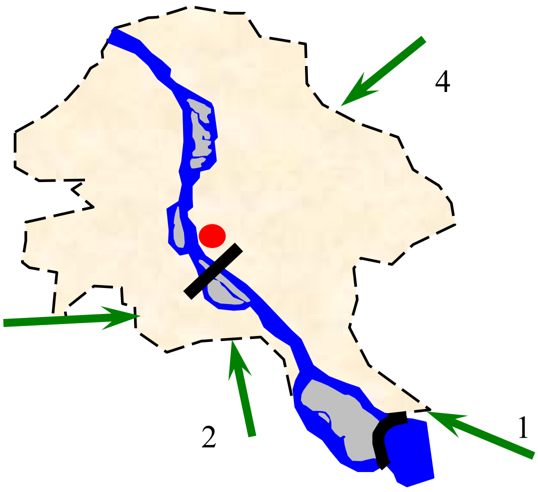
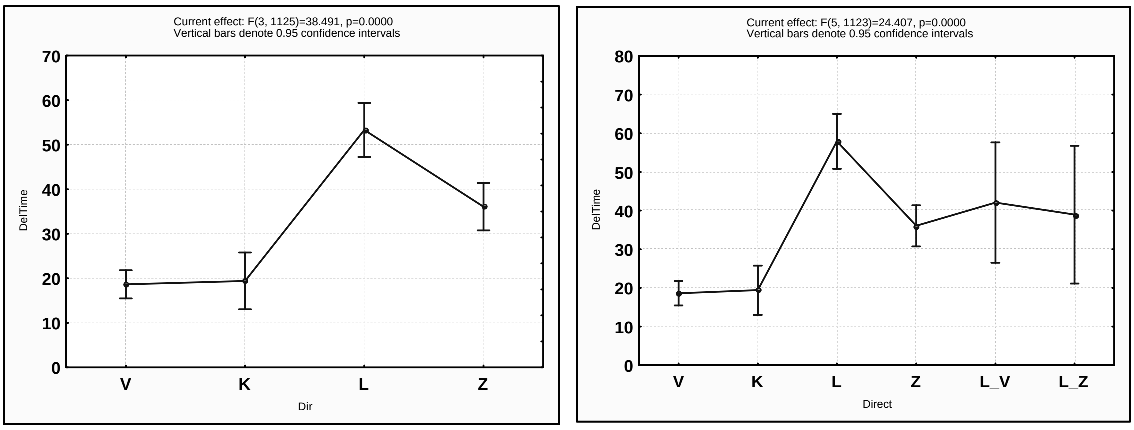


Figure 6. *Basic directions of buses entry to Riga*



a) 4 gates *b) 6 gates*

Figure 7. *95% confidence intervals for delay depending on directions (July, 2007)*

On Figure 7a) it is clearly evident that the value of the delay is considerably greater than in case of the Latgale's direction of trips. Changing of entry direction to the city is typical for four international trips. For example, trips from Minsk or Lvov can follow in Riga to the station through Latgale's or Zemgale's direction, and trips from Moscow and Saint Petersburg – either through the Latgale's or through Vidzeme's direction. On Figure 7b*)* this case of factor influence analysis is presented (6 levels – directions of entry and the duration of delay). Even in this case the Latgale's direction is meaningfully outstanding by the duration of delay. The F criterion is equal to 24.41 at critical level of F(3,1125) = 2.22. In case of 4 directions (without taking into account possible changing of direction) the F criterion is equal to 38.45 at critical level of F (3,1125) = 2.61.

Delays for over 2.5 hours in July 2005–2007 have been also analysed (see Table 4). Among them in July, 2005 the first place is occupied by Moscow with maximal value of delay – 625 minutes and in July, 2007 the first place is occupied by Odessa with maximal value of delay in July – 447 minutes.

Table 4. Distributing of delays of over 2.5 hours for July, 2005–2007

2005			2006			2007		
From…	**N**	**Max**	**From…**	**N**	**Max**	**From…**	**N**	**Max**
Moscow	11	625	Cologne	2	262	Odessa	4	447
London	8	388	Moscow	2	235	Tallinn	4	367
Cologne	2	288	London	1	313	Kiev	3	443
Warsaw	2	240	Truskavec	1	284	Kishinev	2	371
Paris	2	227	Stuttgart	1	212	Cologne	2	340
Roma	1	646	Vilnius	1	178	London	1	286
Kiev	1	339	Simferopol	1	171	Doneck	1	212
Vilnius	1	271	Tallinn	1	164	Truskavec	1	207
Stuttgart	1	258	Bonn	1	161	Bonn	1	205
Tallinn	1	228	Doneck	1	160	Berne	1	200
Lvov	1	207				Krakow	1	190
St-Petersburg	1	170						
Total	**32**			**12**			**22**	

It is clear that considerable delays showed in Table 4 relating to international trips are also connected to the problems of border crossing.

5. Conclusions

The task of estimating the quality of services from viewpoint of reliability is very important for the area of bus and coach operations. In the presented research delay time of arrival of buses at Riga Coach Terminal for July, 2005, 2006 and 2007 has been collected and analysed.

The conducted calculation and analysis of empiric descriptions of delay allows developing algorithms for realization of the proper tasks in analytical part of Information System with the purpose of decision of strategic and tactical tasks of terminal management. In addition, this information can be useful from |the standpoint of simulation model construction of bus terminal with the purpose of critical situation analysis during a day. Examining quality of information, one of the major terms of high-quality simulation model, the real information on delay will allow making the model more realistic [5].

One of the important results of this analysis is the discovery of the company being a leader by trip delays with the aim to improve the passenger service quality.

The realization of this task gives the possibility to analyse the reliability of the bus service and to improve the level of quality on the base of these results. Also, the possibility to analyse the factors, which influence on reliability of the bus and coach service is of great importance. The next step of investigation is to analyse the dependence between delay and the following factors: traffic and road conditions; route length and bus occupancy.

References

1. Gromule, V., Yatskiv, I. Coach Terminal as an important element of transport infrastructure. In: *Proceedings of the International Scientific Conference "Transbaltica 2007", Vilnius, 11th–12th April, 2007.* Vilnius, 2007.
2. Gromule, V. Development of Information System for Coach Terminal. In: *Proceedings of the 7th International Conference RELIABILITY and STATISTICS in TRANSPORTATION and COMMUNICATION (RelStat'07)", October 24–27, 2007, Riga, Latvia*. Riga: TTI, 2007, pp. 44–52.
3. Gromule, V., Yatskiv, I. Information System Development for Riga Coach Terminal. In*: Proceedings of the 6th WSEAS International Conference on SYSTEM SCIENCE and SIMULATION in ENGINEERING. Venice, Italy, November 21–23, 2007.* Venice, 2007, pp. 173–178.
4. Kittelson, P. B., Quade, K., Hunter-Zaworski, K. M. *Transit Capacity and Quality of Service Manual, 2nd Edition*. Washington, DC: Transportation Research Board, National Academy Press, 2003.
5. Kho, S.-Y.,Park, J.-S. Kim, Y.-H. Kim, E.-H. A Development of punctuality index for bus operation, *Journal of the Eastern Asia Society for Transportation Studies,* Vol. 6, 2005, pp. 492–504.
6. Gromule, V., Jurshevich, J., Yatskiv, I. Application of Simulation Modelling at the Stage of Transport Node Planning, *Transport and Telecommunication*, *RelStat'06*, Vol. 7 (3), 2006, pp. 178–187.

Transport and Telecommunication, 2008, Volume 9, No 2, 46–51
Transport and Telecommunication Institute, Lomonosov 1, Riga, LV-1019, Latvia

A SIMULATION MODEL OF CHOOSING AN AIR FLIGHT BY A PASSENGER

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The purpose of this research is as follows: creation of a passenger's behaviour model in choice of flight. For practical calculations the simulation approach has been used. Simulation has been carried out with MathCAD software.

***Keywords**: choice model, choice of flight, simulation approach*

1. Introduction

Choice models describe rather a general situation when it is necessary to make only one decision from the several available. In the choice models the subject is the person who makes a decision, and alternatives are his possible decisions.

There are a lot of different mathematical theories describing various choice models, for example, rather a detailed choice models applied to transport processes can be found at M. Ben-Akiva and S. Lerman [1].

Modern choice models are built on a multi-alternative basis and have obtained a wide distribution at the creation of the flight choice models by a passenger.

The creation of the potential passenger's behaviour analytical model includes two problems: firstly, it is necessary to create the model itself; secondly, it is necessary to estimate its parameters.

It is necessary to note, that the creation of the analytical expression for multi-alternative choice models is complex enough. Moreover, very often such models not give satisfactory results. Therefore for practical application simulation models most often are used. The example of creation of simulation multi-alternative model of a flight choice by a passenger can be found at J. Paramonov [2].

2. A Potential Passenger's Behaviour at a Flight Choice Description

When choosing an air flight the passenger may take into account a number of different factors. For example: the cost of the ticket, the departure time, the type of the flying plane, the length of flight, the type of the flight (direct flight or flight with change), service quality, etc. From all the variety of the possible factors for creation of the considered choice model the most significant and dataware provided factors have been chosen. Let us start the description of the model.

2.1. Flights' Description

A pair of cities (direction) is fixed, between these cities m available flights are executed every day. All flights are described by three parameters collected in vectors:

– the number of seats $\mathbf{r}_1 = \left(r_1^{(1)}, r_1^{(2)}, ..., r_1^{(j)}, ..., r_1^{(m)}\right)$;

– the cost of tickets $\mathbf{r}_2 = \left(r_2^{(1)}, r_2^{(2)}, ..., r_2^{(j)}, ..., r_2^{(m)}\right)$;

– the time of departures $\mathbf{r}_3 = \left(r_3^{(1)}, r_3^{(2)}, ..., r_3^{(j)}, ..., r_3^{(m)}\right)$.

2.2. Passengers' Flow Description

There is a flow of the passengers wishing to depart by one of m flights. It is supposed, that each passenger's wishes to get a ticket for a flight on a certain day. However, if there are no tickets suitable for any flight that day, then he transfers the ticket purchase next day. If on the next day he is refused too, the ticket purchase will be transferred for a day after tomorrow, and so on. Thus, the flight can be postponed for some days, but not more than for h days, after that the passenger finally cancels the trip. Let name the value h as a deadline of postponement the flight by the passenger.

On the first (prospective) day of departure the passenger tries to choose the flight from a certain time interval, being guided by a desirable departure time and some values of deviation from this time. If there is a flight, which departure time belongs to the specified range, the passenger chooses this flight. If there is a number of flights available the passenger chooses the cheapest one.

If there is not any suitable flight in the desirable departure time for the passenger, he transfers the ticket purchase on the next day. On this day and all the following days of the possible departure, the passenger chooses the flight with the minimal cost of the ticket.

It is assumed that each passenger is described by four parameters:

- X is the desirable time of departure;
- Δ_+ is the admissible value of positive deviation of the actual time of flight from the desirable one (the positive deviation is understood as a later departure of a plane in relation to desirable)
- Δ_- is the admissible value of negative deviation of the actual time of flight from the desirable one (the negative deviation is understood as an earlier departure of a plane in relation to desirable)
- h is the maximal number of days for which the passenger can postpone his flight.

Each of the listed characteristics is a random variable and has its own distribution.

The random variable X defines the desirable time of departure within a day. It is described by the corresponding density of distribution. It takes whole values from 1 up to 24 with certain probabilities which correspond to the change of intensity of demands within a day.

It is obviously, that for each passenger the values Δ_+, Δ_- and h have the random meanings as well. Let $D = \Delta_+ + \Delta_-$ is an interval of desirable by the passenger time of departure. All characteristics of the passenger can be seen on Figure 1.

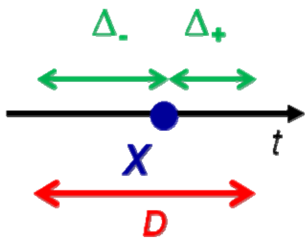

Figure 1. *Passengers' characteristics*

Let us consider the process of a flight choice beginning from the prospective day of departure. For everyone i – th passenger the modelling of a flight choice process can be described in the following way.

From all m flights those flights are selected, the moments of departure of which $r_3^{(j)}$ are situated within the corresponding time interval $r_3^{(j)} \in \left(X^{(i)} - \Delta_-^{(i)},\ X^{(i)} + \Delta_+^{(i)}\right)$, i.e. $r_3^{(j)} \in D^{(i)}$. If there are some flights available then we select one with the minimal cost of the ticket $r_2^{(j)}$:

$$j^{(i)} = \min_j \left\{ r_2^{(j)} : r_3^{(j)} \in \left(X^{(i)} - \Delta_-^{(i)},\ X^{(i)} + \Delta_+^{(i)}\right) \right\}. \tag{1}$$

If there is not any suitable flight, the passenger tries to depart on the following day.

If the passenger cannot depart within t days, he transfers the next attempt on $t+1$ day ($t = 1, 2, ..., h-1$) with the trip refusal probability p_t. Here $\mathbf{p} = (p_1, p_2, ..., p_h)$ is a vector of the trip refusal probability, and an increase of the value h leads to the value's $\{p_i\}$ increase. This probability reaches 1 on the last day of the possible departure.

For each passenger who agrees to depart on the t – th day after the prospective day of a departure ($t = 1, 2, ..., h-1$) the defining characteristic at the flight choice is the minimal cost of the ticket:

$$j = \min_j \left\{ r_2^{(j)} \right\}. \tag{2}$$

It was accepted that the number of potential passengers for each day, originally addressing for the ticket purchase, is a random variable N having a normal distribution with parameters μ_N and σ_N. Besides that, the values $\{N_k\}$ for different days are independent identically distributed (i.i.d.) random variables.

Modelling of the choice process has been carried out for H days, where H is the modelling horizon. As the output data by the end of the modelling horizon H the following parameters are obtained:

1) the percent of the payload capacity of flights;

$$Com_j = \frac{R_1^{(j)}}{r_1^{(j)}} \cdot 100\% , j = 1, 2, \ldots, m, \tag{3}$$

where:

$r_1^{(j)}$ is the number of seats on the *j*-th flight;

$R_1^{(j)}$ is the average number occupied seats on the *j*-th flight.

2) the share of refusals $Rej/E(N)$, where Rej is the average number of refusals for a day, $E(N)$ is the average number of potential passengers of one day;
3) the share of the passengers who departed during the desirable time of the day K relative to the average number of the potential passengers for one day ($K/E(N)$);
4) the percent of the passengers who did not depart on a desirable day;
5) the average waiting time of departure by passengers (in days).

3. Simulation Model Description

A special algorithm for solving the task in view has been developed. Its novelty and originality consists in consideration of the simulation process not from the side of a newly arrived passenger, but from the side of the already existent query of claims of not departed passengers $\mathbf{Q} = (Q_0, Q_1, ..., Q_t, ..., Q_h)$, where *t* is the ordinal number of one of the days on which the passenger can postpone the flight (*t* = 0, 1, …, *h*), Q_t is a number of passengers of this day. Further for the model description instead of the term "the claim of the passenger" the term transaction accepted in modelling is used.

The described process of modelling is complex enough, therefore for practical calculations the simulation approach has been used. Simulation was carried out with MathCAD software.

Conceptually the simulation model is based on the consideration of the transactions turn, which corresponds to the passengers' flow, wishing to get tickets for this or that flight. Depending on the fact whether the passengers corresponding to transactions are the passengers of the prospective day of the departure ($t = 0$), or they are already the passengers of the t-th day of the postponement of flight, or they are the passengers of the final day of postponement of flight ($t = h$), the transactions describing them also differ.

Simulation model description for one run from the modelling horizon H follows below.

4. Modelling Algorithm for One Run

Begin

Cycle by the modelling horizon (by j, $j = 1, 2, ..., H$)

1. Cycle by days of expectation in reverse order (by t, $t = h, h-1, ..., 1$)
    1.1. Cycle by transactions (by k, $k = 1, 2, ..., Q_t$)
        1.1.1. For each $t -$ the day transaction the choice of flight is defined by cost of the ticket $\mathbf{r}_2$ (2). If the flight is not chosen the transaction remains in the queue of the current day transactions Q_t.
        1.1.2. For the remained $t -$ the day transactions the number of the refusing the further expectation transactions is drawn. This number Rej_t has binominal distribution with parameters $n = Q_t$ and $p = p_t$: $Rej_t := rbinom(1, p, n)$.
2. Generate N transactions, which appeared on the current day ($t = 0$), and the values $X^{(i)}$, $\Delta_-^{(i)}$, $\Delta_+^{(i)}$ ($i = 1, 2, ..., N$) as well.
3. Cycle by the number of the current day transactions N (by i, $i = 1, 2, ..., N$)
    3.1. For each transaction the choice of flight is defined by two factors: the interval of the desirable time of departure D, and the cost of the ticket $\mathbf{r}_2$ (1) as well.
    3.2. If flight is not chosen the transaction passes into the queue of the current day transactions Q_0.
4. Rewrite the queue of transactions, increasing a waiting time for one day: $Q_{t+1} = Q_t$ ($t = 0, 1, ..., h-1$).

End

5. Numerical Example

In the considered below numerical example the initial data are the following:

1. Flights' characteristics:
   - the number of flights $m = 5$;
   - the vector of seats number $\mathbf{r}_1 = (80 \quad 80 \quad 100 \quad 80 \quad 100)^T$;
   - the vector of the tickets cost $\mathbf{r}_2 = (50 \quad 75 \quad 100 \quad 125 \quad 150)^T$;
   - the vector of the plane departure time $\mathbf{r}_3 = (21 \quad 12 \quad 9 \quad 17 \quad 19)^T$.
2. Passengers' characteristics:
   - the admissible values of the positive and negative deviations of the actual time of flight from the desirable by the passenger time of departure (Δ_- и Δ_+) are identical for all the passengers, besides $\Delta_- = \Delta_+$;
   - the passenger's lookup horizon $h = 3$ is the same for all passengers;
   - the vector of probabilities of refusal of departures $\mathbf{p} = (0 \quad 0 \quad 0 \quad 1)^T$.
3. Besides, it has been accepted that:
   - the modelling interval $H = 100$.
   - the initial queue of transactions (of the expecting passengers) is empty $\mathbf{Q} = (0 \quad 0 \quad 0 \quad 0)^T$;

At the given vector $\mathbf{p}$ for all the passengers the waiting time is 3 days. Thus passengers choose flights according to the minimal cost of the ticket. Exception is made by newly arrived passengers (at $t = 0$), they choose the flights in view the factors: minimal cost of the ticket, and desirable time of departure.

The number of the newly arrived passengers N of one day has a normal distribution with parameters $\mu_N = 500$ and $\sigma_N = 20$. In this case, the total sum of seats on flights for one day $\sum_{j=1}^{m} r_1^{(j)} = 440$ is less than the average number of newly arrived passengers μ_N. Thus, lack of seats for the newly arrived passengers is observed.

During the modelling horizon H there is a gradual entering the process a stationary mode. It is possible to consider, that beginning approximately from the 40th day the system is comes into the stationary mode. The following results of the modelling were obtained for a time interval from 40th to 70th day of the modelling horizon.

In this example the dependence of payload capacity of flights Com_j (in %) on the length of the interval of desirable by the passenger time of departure D ($Com_j = f(D)$ has been investigated. The results of obtained simulation are presented in Table 1 and on Figure 2.

Besides, in the given example the dependence of number of passenger's refusal Rej, on the value D is shown ($Rej = f(D)$) (see Figure 2).

Table 1. Dependence of payload capacity of flights Com_j (in %) on the length of the interval of desirable time of departure D

***D* (hours)**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
Com_1 (%)	100	100	98	97	96	97	95	100	100	100	100
Com_2 (%)	50	69	86	99	100	98	100	100	100	100	100
Com_3 (%)	34	51	70	78	87	80	90	88	93	96	97
Com_4 (%)	42	69	89	99	100	99	100	100	100	100	100
Com_5 (%)	33	53	71	58	48	60	45	52	54	63	66

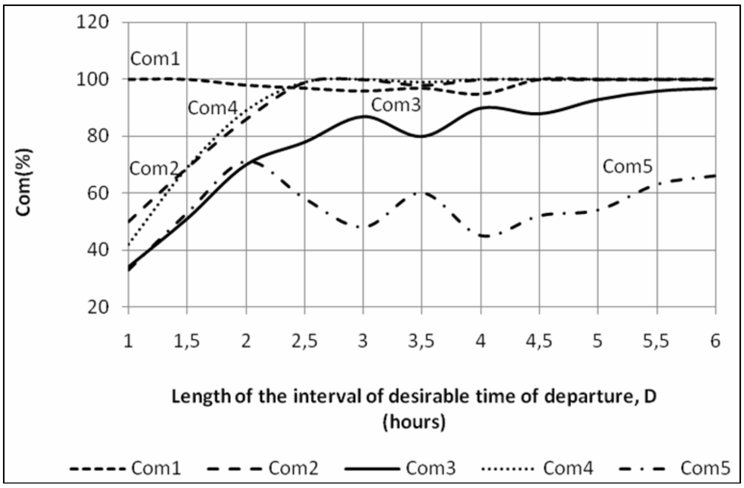

Figure 2. *Simulation results of* $Com_j = f(D)$

Analysis and comment of the obtained results is given below.

We would like to remind, that the capacity of planes has only two meanings: 80 and 100 seats. Numbers of flights are sorted in ascending order by costs of tickets. The following regularities have been revealed:

1. The cheapest flight (the first one) is filled practically completely (95 % – 100 %), without dependence on the length of an interval D.
2. The increase of value *D* to the meaning $D = 2$ leads to the growth of payload capacity of all flights.
3. The further increase of value D ($D > 2$) shows the steady growth of payload capacity of flights only for flights with the number of seats equal to 80.
4. Tendencies of the payload capacity of flights with number of seats 100 differ depending on cost of flight. So, the third flight with the growth of value D is filled completely, but the filling the fifth flight (the most expensive) stabilized at a level of 60 %.
5. As seen from Figure 3 the value of refusals Rej practically does not vary from the value D.

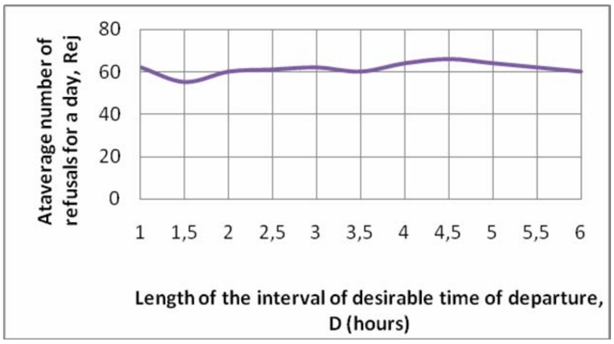

Figure 3. *Simulation results* $Rej = f(D)$

Let's comment separately the 3-rd flight. The low percentage of the payload capacity of this flight on the initial stage of modelling is connected with the inconvenient moment of the flight departure for the passenger (9 AM) and with rather high cost of the ticket. For the increase of this flight payload capacity the following variants has been considered:

- Reduction of the cost of the ticket;
- Changing of the plane departure time;
- Replacement of the plane by the plane of smaller capacity.

Let's analyse one possible variant. At the $D = 4$ the first and the second flight are filled completely because they are cheaper than the third flight. Maximal values of the third flight payload capacity are observed whether when the departure time moves at 10 AM or when the departure time is between 15 and 18 PM (see Figure 4). In the specified time intervals the third flight “takes away” passengers of more expensive fourth and fifth flights.

The analysis of results of the shown numerical examples allows drawing a conclusion that simulation results adequately describe the considered process.

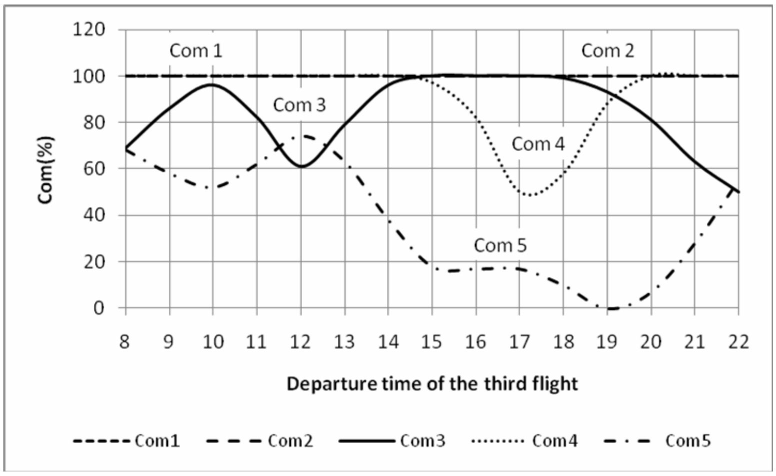

Figure 4. *Dependence of payload capacity of flights on the third flight departure time*

6. Conclusions

The passenger’s behaviour model at a flight choice for one Origin-Destination pair of cities has been created out in this research. This model takes into account three characteristics of flight: the number of seats, the cost of air-ticket and the time of departure; and four characteristics of passenger as well: the desirable time of departure, the positive and negative passenger-flight deviations, and the passenger’s lookup horizon. The originality of the model consists in the choice process consideration from the side of the expecting passengers queue. For practical calculation the simulation approach has been used. Numerical examples confirm the adequacy of the considered model.

References

1. Ben-Akiva M. and Lerman S. *Discrete Choice Analysis: Theory and Applications to Travel Demand*, sixth ed. The MIT Press, Cambridge, MA, 1994. 416 p.
2. Paramonov J. M. Some models for the forecast of demand for aviation passenger transportations. In: *Scientific Papers of Riga Aviation University, issue No 167.* Riga, 1970, pp. 79–98.

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CUMULATIVE INDEX

TRANSPORT and TELECOMMUNICATION, Volume 9, No 2, 2008 (Abstracts)

Alexander Krainyukov, Valery Kutev. Results of Inverse Problem Solution for Radar Monitoring of Roadway Coverage, *Transport and Telecommunication*, Vol. 9, No 2, 2008, pp. 4–13.

This work has been focused on the development of approach to the inverse problem of subsurface radar sounding solution in frequency domain. We propose to use an Ultra Wide Band pulse radar combined with a line transmitter and receiver antennas.

Forward modelling is based on using of three-component mixing formula for estimation of soil electromagnetic properties in frequency domain, as well as on linear system response functions for the radar antenna system, and on the equations for wave propagation in a horizontally multi-layered medium representing the subsurface.

Model inversion, realized by numerically, uses results of forward modelling simulation in limited range of the soil electromagnetic properties changing. For realization of model inversion data the genetic algorithm of calculations has been chosen.

Keywords: radar, soil dielectric properties, radar monitoring, forward modelling, inverse modelling

Eugene Kopytov, Vasilijs Demidovs, Natalia Petoukhova. Application of Temporal Elements in the Railway Schedule Systems, *Transport and Telecommunication*, Vol. 9, No 2, 2008, pp. 14–23.

The paper deals with the issues of building a temporal database for the railway schedule. For the mathematical description of the railway schedule system, we suggest to use set theory and algebra of logics. We define the periodicity parameters and temporal elements and formulate the rules of their calculation. We also consider practical examples on defining the dates on which the set version of the train schedule becomes an actual subject.

Keywords: railway transportation, schedule, periodicity, temporal database, temporal element

Gabriel Nowacki, Izabella Mitraszewska, Tomasz Kamiński. The National Automatic Toll Collection System for the Republic of Poland, *Transport and Telecommunication*, Vol. 9, No 2, 2008, pp. 24–38.

The paper refers to some problems of worldwide applications in electronic toll collection systems for motorways and expressways. According to Directive 2004/52/EC, these systems should use one or more of the following technologies: satellite positioning, mobile communications using the GSM-GPRS standard (reference GSM TS 03.60/23.060) and 5, 8 GHz microwave technology. Authors have analysed the systems, which meet these requirements, especially the states as follows: The United States of America, Japan, Taiwan, Australia, Austria, Czech Republic, France, Norway and Germany. As a result of the analysis, it has turned out that only system using satellite positioning technology and mobile communications (GSM/GPRS) is the best toll solution of unique capabilities and this kind of technologically sophisticated system should be implemented in Poland. Author will present the initial structure of GSM/GPS based Toll Collection System for Poland. This type of system has many advantages. The first one is absence of the need for new road infrastructure (gantries); operators can keep using the existing infrastructure. System works without toll booths, extra lanes, speed restrictions or complex structures along toll roads. The second one is much greater flexibility in defining or changing payment by simply redefining the "virtual" toll areas. It means ability to adapt easily and quickly to changes in charge parameters (road classes, vehicle types, emission levels, times slots, etc.). The third advantage is the system's ability to support other value-added services on the same technology platform.

Keywords: Electronic Toll Collection (ECT), microwave technology, on-board unit (OBU)

TRANSPORT and TELECOMMUNICATION, 9.sējums, Nr.2, 2008 (Anotācijas)

Aleksandrs Kraiņukovs, Valērijs Kutevs. Ceļa klājuma radara monitoringa inversās problēmas risinājuma rezultāti, *TRANSPORT and TELECOMMUNICATION,* 9.sēj., Nr.2, 2008, 4.–13. lpp.

Šī raksta mērķis ir fokusēts uz zemvirsmas radara zondēšanas risinājuma frekvences domēnā inversās problēmas pieejas attīstību. Mēs piedāvājam lietot *Ultra Wide Band* vibrācijas radaru savienojumā ar līnijas raidītāju un uztvērējantenām.

Izskatītā modelēšana pamatojas uz trīs-komponentu sajaukto formulu, lai novērtētu augsnes elektromagnētiskās īpašības frekvenču domēnā, kā arī uz lineāro sistēmu atbildes funkciju radara antenas sistēmā un uz viļņa izplatīšanās horizontālajā multi-slāņainajā vidē vienādojumiem, ko pārstāv zemvirsma.

Modeļa inversija, kas realizēta skaitliski, lieto piedāvātās modelēšanas simulācijas rezultātus augsnes elektromagnētisko īpašību izmaiņu ierobežotā kārtībā.

Atslēgvārdi: radars, augsnes dielektriskās īpašības, radara monitorings, piedāvātā modelēšana, inversā modelēšana

Evgeņijs Kopitovs, Vasilijs Demidovs, Natalia Petuhova. Pagaidu elementu pielietošana dzelzceļa sarakstu sistēmā, *TRANSPORT and TELECOMMUNICATION,* 9.sēj., Nr.2, 2008, 14.–23. lpp.

Rakstā tiek izskatītas dzelzceļa sarakstu pagaidu datubāzes izveides iespējas. Autori piedāvā lietot rindu teoriju un loģikas algebru dzelzceļa sarakstu sistēmas matemātiskajam aprakstam. Periodiskuma parametri un pagaidu elementi tiek noteikti, kā arī tiek formulēti to kalkulācijas noteikumi. Autori piedāvā arī praktiskos piemērus datumu noteikšanā, kurā vilcienu saraksta rindu versija kļūst par faktisku priekšmetu.

Atslēgvārdi: transportēšana pa dzelzceļu, saraksts, periodiskums, pagaidu datubāze, pagaidu elements

Gabriel Novackis, Izabella Mitraševska, Tomasz Kaminskis. Nacionālā automātiskā nodevu iekasēšanas sistēma Polijas Republikai, *TRANSPORT and TELECOMMUNICATION,* 9.sēj., Nr.2, 2008, 24.–38. lpp.

Rakstā autori izskata pasaulē plaši pielietojamās elektroniskās nodevu iekasēšanas sistēmas uz autoceļiem un ātrgaitas automaģistrālēm. Saskaņā ar 2004/52/EC Direktīvu šajās sistēmās ir jālieto viena vai vairākas sekojošas tehnoloģijas: satelītu pozicionēšanas, mobilo sakaru, lietojot GSM-GPRS standartu (skat. GSM TS 03.60/23.060) un 5.8 GHz mikroviļņu tehnoloģiju. Autori rakstā ir izanalizējuši šīs sistēmas, kurās tiek lietotas minētās prasības; tās ir sekojošas valstis: ASV, Japāna, Taivāna, Austrālija, Austrija, Čehijas Republika, Francija, Norvēģija un Vācija.

Pēc veiktās analīzes, autori var secināt, ka vislabāk pielietojamās sistēmas ir satelītu pozicionēšanas tehnoloģiju un mobilo sakaru (GSM/GPRS) sistēmas, lai iekasētu nodevas uz automaģistrālēm. Tās dod unikālas iespējas nodevu iekasēšanā, un šāda veida sistēmas tiks ieviestas arī Polijā. Šīm sistēmām ir vairākas priekšrocības: *pirmkārt,* nav nepieciešamība pēc jaunas ceļu infrastruktūras (radiolokācijas antenas), operatori var turpināt izmantot esošās infrastruktūras. Sistēma strādā bez nodevu iekasēšanas novietnēm/kabīnēm, īpašiem ceļiem, ātruma ierobežojumiem vai kompleksām struktūrām gar nodevu iekasēšanas maģistrālēm; *otrkārt,* pastāv daudz lielāka elastība maksājuma noteikšanā vai izmainīšanā, veicot vienkāršu jaunu maksājuma noteikšanu virtuālajā nodevu laukā. Tas nozīmē, ka šīs sistēmas dod iespēju adaptēties vienkārši un viegli cenu parametros (ceļu klases, transporta līdzekļu tips, emisiju līmeņi, paredzētais laiks utt.); *treškārt,* sistēmas spēj atbalstīt citus pievienotās vērtības pakalpojumus šajā pašā tehnoloģijas platformā.

Atslēgvārdi: elektroniskā nodevu iekasēšana – *Electronic Toll Collection (ECT)*, mikroviļņu tehnoloģija, vienība, kas atrodas transportlīdzeklī (*onboard unit*)

Vaira Gromule, Irina Jackiva, Aleksandrs Medvedevs. Autobusu un starptautisko autobusu servisa kvalitātes pētīšana, pamatojoties uz informācijas sistēmas bāzi, Rīgas starptautiskajā autoostā, *TRANSPORT and TELECOMMUNICATION,* 9.sēj., Nr.2, 2008, 39.–45. lpp.

Šī raksta mērķis ir analizēt autobusu un tālbraucēju autobusu pārvadājumu kvalitāti Latvijā. Reģionālie, starppilsētu un starptautiskie braucieni, kas ierodas Rīgas starptautiskajā autoostā, tiek rūpīgi analizēti. Pasažieru pārvadājumu uzlabošanas nolūkā ir īpaša uzmanība jāveltī dažādu operatoru punktualitātes rādītājiem, dažādiem autobusu maršrutiem dienas laikā un nedēļā kopumā. Šī uzdevuma risināšana var kalpot par pamatu pasažieru loģistiskā parka izveidei uz Rīgas starptautiskās autoostas bāzes.

Atslēgvārdi: autobuss, informācijas sistēma, precizitāte, aprakstošie rādītāji, analīze

Jekaterina Žukovska. Pasažieru avioreisa izvēles imitācijas modelis, *TRANSPORT and TELECOMMUNICATION,* 9.sēj., Nr.2, 2008, 46.–51. lpp.

Veiktā pētījuma mērķis ir pasažiera uzvedības avioreisu izvēlē modeļa veidošana. Praktiskākiem aprēķiniem tiek izmantoti imitācijas modelēšanas paņēmieni. Aprēķini ir veikti MathCAD vidē.

Atslēgvārdi: izvēles modelis, avioreisa izvēle, imitācijas modelēšana

TRANSPORT
&
TELECOMMUNICATION

ISSN 1407-6160 & ISSN 1407-6179 (on-line)

All articles are reviewed.
Articles can be presented in the journal in English.

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TRANSPORT and TELECOMMUNICATION, 2008, Vol. 9, No 2
ISSN 1407-6160
The journal of Transport and Telecommunication Institute (Riga, Latvia).
The journal is being published since 2000.

The papers published in Journal "Transport and Telecommunication" are included in **SCOPUS** (since 2008, Vol. 9, No 2), **Elsevier Database**
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