RIGA TECHNICAL UNIVERSITY
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MODELLING OF INTELLIGENT ELECTRICAL TRANSPORT CONTROL SYSTEMS SCHEDULING PROBLEMS IN THE UNFORSEEN CASES

Abstract of Thesis

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RTU Publishing House
Riga 2012

UDK 656.021:004.94(043.2)
Al 746 m

Alps I. Modelling of Intelligent Electrical Transport Control Systems Scheduling Problems in the Unforseen Cases.
Abstract of thesis.-R.: RTU Publishing House, 2012.-35 pp.

Published in accordance with the Institute of IEE resolution from
June, 28, 2012, protocol Nr.43ю

The development of this research was supported by the European Social fund support project «Support for the implementation of doctoral studies at Riga Technical University».

ISBN 978-9934-10-367-4

DOCTORAL THESIS
IS SUBMITTED FOR THE PROMOTION OF DOCTOR DEGREE
OF ELECTRICAL ENGINEERING SCIENCES
AT RIGA TECHNICAL UNIVERSITY

The Doctoral thesis is openly defended on 13th December 2012 at Riga Technical University, Faculty of Electrical and Power Engineering, Kronvalda blv. 1, 117 room.

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AKNOWLEDGMENT

I acknowledge that the work I submitted to Riga Technical University for the promotion of Doctor degree in engineering sciences is my own. No part of this work is submitted to other universities or other institutions for any degree obtaining.

Ivars Alps …………………………….(Signature)

Data: ……………………..

The promotion paper is written in the Latvian language, it contains an introduction, five chapters, conclusions, list of references, one appendix, 32 figures and illustrations, 70 tables on totally 155 pages. The list of literature refers to 101 sources.

CONTENTS

TOPICALITY OF THE WORK

With the increasing of vehicles number and intensity of transport flows the management and organization of these flows is becoming more topical not only in large cities but in the regions as well. Although the city authorities are solving this problem the traffic congestion and accidents are becaming everyday reality. In spite of the fact that it is hard to evaluate the losses from the accidents, energy consumed and time spent in the traffic jams and all these consequences for the state in general and a separate citizen its negative effect is definitely proved.

If in most of the cases the time and energy consumed by transport and passengers in the traffic congestions are increased then the transport accidents are connected with more considerable technical and human losses. More serious consequences are colliding railway transport with auto vehicle. As European Railway Agency informs in the report for 2010 a significant number of accidents in the railway transport are connected with railway crossings. Organization NSA (National Safety Authorities) reports about 3774 accidents connected with railway crossings and resulted in 1287 people died from 2006 till 2008.

Therefore the promotion paper proposes the solutions for the following tasks:

- applying the embedded devices, schedule theory and evolutionary algorithms to decrease to the minimum the possibility of simultaneous existence of a railway transport and auto vehicle at a crossing, i.e. avoiding a possibility of collision,
- to increase the bandwidth capacity of a railway crossing reducing therefore waiting time of public and other type transport at a closed crossing,
- to recommend for the vehicles transportation speed along all the route decreasing the waiting time of the public transport in traffic congestions, often braking following with acceleration directly influencing the electric power consumption, providing the passenger with high level of comfort and safe transport services.

THE GOAL OF THE RESEARCH

The main goal of the promotion work is to investigate and develop the algorithms of information flows processing for the city transport including electric transport for the movement computer control with artificial intelligent devices and the methods of schedule theory.

The achievement of this goal proposes and states for the completeing the following tasks:

- to analyse the existing railway, public and city transport system, to develop the mathematical models of movement control of the systems objects and to determine the target function;
- to investigate genetic and immune algorithms, to develop the procedures for embedded devices for the monitoring of accidents and emergency situations at the crossing points of different transport types;
- to investigate the algorithms of the schedule theory, the opportunities to apply them in the tasks of transport flows control within the series and parallel tasks processing systems;
- by menas of computer model to investigate the application of the developed procedure for the control of the transport flows according to the minimization criteria of safety, energy consumption and idle time;
- to compare the influence of different control algorithms on the development of transport safe movement schedule;

- applying the method of hypothetic statistical estimation to evaluate the influence of the application of the developed algorithms and embedded devices on the set of waiting time and safety.

MEANS AND METHODS OF THE RESEARCH

The description of the transport system elements is made by means of set theory, graphs theory, analysis of the systems and processes. The mathematical model of the system control is developed applying the theory of evolutionary algorithms, theory of schedules and probabilistic theory. For the model of the transport system control Arduino programmable logic controller was used. Visual and object oriented programming methodology was uses for the control of the model. The method of statistical analysis was applied for the evaluation of the results of computer modeling.

SCIENTIFIC NOVELTY OF THE RESEARCH

The following mathematical models of the intelligent transport system control were developed in the promotional work:

- The control model of railway transport with the use of schedule theory algorithms for the decreasing of total time at the closed crossing
- The model of public electric transport control with the use of an embedded device taking into account the schedule of movement around all the routes
- The model of city transport flow control applying the model and procedures of schedule theory with the definition of target function for multicriteria tasks solution using the evolutionary algorithms. The evolutionary algorithms and those of schedule theory solves the tasks of transport control taking into account the five criteria:
  - minimization of electric transport electricity consumption during acceleration,
  - development of railway transport schedule with the aim to minimize the waiting time at the closed railway crossing,
  - probabilistic minimization of railway and city transport simultaneous existence at the crossing points,
  - minimization of public transport waiting time in traffic congestions,
  - minimization of the difference of the new developed schedule from the previous.
- The model of genetic and immune algorithm for the solution of the multicriteria task of public transport system control
- The model of functional interoperation of public transport systems including its separate elements and allowing the modeling of the descriptive processes of public transport system including intelligent control of its electric mechanical processes
- Mathematical model of public transport vehicle schedule developed for the control of transport taking into account the criteria of safety and profitability
- A new model for development of transport schedule and its evaluation by means of genetic and immune algorithms
- The algorithm of speed control of city transport vehicle for the advisible speed calculation following the criteria of safe transport flow control at the crossing points and directive time.

APPLIED IMPORTANCE OF THE RESEARCH

The developed algorithms and the proposed procedures of transport systems control can be applied in the city transport system including the improvement of public electric transport control. The algorithms and procedures improve the safety level of control of interoperative city transport system. Applying the developed algorithms gives an opportunity to reduce the wating time at the transport crossing points decreasing thus the number of transport vehicles at one such point of any route therefore decreasing the traffic congestions and consumption of electric energy by the city electric transport. Thus the developed algorithms can provide as fast regulation as possible for the transport schedule in the case of its deviation under unforeseen conditions.

APPROBATION OF THE RESEARCH

1. Starptautiskā konference „Intelligent Technologies in Logistics and Mechatronics Systems (ITELMS'2008)"Lietuva, Paņeveži, 2008.gada 23.maijs. Referāts "Modeling of Scheduling Theory in Intelligent Electric Transport Systems"
2. Rīgas Tehniskās Universitātes 49.starptautiskā zinātniskā konference, sekcijas „Enerģētika un elektrotehnika" apakšsekcija „Elektrotehnika", Latvija, Rīga, 2008.gada 15.oktobris. Referāts „Sarakstu teorijas modelēšana intelektuālajās elektriskā transporta sistēmās"
3. Starptautiskā konference „Intelligent Technologies in Logistics and Mechatronics Systems (ITELMS'2009)"Lietuva, Paņeveži, 2009.gada 5.jūnijs. Referāts „Mathematical Formulation of Public Electric Transport Scheduling Task for Artificial Immune Systems"
4. Rīgas Tehniskās Universitātes 50.starptautiskā zinātniskā konference, sekcijas „Enerģētika un elektrotehnika" apakšsekcija „Elektrotehnika", Latvija, Rīga, 2009.gada 15.oktobris. Referāts „Mathematical Formulation of Public Electric Transport Scheduling Task for Artificial Immune Systems"
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12. Rīgas Tehniskās Universitātes 52.starptautiskā zinātniskā konference, sekcijas „Enerģētika un elektrotehnika” apakšsekcija „Elektrotehnika”„ Latvija, Rīga, 2011.gada 15.oktobris. Referāts „Algorithm for Increasing Traffic Capacity of Level-Crossing Using Scheduling Theory and Intelligent Embedded Devices”
13. Starptautiskā konference „First International Conference on Railway Technology: Research, Development and Maintenance” Las Palmas de Gran Canaria, Spānija 2012. gada 20.aprīlis. Referāts „Algorithm for Embedded Anti-Collision Devices of Rolling Stock in Safety Tasks”

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8. Ivars Alps, Mikhail Gorobetz, Anatoly Levchenkov „Algorithm for Increasing Traffic Capacity of Level-Crossing Using Scheduling Theory” //In proceedings of 6th International Conference Intelligent Technologies in Logistics and Mechatronics Systems (ITELMS’2011), Lithuania, Panevezys, 2011, 99-108 lpp.
9. Ivars Alps, Mikhail Gorobetz, Anatoly Levchenkov „Algorithm for Increasing Traffic Capacity of Level-Crossing Using Scheduling Theory and Intelligent Embedded

Devices **”** In proceedings of RTU 52nd International Scientific Conference “Power and Electrical Engineering” Latvia, Riga 2011, 129-136 lpp.
10. Levchenkov A., Gorobetz M., Balckars P. and Alps I. „Algorithm for Embedded Anti-Collision Devices of Rolling Stock in Safety Tasks” //In proceedings of the First International Conference on Railway Technology: Research, Development and Maintenance, Las palmas de Gran Canaria, Spain 2012, 178 page

THE OBTAINED PATENTS

The results obtained during the development of the research are patented and Latvian Republic sertificate is given to the authors A.Ļevčenkovs, M.Gorobecs, I.Raņķis, L.Ribickis, P.Balckars, A.Potapovs, I.Alps, I.Korago, V.Vinokurovs under the title “The device for auto transport safety at the crossings using the satellite navigation systems” Riga, Latvia, LV 14405 B.

In May 2012 Patent Law Office FORAL acknowledged that the application for International patent PCT/EP2011/067474 was considered according to the correspondence to the patentability criteria, and the report of international patent searching and opinion of the internation searching institution proved that the invention meets the criteria.

STRUCTURE OF THE PROMOTION PAPER

The promotion paper consists of the introduction, five chapters, conclusions and list of the applied literature sources.

The first chapter of the promotion paper analyses the existing systems of the city transport, clissifies the elements of the system and their interoperation; the mathematical model of the transport system is developed from the set theory point of view, the constant and variable elements are defined in the system, the detailed mathematical model of the research object – transport system element – crossing – is developed, the task of the schedule theory is stated and the target function is defined for the solution of this task in accordance with computer control of the electric transport movement by means of embedded device and schedule theory.

The second chapter of the promotion paper contains the description of the developed algorithms for the calculation of each criterion as well as the total value of the target function. Therefore the application of the immune and genetic algorithms allowed developing the model of transport system control.

The third chapter describes the prototype of the developed embedded device, the electrical circuits of it and its components; the connection of the intelligent transport system to the elements of infrastructure, crossings, and city transport and railway transport units is analysed.

The opportunities of the investigated algorithms application for the control of city transport are researched in the fourth chapter. A real existing transport system of Riga is investigated at the particular parts of the city; and for the approbation of the algorithm a simplified computer model of railway and auto transport movement at the particular crossing was developed with determined number of transport units and their schedule. The control of the transport system fragment is modeled in accordance with the developed algorithms realizing different sets of experiments.

The fifth part of the promotional paper analyses and evaluates the results obtained in the previous chapter. According to the target function criteria the proposed changes of transport schedules of genetic and immune algorithms for each separate criterion as well as for the target function in general. The evaluation of the schedules changes was realized by means of the statistical evaluation method according to z-criterion, chi-square and Kolmogorov-Smirnov test.

STATEMENT OF THE TASK FOR THE CONTROL OFTRANSPORT SCHEDULE INFORMATION SYSTEM IN UNFORSEEN CASES

Analysing the structure of the transport system results in the conclusion that railway transport vehicles drivers He, Hd and auto transport drivers Hc, Hv and Hb drive the correspondent vehicles by means of control elements of these vehicles Ke, Kd, Kc, Kv and Kb. Diesel trains control elements operate with diesel engines Mde, that by means of generators Ge are connected with diesel engines Mdd. The control equipment of electric trains operates by means of electric motors Mee. Transmission of railway trasnport We and Wd through the rail circuits Rw operates with the crossing relays Rp, which in their turn send the control signals to the crossing barrier bp and traffic lights Lp. The drivers of the auto transport follow these visual control signals and make decisions on the correspondent reaction. In addition to the visual control signals the drivers of the railway transport and buses are provided with the defined schedules of the transport units movement $\sigma_E \sigma_A \sigma_D$. The disadvantage of this system is that there is no coordination among the transport means of different type, the drivers do not have much enough information about the current situation on the route, the monitoring of the schedule is fully dependent on the driver's skills and abilities. The research under consideration proposes to replenish the transport system with the element realising Intelligent Transport System (ITS). ITS structural scheme is given in Fig.1.

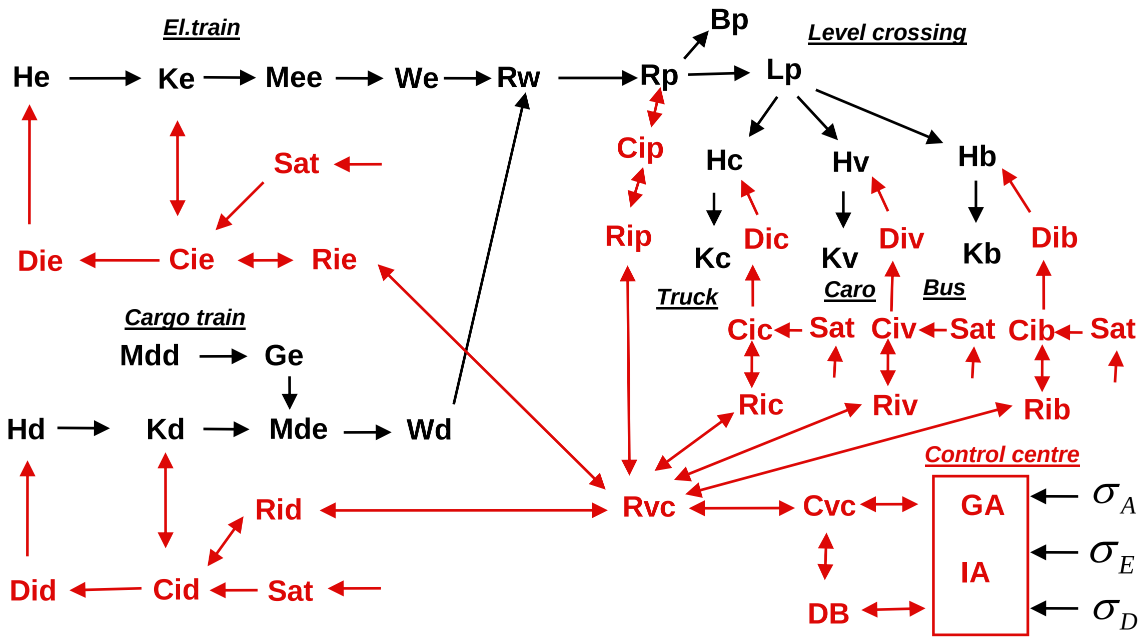

Fig.1 The interoperation of the proposed transport system elements with the existing system

In accordance with the proposed scheme of the transport system each unit of it is completed with controller Cic, Civ, Cib, Cie, Cid, obtaining the information about the location and speed of the system moving elements by means of SAT and GPS satellites. The railway crossings are controlled with controller Cip. The transport system is equipped with control center including controller Cvc, data base DB, immune and genetic algorithm blocks IA, GA. The control center is also equipped with all the schedules of the transport system elements $\sigma_E\ \sigma_A\ \ \sigma_D$. The control center by means of transmitter Rvc transmits and receives the control signals from all the transmitters installed at the vehicles of the system Ric, Riv, Rib, Rie, Rid, Rip. According to the received signals and schedules and the developed algorithms in the control center a schedule for the actual situation is generated and through the transmitters the embedded controllers give the necessary recommending information on the displays Dic, Div, Dib, Die, Did, Dip. According to the recommendations the drivers make decisions about the advisible speed of the vehicle. If the probability of the collision on the route achieves a critical value and there is a necessity to start an emergency braking of the railway transport the controller sends the information about this emergency braking to the system without informing the driver. Therefore it is becoming possible to manage all the transport system allowing the development of an control model, sending to the drivers the recommending information for the decision making or in the case of emergency situation to initiate the operation of braking system without participation of human driver avoiding the possibility of accidents.

The target function is developed for the solution of the task

The target function is formed as a set of four separate criteria describing the transport flow. The following criteria are defined as the most important for the solution:

- criterion of total energy consumption E (used electricity to accelerate all electric transport units)
- anticollision criterion Q (the probability of different types of transport units existence at the crossing points X)
- criterion of coincidence Θ (simultaneous existence of one transport type units in opposite directions at the crossing points X)
- idle standing criteion T_{Σ} (total idle standing time of vehicles in the general transport flow)
- shift criterion Δt_{sum} (shift of the schedule obtained as a result of its changes)

$$F(\Delta t) = \begin{cases} E = \sum_{i=1}^{n} \sum_{j=1}^{k_i} \int_{t_1^j}^{t_2^j} UIdt \to \min \\ Q = Q(T_X^1 \cap ... \cap T_X^i \cap ... \cap T_X^n) \to \min \\ \Theta = \left| \left[t_{S\max}^{U2\to}; t_{B\min}^{U2\to} \right] \right| \cup \left| \left[t_{S\max}^{U2\leftarrow}; t_{B\min}^{U2\leftarrow} \right] \right| \to \min \\ T_{\Sigma} = f(\Sigma) \to \min \\ \Delta t_{sum} = f(\Sigma, \Sigma') \to \min \end{cases} \quad (1)$$

The calculation of the total target function is realized calculating and normalizing each of the function elements assigning each element with an expert defined valuable characterising weight factor. The following expressions are used for the normalizing of the target function criteria:

$$\begin{aligned} E_{norm} &= \frac{E_{\max} - E}{E_{\max} - E_{\min}} \\ Q_{norm} &= Q \\ \Theta_{norm} &= \frac{\Theta_{\max} - \Theta}{\Theta_{\max} - \Theta_{\min}} \\ T_{\Sigma norm} &= \frac{T_{\Sigma} - T_{\min}}{T_{\max} - T_{\min}} \\ \Delta t_{sum.norm} &= \frac{\Delta t - \Delta t_{\min}}{\Delta t_{\max} - \Delta t_{\min}} \end{aligned} \quad (2)$$

The following weight factors are proposed for the criteria:

α_E - energy consumption criterion

α_Q - anticollision criterion

α_{Θ} - coincidence criterion

$\alpha_{T\Sigma}$ - idle standing criteron

$\alpha_{\Delta t}$ - shift criterion

Following relevance should be taking into account

$$\alpha_E + \alpha_Q + \alpha_\Theta + \alpha_{T_\Sigma} + \alpha_{\Delta t} = 1 \quad (3)$$

Therefore the calculation of the total target function is expressed with the following furmula:

$$F(\Delta t) = \alpha_E E_{norm} + \alpha_Q Q_{norm} + \alpha_\Theta \Theta_{norm} + \alpha_{T_\Sigma} T_{\Sigma norm} + \alpha_{\Delta t} \Delta t_{sum.norm} \to \min \quad (3)$$

The proposed hypothesis

Analising the criteria of the developed target function the following hypotheses were proposed:

These schedules exist

Σα= (σα1,..,σαn1); Σβ= (σβ1,..,σβn1); Σa= (σa1,..,σan1); Σb= (σb1,..,σbn1);

Under which the following conditions are completed:

1. α , β , an and bm at points X do not exist simultaneously;

$$(d(a_{ts}) \bigcup d(b_{ts})) \bigcap (d(\alpha_{tb}) \bigcup d(\beta_{tb})) = \varnothing \quad (4)$$

where: $d(a_{ts})$ and $d(b_{ts})$ – initial moments of the operation of a and b units flows at crossing points X

$d(\alpha_{tb})$ un $d(\beta_{tb})$ – final moments of the operation of a and b units flows at crossing points X

2. oppositely directed units α and β at points X exist simultaneously;

if d(α)>d(β), then $\begin{cases} t_\alpha^s \le t_\beta^s \\ t_\alpha^b \ge t_\beta^b \end{cases}$ and if d(α) <d(β), then $\begin{cases} t_\alpha^s \ge t_\beta^s \\ t_\alpha^b \le t_\beta^b \end{cases}$

where t_α^s : t_α^b and t_β^s ; t_β^b are the initial and final moments of transport units α and β operation

THE ALGORITHMS PRODUCED FIR THE CONTROL OF INFORMATION FLOW OF THE TRANSPORT SYSTEMAND DEVELOPMENT OF SCHEDULES

Algorithm of the general value calculation of the target function for level-crossing task

Given: coordinates of all the auto transport and railway transport routes crossing points: $\chi_s^p = \{\chi_s^{p^1}, \chi_s^{p^2}, ..., \chi_s^{p^c},\}$; $\psi_s^{p^1} = \{\psi_s^{p^1}, \psi_s^{p^2}, ..., \psi_s^{p^c}\}$

χ_s^p - geographic width of the initial point of the railway sector (crossing)

ψ_s^p - geographic length of the initial point of the railway sector (crossing)

c – number of crossings

$\overline{V}^u$ - average speed m/s of each vehicle u $u \in U^1 \bigcup U^2 \bigcup U^3$,

V_S - standard deviation of speed (m/s) of each vehicle u

L_u – length of each train $u \in U^1$, m

t^p_{vest} – safe closing time of each crossing $p \in P^2$

1.step. Determine the current speed of all auto and railway transport

$$V_{tek} = norm(\overline{V}^u, V_S) \text{ m/s} \quad (5)$$

2.step. For each vehicle the route of which is crossed with that of another type of transport determine:

2.1. current location at the route

$$<\chi_0^1,\psi_0^1>;<\chi_0^2,\psi_0^2>;...;<\chi_0^U,\psi_0^U>$$

2.2. distance $d_{u.p}$ from the current location till all the crossing points in front

$$d_{u.p}=\sqrt{(\chi_1^{R^U}-\chi_0^{U_n})^2+(\psi_1^{R^U}-\psi_0^{U_n})^2}+\sum_{i=2}^{z}\sqrt{(\chi_i^{R^U}-\chi_{i-1}^{R^U})^2+(\psi_i^{R^U}-\psi_{i-1}^{R^U})^2}\ \text{m} \qquad (6)$$

where $u\in U$ and $p\in P^2$; z – number of processors till crossing p in accordance with the route

2.3. the average time necessary for movement $t^U_{vid.nepiecieš}$ from the current location till the crossings

$$t^U_{vid.nepiecieš}=\left(\frac{d_{u,p}}{(\overline{V}^u+V_S)}+\frac{d_{u,p}}{(\overline{V}^u-V_S)}\right)/2\ \ \text{s} \qquad (7)$$

2.4. time of standard deviation t_S^U

$$t_S^U=t^U_{vid.nepiecieš}-\frac{d_{u,p}}{\overline{V}^u+V_S}\ \ \text{s} \qquad (8)$$

3.step. Determine crossing interval t^{int} of normal t^{int}, when the correspondent railway and auto transportpair of vehicles <u$_1$, u$_2$> vai <u$_1$, u$_3$> will be located at the route crossing point under consideration p:

$$t^{\text{int}}=\left[t^{\text{int}}_{\min};t^{\text{int}}_{\max}\right]=\left[t^1_{\min};t^1_{\max}\right]\cap\left[t^2_{\min};t^2_{\max}\right] \qquad (9)$$

4. step. Determine probability Q for the case ξ, when:

4.1.auto transport is located at the route crossing within the time interval t^{int}

$$Q^{U^2U^3}=\Phi\left(\frac{t^{\text{int}}_{\max}-t^{U^2U^3}_{vid.nepiecieš}}{t_S^{U^2U^3}}\right)-\Phi\left(\frac{t^{\text{int}}_{\min}-t^{U^2U^3}_{vid.nepiecieš}}{t_S^{U^2U^3}}\right) \qquad (10)$$

4.2. train is located at the route crossing within the time interval t^{int}

$$Q^{U^1}=\Phi\left(\frac{t^{\text{int}}_{\max}-t^{U^1}_{vid.nepiecieš}}{t_S^{U^1}}\right)-\Phi\left(\frac{t^{\text{int}}_{\min}-t^{U^1}_{vid.nepiecieš}}{t_S^{U^1}}\right) \qquad (11)$$

5.step Determine general probability Q^{kop}

$$Q^{kop}=Q^{U_2U_3}*Q^{U_1} \qquad (12)$$

6.step. Determine maximum probability $Q^{\max}$ for the case when both vehicles are located at the route crossing within time interval t^{int}

$$Q^{\max}=\max(Q^{kop1};Q^{kop2},...,Q^{kopn}) \qquad (13)$$

7. step. For each pair of train-crossing $<u,p>$, at which $u\in U^1$ and $p\in P^2$, determine: 7.1. maximum time $t^{u^1,p}_{\max.pirm}$ necessary for driving for the first wagon from the current location till the crossing closing point

$$t^{u^1,p}_{\max.pirm}=\frac{d_{u,p}}{(\overline{V}^u-V_S)}-t^p_{vest}\ \ \text{s} \qquad (14)$$

7.2. minimum time $t^{u^1,p}_{\min.pirm}$ necessary for driving for the first wagon from the current location till the crossing closing point

$$t^{u^1,p}_{\min.pirm} = \frac{d_{u,p}}{(\overline{V}^u + V_S)} - t^p{}_{vest} \ \text{s} \qquad (15)$$

7.3. maximum time $t^{u^1,p}_{\max.ped}$ necessary for driving for the last wagon from the current location till the crossing opening point

$$t^{u^1,p}_{\max.ped} = \frac{d_{u,p} + L_u}{\overline{V}^u - V_S} \ \text{s} \qquad (16)$$

7.4. minimum time $t^{u^1,p}_{\min.ped}$ necessary for driving for the last wagon from the current location till the crossing opening point

$$t^{u^1,p}_{\min.ped} = \frac{d_{u,p} + L_u}{\overline{V}^u + V_S} \ \text{s} \qquad (17)$$

8.step. Calculate for each crossing:

8.1. average closing time for each train

$$t^{aizvers}_{vid} = \frac{t^{u^1,p}_{\min.pirm} + t^{u^1,p}_{\max.pirm}}{2} \ \text{s} \qquad (18)$$

8.2. average opening time for each train

$$t^{atvers}_{vid} = \frac{t^{u^1,p}_{\min.ped} + t^{u^1,p}_{\max.ped}}{2} \ \text{s} \qquad (19)$$

9.step Calculate for two in opposite direction driving vehicles total time of the existence at closed crossing t^{kop}_{slegts}

$$t^{kop}_{slegts} = \left| \left[t^{\text{int}}_{sakuma} ; t^{\text{int}}_{beigu} \right] \right| = \left| \left[t^{aizversU^{1\rightarrow}}_{vid} ; t^{atversU^{1\rightarrow}}_{vid} \right] \cap \left[t^{aizversU^{2\leftarrow}}_{vid} ; t^{atversU^{2\leftarrow}}_{vid} \right] \right| \ \text{s} \qquad (20)$$

10.step. Calculate the total time of the existence at closed crossing of the vehicles driving in opposite directions Θ

$$\Theta = \sum_{i=1}^{n} t^{kop}_{slegts}{}^{i} \qquad (21)$$

11. step. Calculate the idle time of each vehicle $t^{u^{2,3}}_{dikst}$

$$\text{IF } t^{aizvers}_{vid} \le t^{u^{2,3}}_{vid,nepiecieš} \le t^{atvers}_{vid} \text{ THEN } t^{u^{2,3}}_{dikst} = t^{atvers}_{vid} - t^{u^{2,3}}_{vid,nepiecieš} \text{ ELSE } t^{u^{2,3}}_{dikst} = 0 \qquad (22)$$

12. step. Calculate the total idle time of vehicles T_Σ

$$T_\Sigma = \sum_{i=1}^{n^{U1}} t^i_{dikst} + \sum_{i=1}^{n^{U2}} t^i_{dikst} \ \text{s} \qquad (23)$$

13. step. Calculate the total change of the schedule Δt form the present

$$\Delta t_{sum} = \sum_{i=1}^{3} \Delta t^{U^i} \qquad (24)$$

14. step. Calculate normalised values:

14.1. for the criterion of coincidence

$$\Theta_{norm} = \frac{\Theta_{\max} - \Theta}{\Theta_{\max} - \Theta_{\min}} \qquad (25)$$

14.2. for the idle standing criterion

$$T_{\Sigma norm} = \frac{T_{\Sigma} - T_{\min}}{T_{\max} - T_{\min}} \tag{26}$$

14.3. for the shift criterion

$$\Delta t_{sum.norm} = \frac{\Delta t - \Delta t_{\min}}{\Delta t_{\max} - \Delta t_{\min}} \tag{27}$$

15. step. Calculate the total value of the target function

$$F = \alpha_E E_{norm} + \alpha_Q Q_{norm} + \alpha_{\Theta} \Theta_{norm} + \alpha_{T_{\Sigma}} T_{\Sigma norm} + \alpha_{\Delta t} \Delta t_{sum.norm} \tag{28}$$

Immune algorithm of double population for the transport flow control

Nomenclature

A(0) – initial antibody population
M(0) – initial population of memory
$N_c > n$ - integer, size of clones
T_P^C - operator of the clones propagation
T_M^A - operator of the similarity development
T_S^C - operator of the clones selection
T_M^U - operator of the memory replenishment
T_A^U - operator of the antibody replenishment
$T\%$ - factor of the feedback
s - size of the memory population

Step 1. Initialization According to the principle of randomness the initialization or initial population of antibodies is realized $A(0) = \{a_1(0), a_2(0), ...a_n(0)\}$. Therefore according to the same principle the initial memory population is organized $M(0) = \{m_1(0), m_2(0), ..., m_s(0)\}$. Calculate the equality of all antibodies from the sets $A(0)$ and $M(0)$. Initially $k = 0$.

Step 2. Clonal Proliferation. From set $A(k)$ application the operator of clonal proliferation T_P^C obtains set $Y(k)$.

$$Y(k) = T_P^C(A(k)) = \{T_P^C(a_1(k)), T_P^C(a_2(k)), ..., T_P^C(a_n(k))\} \tag{31}$$

where $Y_i(k) = T_P^C(a_i(k)) = I_i \times a_i(k)$, $i = 1,2,...,n$, and I_i is q_i dimension unit vector.

$$q_i(k) = \left| N_c \times \frac{affinity(a_i(k))}{\sum_{j=1}^{n} affinity(a_j(k))} \right|, \; i - 1,2,...,n \tag{32}$$

$q_i(k)$ value is proportional to the measurement unit of coincidence. As the clones propagation the population becomes equal to

$$Y(k) = \{Y_1(k), Y_2(k), ..., Y_n(k)\}, \tag{33}$$

where $Y_i(k) = \{y_{ij}(k)\} = \{y_{i1}(k), y_{i2}(k), ..., y_{iq_i}(k)\}$, $y_{ij}(k) = a_i(k)$, $j = 1,2,...,q_i$, $i = 1,2,...,n$

Step 3. Affinity Maturation. The Affinity Maturation is diversified basically by two mechanisms: hypermutation and receptor editing. Random changes are introduced into the genes, i.e. mutation. Such changes may lead to an increase in the affinity of the clonal antibody occasionally. Antibodies had deleted their low-affinity receptors (genes) and developed entirely new ones through recombination, i.e. receptor editing. Receptor editing offers the ability to escape from local optima on an affinity landscape. Hypermutation example: for the antibody $y_{ij}(k), j=1,2,...,q_i, i=1,2,...,n$ in the antibody population $Y(k)$ replacing its certain numbers by the random integer between 0 and 9. The receptor editing example: the receptor editing is designed similar to uniform recombination. Let $a=(a_1,a_2,...,a_I)$ be the antibody to be edited. Then randomly select a member $m=(m_1,m_2,...,m_D)$ from the current memory population $M(k)$. Randomly genereate a Boolean vector $r=(r_1,r_2,...,r_D)$ where $r_i \in \{0,1\}, i=1,2,...,D$ then the new antibody a' is expressed as $a'=(a_1',a_2',...,a_D')$ where

$$a_i' = \begin{cases} a_i & ja \quad r_i = 0 \\ m_i & ja \quad r_i = 1 \end{cases} \qquad i=1,2,...,D$$

From set $Y(k)$ application the operator of Affinity Maturation T_M^A obtains set $Z(k)$.

$$Z(k)=\{Z_1(k),Z_2(k),...,Z_n(k)\}, \tag{34}$$

where $Z_i(k)=\{z_{ij}(k)\}=\{z_{i1}(k),z_{i2}(k),...,z_{iq_i}(k)\}$, $z_{ij}(k)=T_M^A(y_{ij}(k))$, $j=1,2,...,q_i$, $i=1,2,...,n$

Step 4. Evaluation. Calculation of similarity for all elements of set $Z(k)$

Step 5. Clonal Selection. Applying set $Z(k)\cup A(k)$ the operator of clones propagation T_S^C obtains set $A(k+1)$.

Determine, that $\forall i=1,2,...,n$; $z_i^*(k)\in Z_i(k)$ is the best antibody in set $Z_i(k)$, then

$$a_i(k+1)=T_S^C(Z_i(k)\cup a_i(k))=\begin{cases} z_i^*(k) if affinity\,(a_i(k))\le affinity\,(z_i^*(k)) \\ a_i\,(k) if affinity\,(a_i(k))> affinity\,(z_i^*(k)) \end{cases} \tag{35}$$

The next population is calculated as

$$A(k+1)=T_S^C(Z(k)\cup A(k))=\{T_S^C(Z_1(k)\cup a_1(k), T_S^C(Z_2(k)\cup a_2(k),...,T_S^C(Z_n(k)\cup a_n(k))\}= \\ =\{a_1(k+1),a_2(k+1),...,a_n(k+1)\}\ , \tag{36}$$

where $a_i(k+1)=T_S^C(Z_i(k)\cup a_i(k))$, $i=1,2,...,n$

Step 6. Replenishment of the memory population Replenishing set $M(k)$ using the operator of memory replenishing T_M^U a new memory population $M(k+1)$ is obtained

Define that $a^*(k+1)\in A(k+1)$ is the best in the antibody population $A(k+1)$, then calculate the difference (distance) between $a^*(k+1)$ and each element of set $M(k)$. If the difference (distance) between $m_j(k)$ and $a^*(k+1)$ is minimum and its value is δ_{j0} then two possibilities exist. The first, $\delta_{j0}\le\delta_0$ where δ_0 is minimum difference (distance) between each two $M(k)$ elements of the sets, then compare $a^*(k+1)$ and $m_j(k)$ similarity in the following way

$$m_j(k+1)=\begin{cases} a^*(k+1) if .affinity\,(a^*(k+1))> affinity\,(m_j(k)) \\ m_j(k)...else \end{cases} \tag{37}$$

In the second case, if $\delta_{j0} > \delta_0$, then antibodies $a^*(k+1)$ are added to the memory population and delete the weakest values in the memory population. As a result

$$M(k+1) = \{m_1(k+1), m_2(k+1), ..., m_s(k+1)\} \quad (38)$$

Step 7. Replenishment of the antibodies population It is made in the interconnection of $M(k+1)$ and $A(k+1)$ with operator of antibodies replenishment T_A^U. The weakest t antibodies from set $A(k)$ are replaced with those $t = \lfloor T\% \times s \rfloor$ randomly selected from $M(k+1)$ set.

Step 8. Testing of the breaking criterion If the conditions of the breaking criterion are faced then the algorithm is broken. If not then $k = k+1$ and the algorithm goes to Step 2.

Genetic algorithm for the transport flow control

Step 1. Initialization Initialise the set of schedule shift $SNK = \{\Delta t^1, \Delta t^2, ..., \Delta t^p\}$ (39)

$\Delta t^i = \{\Delta t_1^i, \Delta t_2^i, ..., \Delta t_n^i\}$ - the i-th shift set,

where:

p - size of population (even number);

n - number of vehicles,

Δt_j^i - j-th shift of vehicle from the initial schedule

i = 1...p; j = 1...n

Step 2. Evaluation. Calculate (evaluate) according to the target function:

$$MF = \{F(\Delta t^1), F(\Delta t^2), ..., F(\Delta t^p)\}; \quad (40)$$

Step 3. Ordering. Order the sets of schedule shifts according to the evaluation:

$$\overline{SNK} = \{\overline{\Delta t^1}, \overline{\Delta t^2}, ..., \overline{\Delta t^p}\}; \quad F(\overline{\Delta t^1}) = \min(MF), \quad F(\overline{\Delta t^{i-1}}) \le F(\overline{\Delta t^i}), \quad i = \overline{2, p} \quad (41)$$

Step 4. Superstrain organizing. Select the best sets of shifts for the organization of superstrain set $SNK_{elite} \subset \overline{SNK}$; (42)

Step 5. Procedure of selection. The algorithm of random selection of chosen

$$SNK_{sel} = \overline{SNK}; \quad (43)$$

5.1. generate random numbers $g \in [1, p]$

5.2. add selection set SNK_{sel} with the g-th element from the shift set an from the shifts set take the g-th element.

$$SNK_{sel} = SNK_{sel} \cup \{\overline{\Delta t^g}\}; \quad \overline{SNK} = \overline{SNK} \setminus \{\overline{\Delta t^g}\}; \quad (44)$$

5.3. If $\overline{SNK} = \varnothing$ then the replenishment of the selection set is completed. In the opposite case go to
step 5.1.

With this procedure a recombined SNK elements set is obtained

$$SNK_{sel} = \{< \Delta\hat{t}^1, \Delta\hat{t}^2 >, ..., < \Delta\hat{t}^{p-1}, \Delta\hat{t}^p >\} \quad (45)$$

Step 6. Crossing procedure. Single point crossing is selected (SPX)

6.1. step. b dividing chromosome s into two parts is defined

6.2. step. From schedule shift set SNK_{sel}^i where i - the order number of generation a pair is selected:

$< \Delta t^{j^i}, \Delta t^{(j+1)^i} >$

6.3. step. Generate new list of bits for the shifts according to the following law:

$$b_k^{{j^{i+1}}} = \begin{cases} b_k^{\,j}, & ja \quad k \le b \\ b_k^{\,j+1}, & ja \quad k > b \end{cases}$$

$$b_k^{{j+1^{i+1}}} = \begin{cases} b_k^{\,j}, & ja \quad k > b \\ b_k^{\,j+1}, & ja \quad k \le b \end{cases} \tag{46}$$

where k - index of the bit in chromosome; k = 1,2,...,z; where z is the number of bits in the set of schedule shift

6.4. step. The set of next generation schedule consists of the calculated bits

$$\Delta t^{\,j^{i+1}} = \left\{ b_1^{j^{i+1}}, b_2^{j^{i+1}}, ..., b_z^{j^{i+1}} \right\}$$

$$\Delta t^{\,j+1^{i+1}} = \left\{ b_1^{(j+1)^{i+1}}, b_2^{(j+1)^{i+1}}, ..., b_z^{(j+1)^{i+1}} \right\} \tag{47}$$

6.5. step. If $j+1=p$, then the procedure is completed with new (i+1) generation set of schedule shift:

$$SNK^{i+1} = \left\{ \Delta t^{1^{i+1}}, \Delta t^{2^{i+1}}, ..., \Delta t^{p-1^{i+1}}, \Delta t^{p^{i+1}} \right\} \tag{48}$$

In the opposite case go to step 6.2.

Step 7. Mutation procedure. Introduction of random changes during the operation of the algorithm

It does not allow a uniformity of all the population elements.

7.1. Generate random number $g = rand(1;1/\mu)$

where μ - factor of mutation (accepted 1/100)

7.2. The gen mutates according to the law

If $b_k^j = 0$ then

$$b_k^i = \begin{cases} 0, & ja \; g > 1 \\ 1, & ja \; g = 1 \end{cases} \tag{49}$$

in the opposite case

$$b_k^i = \begin{cases} 1, & ja \; g > 1 \\ 0, & ja \; g = 1 \end{cases} \tag{50}$$

Step 8. Evaluation. Evaluate new population according to the target function:

$$MF^{\,j+1} = \left\{ F(\Delta t^{1^{j+1}}), F(\Delta t^{2^{j+1}}), ..., F(\Delta t^{p^{j+1}}) \right\}; \tag{51}$$

Step 9. Organization according to the evaluation. Organize a new population in accordance with the evaluation:

$$\overline{SNK^{\,j+1}} = \left\{ \overline{\Delta t^{1^{j+1}}}, \overline{\Delta t^{2^{j+1}}}, ..., \overline{\Delta t^{p^{j+1}}} \right\}; \quad F(\overline{\Delta t^{\,j+1}1}) = \min(MF), \quad F(\overline{\Delta t^{i-1^{j+1}}}) \le F(\overline{\Delta t^{i^{j+1}}}), \quad i = \overline{2, p} \tag{52}$$

Step 10. Joining of new generation with superstrain.

$$SNK = (SNK_{elite} + \overline{SNK}^{\,j+1}) \tag{53}$$

Step 11. Deleting. Delete the last elements from the united population if the new one is larger than the determined size:

$$SNK = SNK \setminus \left\{ \Delta t^{p+1}, \Delta t^{p+2}, ... \right\} \tag{54}$$

THE OPPORTUNITIES OF EMBEDDED DEVICES APPLICATION FOR THE SOLVING OF THE SCHEDULING TASKS AND THEIR INTEGRATION INTO TRANSPORT SYSTEM

Taking into account the previous positive experience in the application of programming logic controllers for the control of intelligent transport system, many publications devoted to this topic, at RTU defended researches and submitted and obtained patents about controller and satellite navigation application in railway transport this promotion paper proposes for the control of a vehicle an embedded device prototype consisting of the following components:

- controller
- GPS signal receiver
- GPS receiver aerial
- GSM/GPRS transmitter
- GSM/GPRS aerial
- display
- converter

The controller is taken ARDUINO produced Arduino UNO. As a GPS signal receiver a global positioning module produced by VINCOTECH A1080-B is selected with an appropriate aerial. GSM/GPRS transmitter is selected Sagem Hilo module and a correspondent GSM aerial. Display is Seeed Studio Serial LCD1602 produced.

The mounting scheme of the embedded device is given in Fig. 2

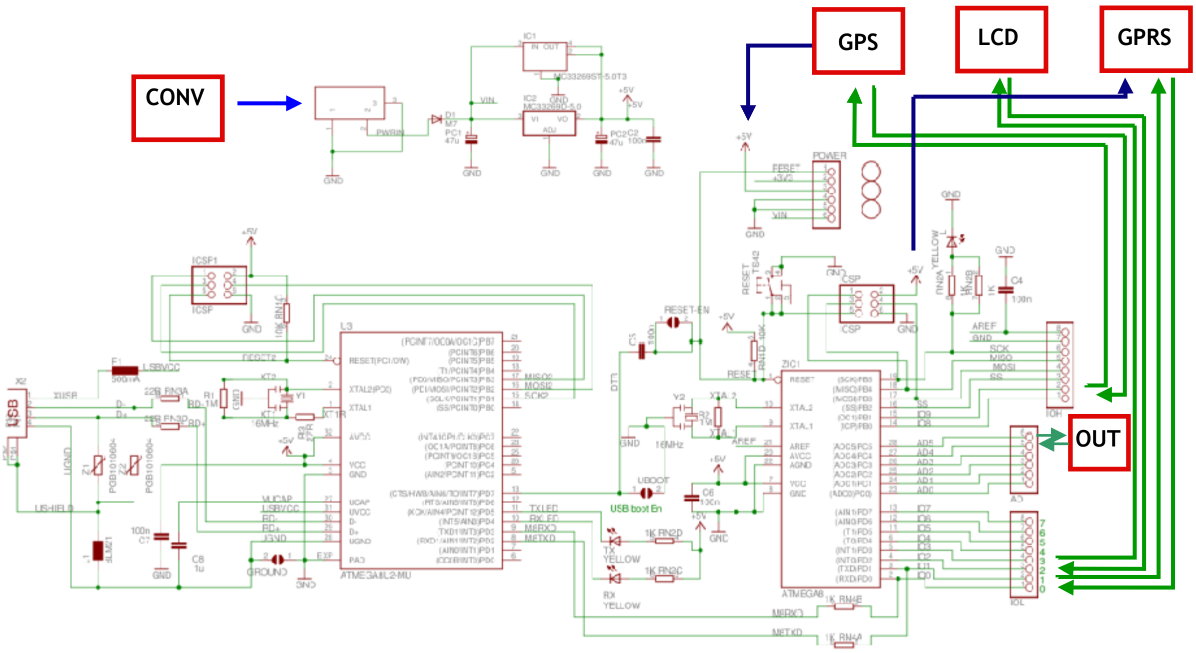

Fig. 2. Mounting scheme of embedded device components

The closing of the crossing is provided in distribution box ŠRU-M giving the signals to the switches. The closing of the barrier takes place at the moment when the train comes to the rail circuit and normally closed switches open the electric circuit. Through the normally closed relays connecting to them in parallel the embedded device gives the command for the closing of the crossing from the control center. In this case the control of the crossing happens by means of transmitters sending the generated in the control center signal wirelessly. The mounting scheme of the crossing control embedded device is demonstrated in Fig.3.

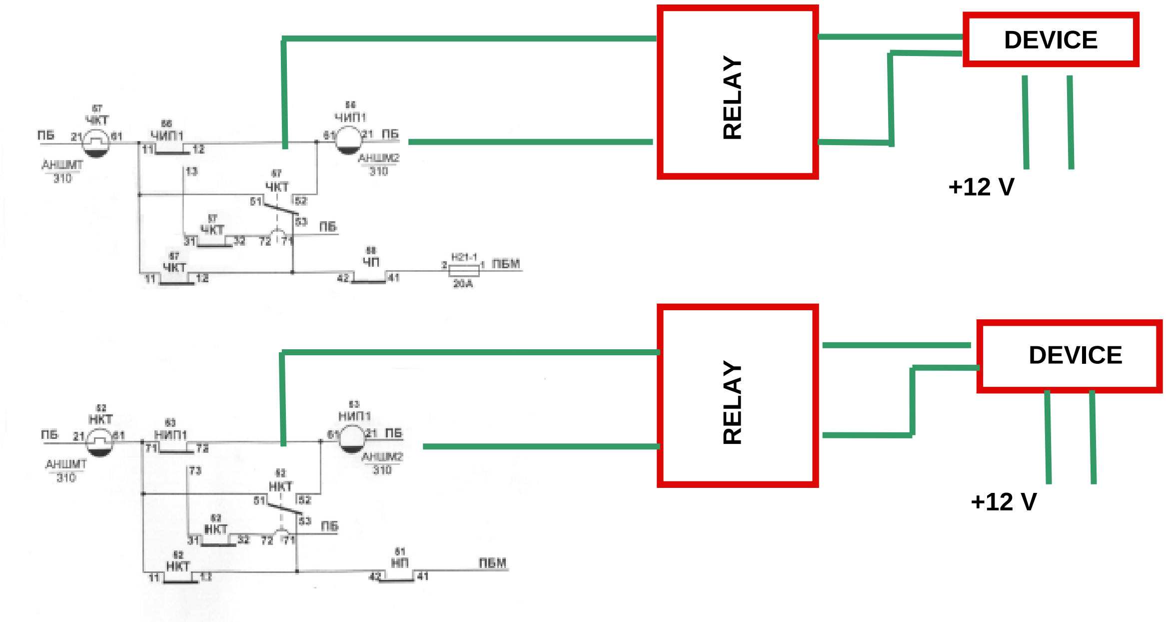

Fig. 3. Electric scheme of the crossing control embedded device

The connection of embedded device to the control rails of the crossing in the distribution box ŠRU M is demonstrated in Fig. 4

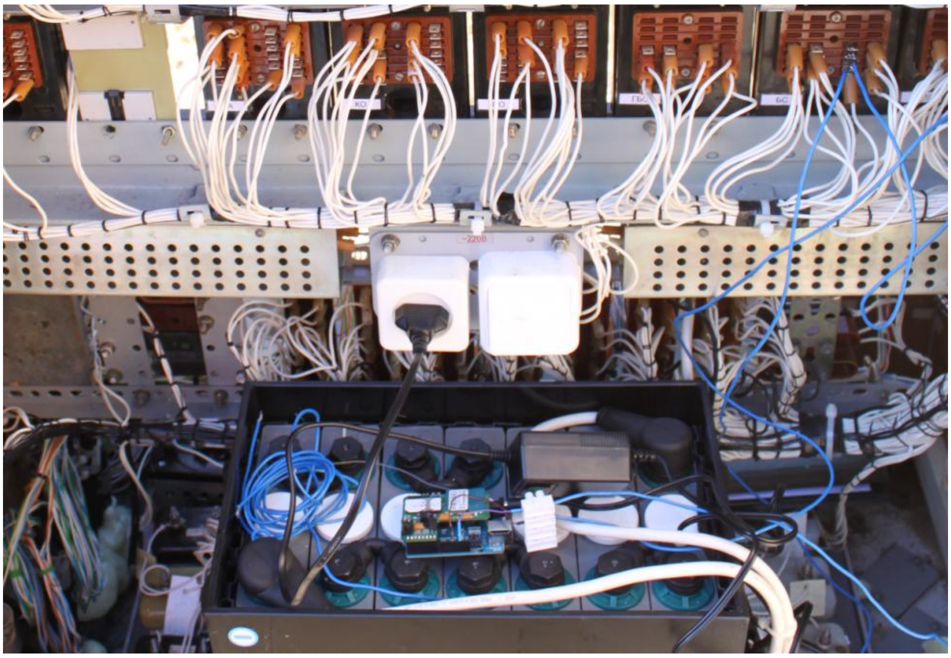

Fig. 4. Connection of device in the distribution box

Fig. 5 demonstrates the sector of the locomotive E62 electric circuit with the help of which the emergency braking is activated. Opening this circuit and connecting device as in Fig. 5 it is possible to activate the emergency braking of the train without participation of the driver when achieving the critical signal from the control center.

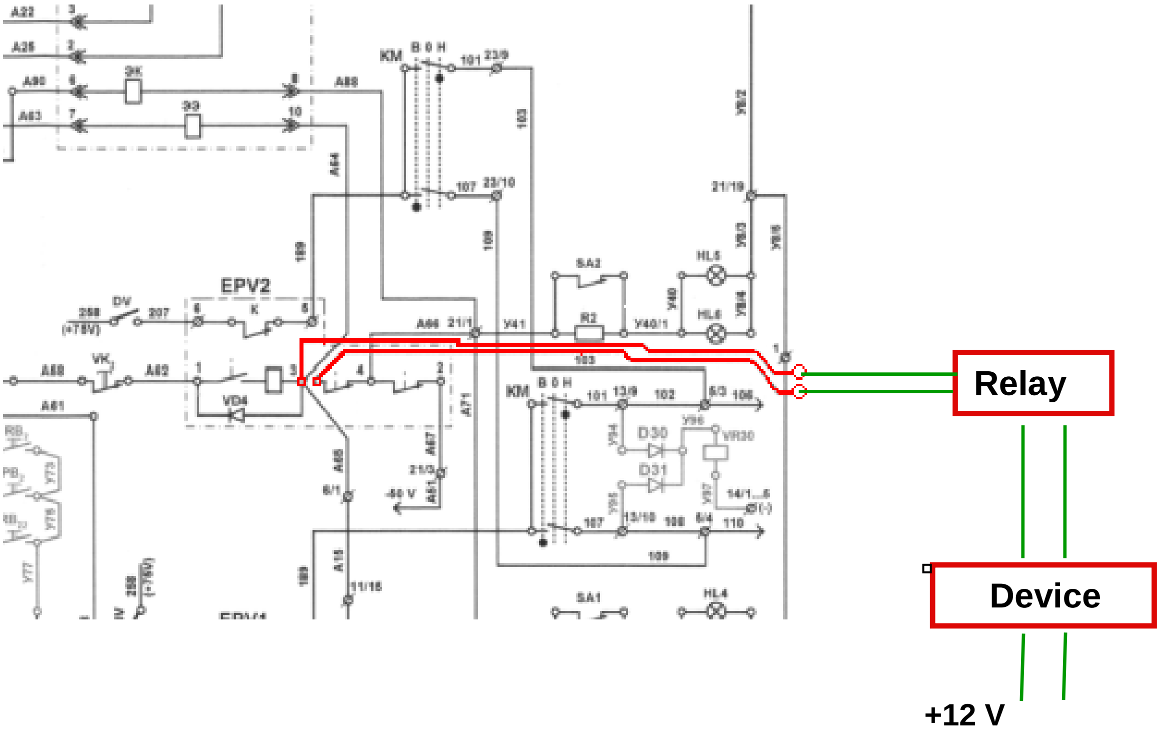

Fig. 5. Electric scheme of the train emergency braking activation

The prototype of embedded device is demonstrated in Fig. 6

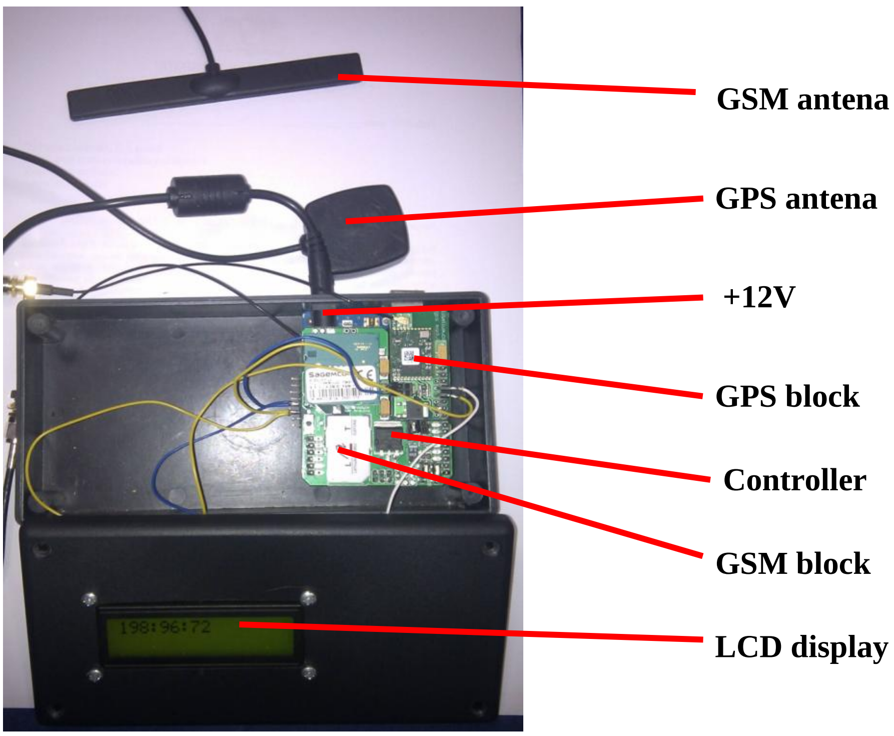

Fig. 6. Prototype of embedded device

RESULTS OF THE COMPUTER EXPERIMENTS OF PUBLIC TRANSPORT

The developed algorithms are testing for two computer model of level crossing and public electric motion control tasks

Computer model for the testing of algorithm for electric motion control task

For the example part of Riga city centre is selected, where seven electric transport routes are crossing. The following is defined: sets of routes, time for each operation, constant movement time between the stages-stops, time intervals between arrivals and floored number of vehicles in 180 minutes are given. The computer model is given in Fig.7.

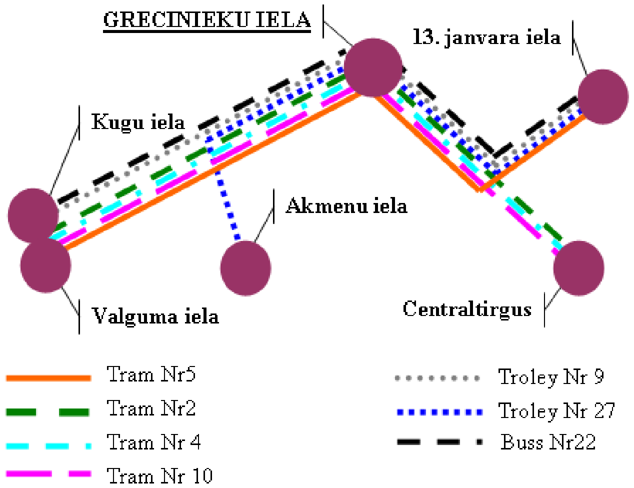

Fig. 7. Schematic figure of the computer model for electric motion task

Computer model for the testing of algorithm for level-crossing task

The following model for the testing of the algorithms of the city transport system is developed. The following is defined: sets of crossings, buses, trains, stops, schedules and routes. The computer model is given in Fig. 8

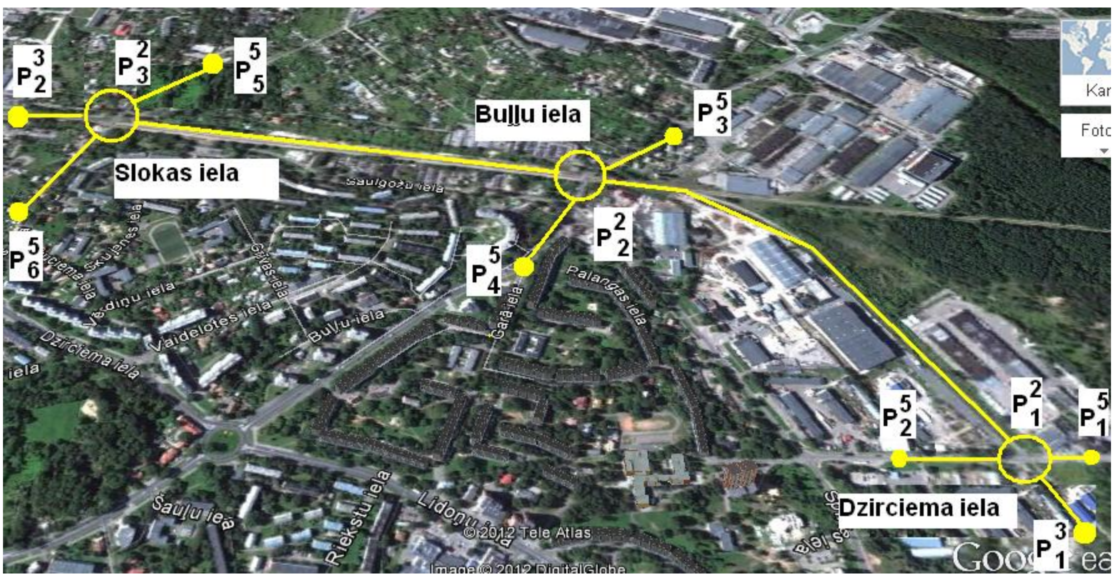

Fig. 8. Schematic figure of the computer model

Application of the evolutionary algorithms for the calculation of target function value

To collect the data for the analysis and evaluation with the help of statistical methods eight series of experiments with 30 experiments in each have been made changing basic parameters of different evolutionary algorithms. Totally 2880 experiments were realised. The following variables were determined in the experiments; accuracy of the measurements reading, accepted deviation from the initial schedule, accepted deviation of the buses speed, accepted deviation of the trains speed, size of population and superstrain, factor of mutation, size of memory storage, number of clones.

EVALUATION OF THE EXPERIMENTS RESULTS USING THE METHOD OF STATISTICAL ESTIMATION OF THE HYPOTHESIS

The hypothesis proposed for the examining

zero hypotheses:

1) H01: The schedule proposed by the genetic algorithm is better than the present one;
2) H02: The schedule proposed by the immune algorithm is better than the present one;

alternative hypotheses:

1) H11: The schedule proposed by the genetic algorithm is not better than the present one;
2) H12: The schedule proposed by the immune algorithm is not better than the present one

Electric motion control task

For each experiment mean values and standrad deviations of the schedules proposed by the immune algorithm (IA) and the genetic algorithm (GA) calculate. Average values are presented in Tab. 1

Tab. 1. Average values of criterions

Criterion	**Origin**	**IA**	**GA**
Target function value	0.246489	0.19643	0.15277
Conflict probability	0.99987	0.95468	0.74253
Extra energy consumption Kwh	17.89	0.077	0.17
Schedule deviation min	0	296.42	214.08
Machine time s		2454.48	1895.86

The IA proposed average values and standard deviations are summarised in Tab. 2

Tab. 2. IA proposed average values and Standard deviations

Criterion	**Average**	**St. deviation**
Target function value	0.19643	0.01752
Conflict probability	0.95468	0.08751
Extra energy consumption Kwh	0.077	0.007
Schedule deviation min	296.42	0.13
Machine time s	2454.48	377.54

The results of the statistical evaluation of z-test for electric transport movement control task of the immune algorithm are summarised in Tab. 3

Tab. 3. Immune algorithm statistics z-test evaluation

Criterion	Certainty	Comparison	Value	Result
Target function	99.90%	(0.189 ; 0.2039)	0.2465	**H0 can not be rejected with probability 99.90%**
Conflict probability	99.90%	(0.9175 ; 0.9919)	17.8905	**H0 can not be rejected with probability 99.90%**
Extra energy consumption	99.90%	(0.0741 ; 0.0801)	0.9999	**H0 can not be rejected with probability 99.90%**

The GA proposed average values and standard deviations are summarised in Tab. 4

Tab. 4. GA proposed average values and Standard deviations

Criterion	Average	St. deviation
Target function value	0.15277	0.00472
Conflict probability	0.74253	0.02359
Extra energy consumption Kwh	0.17	0.015
Schedule deviation min	214.08	2.83
Machine time s	1895.86	33.90

The results of the statistical evaluation of z-test for electric transport movement control task of the genetic algorithm are summarised in Tab. 5.

Tab. 5. Genetic algorithm statistics z-test evaluation

Criterion	Certainty	Comparison	Value	Result
Target function	99.90%	(0.1508 ; 0.1548)	0.2465	**H0 can not be rejected with probability 99.90%**
Conflict probability	99.90%	(0.7325 ; 0.7526)	17.8905	**H0 can not be rejected with probability 99.90%**
Extra energy consumption	99.90%	(0.165 ; 0.1784)	0.9999	**H0 can not be rejected with probability 99.90%**

Comparison of genetic and immune algorithm

For the comparison of two algorithms the promotional paper applies first should be test that statistical estimation method of the hypothesis examining. The initial schedule was compared with those proposed by Genetic and Immune algorithms for the control of the transport system control.

In order to compare and verify, which of the two algorithms – immune or genetic algorithm is better, first it is necessary to analyse whether empirical distribution functions of experimental result data are the same for both algorithms. Thus, it will be possible to compare and determine better algorithm by the criteria, for which distribution functions are not the same.

Results of Chi-square test and Kolmogovo-Smirnov test show that algorithms are comparable by all the criteria, excepting electric energy consumption criterion for task of electric transport control. Both algorithms provide the same solution by electric energy consumption criterion and therefore they are not compared.

Average values of electric transport control task criteria are summarized in Tab. 6 for comparison of algorithms

Tab. 6. Values for electric motion control task

Average value of criterion	IA	GA	GA vs IA
Target function value	0.19643	0.15277	22,23%
Schedule conflict	0.95468	0.74253	22,22%
Schedule shifting min	296.42	214.08	27,78%
Machine time s	2454.48	1895.86	22,76%

Results of Chi-square test and Kolmogovo-Smirnov test show that algorithms are comparable by target function, coincidence, schedule shifting and machine time criterions for level crossing task. Both algorithms provide the same solution by collision probability and idle time criterion and therefore they are not compared.

Algorithm comparison according average values of criterions of level crossing task are summarised in tabs and figures

- according target function values Tab7., Fig.9.

Tab. 7. Target function values

	IA	GA	GA vs IA
The 1st series	0,05550	0,05368	3,27%
The 2nd series	0,05708	0,04951	13,26%
The 3rd series	0,06354	0,05709	10,15%
The 4th series	0,05990	0,05406	9,75%
The 5th series	0,04496	0,04556	-1,32%
The 6th series	0,04749	0,04243	10,64%
The 7th series	0,04988	0,04312	13,54%
The 8th series	0,04772	0,04397	7,86%
Average			8,40%

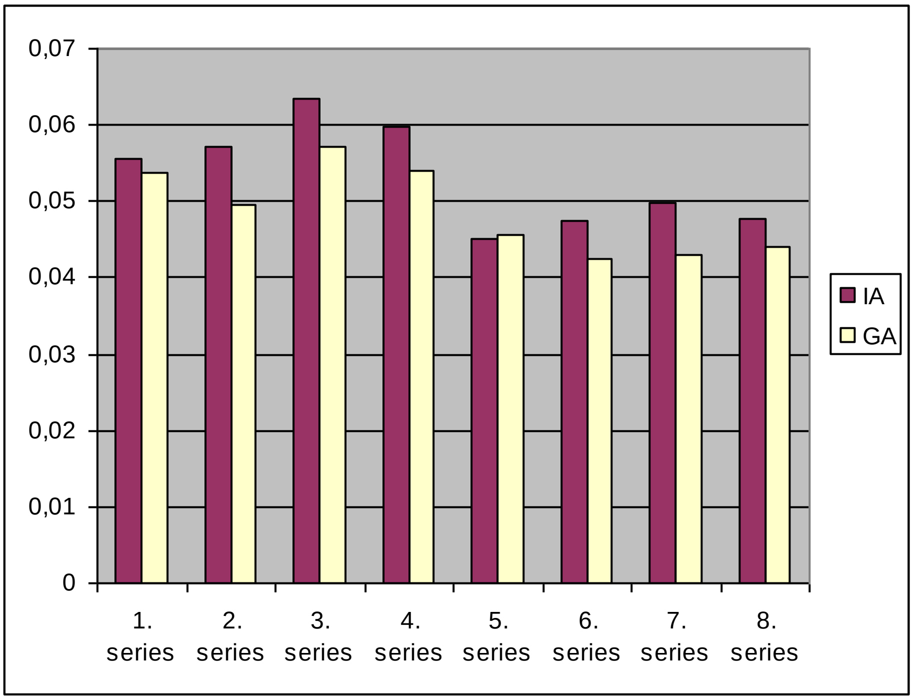

Fig. 9. Graphical comparison according to the target function

– according the schedules shift criterion Tab.8.. Fig.10

Tab. 8. Schedule shifting criterion

	IA	GA	GA vs IA
The 1st series	31,77	25,72	19,04%
The 2nd series	30,04	24,40	18,77%
The 3rd series	48,52	41,68	14,08%
The 4th series	43,76	38,96	10,96%
The 5th series	31,96	27,12	15,15%
The 6th series	30,23	24,84	17,84%
The 7th series	52,65	42,56	19,16%
The 8th series	46,91	42,67	9,04%
Average			15,50%

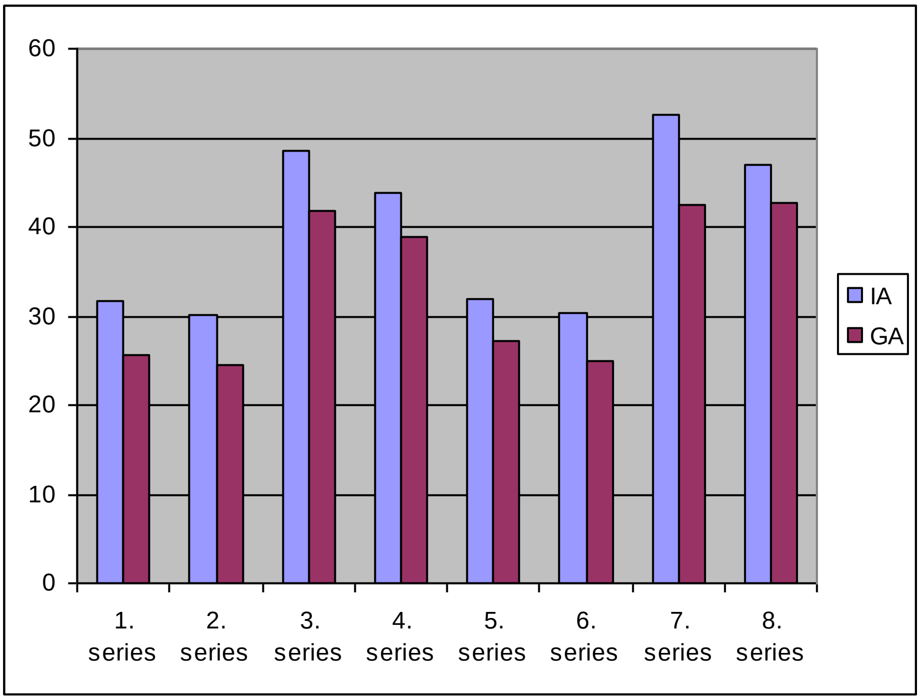

Fig. 10. Graphical comparison to the schedules shift criterion

– according the machine time Tab.9. Fig.11.

Tab. 9. Machine time values

	IA	GA	GA vs IA
The 1st series	241,76	188,64	21,97%
The 2nd series	235,91	201,94	14,40%
The 3rd series	282,51	226,83	19,71%
The 4th series	265,94	247,97	6,76%
The 5th series	249,14	189,99	23,74%
The 6th series	237,88	219,17	7,86%
The 7th series	286,29	237,84	16,92%
The 8th series	273,74	255,15	6,79%
Average			14,77%

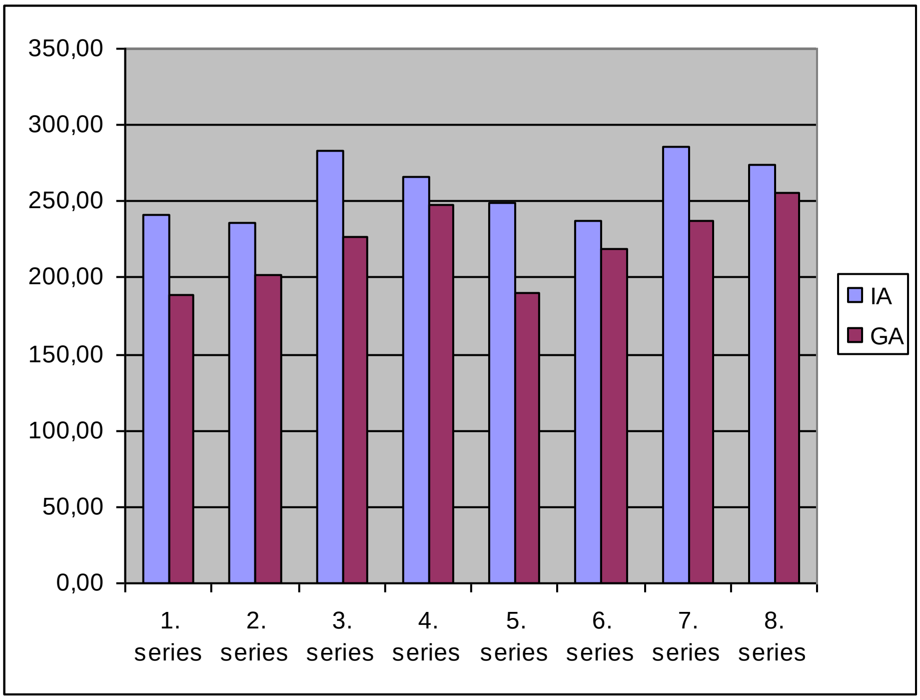

Fig. 11. Graphical comparison according to the machine time

CONCLUSIONS

Analysing the obtained results the conclusions about the achievement of the main goal can be made. During the work on the promotion paper the following has been made:

- The analysed literature contains the information about the control transport systems, modelling of the systems and intelligent embedded devices application in the transport system for the control of data flows.
- The mathematical model of the transport system objects control is developed; the constant and variable elements of the system are defined and described.
- The opportunities of schedule theory and evolutionary algorithms application are investigated for the solving of the multi-stage parallel and series transport tasks.
- Five criteria influencing the transport system control and general target function for safe transport system control are defined.
- The special algorithm is developed for calculation of the values of each separate criterion as well as the total target function.
- The developed algorithms for calculation of the values of each separate criterion are universal and can be applied to solve any transport involving tasks
- Prototype of embedded device is developed to control each element of the transport system.
- Computer model of the transport system is developed for the modelling of different type transport flows control.
- A series of computer experiments has been realized for the approbation of the algorithms.
- The results of the computer experiments were analysed for the hypothesis examination.
- Different algorithms were compared taking into account the created schedule influence on the safety and idle time decreasing.

The experiments made during the research and the obtained results allow make the following conclusions:

1. The developed transport system control algorithm allow:
   - Decrease electricity overconsumption for 99,32% in case to provide strict sequencial transport units arriving in the stops and avoid the schedule conflict
   - Increase the level crossing capacity for 49,46% as result of insignificiant speed changes of the busses and the trains and allow decrease the idle time for 99,96%, i.e. allow practically continious moving pass the level crossing
   - Significantly decrease the collision probability of road and railway transport units from value 0,946267 up to 0,00028
2. 100% of the experiments proved the hypothesis H01: The schedules proposed by the immune and genetic algorithms in accordance with the target function criterion are better that that original
3. Application of embedded devices provide information to the vehicle drivers about the probability of collision and the advisible speed, and, in case the collision probability reaching a critical value, to start the trains emergency braking system without human intervention
4. The schedules proposed by the genetic algorithm are better than those proposed by the immune algorithm. For level crossing task the genetic algorithm propose better shedules average for:
   - 8,40% according target function criterion
   - 4,12% according coincidence criterion
   - 15,5% according shedules shift criterion
   - 14,77% according machine time
5. For the electric transport control task the genetic algorithm propose better shedules than immune algorithm average for:
   - 22,2% according target function criterion
   - 22,2% according chedule conflict criterion
   - 27,78% according shedules shift criterion
   - 22,76% according machine time
6. Coparising of two evolution algorithms allow to conclude, that genetic algorithm provides better schedules than immune algorithm according to all target function criterions.

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IVARS ALPS
MODELLING OF INTELLIGENT ELECTRICAL TRANSPORT CONTROL SYSTEMS SCHEDULING PROBLEMS IN THE UNFORSEEN CASES

Abstract of Thesis

Registered for printing on 09.11.2012. Registration Certificate No. 2-0282. Format 60x84/16. *Offset* paper. 2,25 printing sheets, 1,74 author's sheets. Calculation 20 copies. Order Nr. 105.
Printed and bound at the RTU Printing House, 1 Kalku Street, Riga LV- 1658, Latvia.