RIGA TECHNICAL UNIVERSITY
Faculty of Power and Electrical Engineering
Institute of Industrial Electronics and Electrical Engineering
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Doctoral study program of Computerised Control of Electrical Technologies

Investigation and Development of Embedded Intelligent Devices for Adaptive Control of Railway Transport

Abstract of the Thesis

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DOCTORAL THESIS

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With this I acknowledge that I developed this work submitted for consideration to Riga Technical University for obtaining Doctor Degree. The Doctoral Thesis is not submitted to any other university or institution for scientific degree obtaining.

Andrejs Potapovs ……………………………. (Signature)

Date: ……………………..

The Doctoral Thesis is written in the Latvian language, contains introduction, 5 chapters, basic results and conclusions, list of references, 32 figures and illustrations, 22 tables, totally 155 pages. The list of references contains 207 items.

CONTENTS

TOPICALITY OF THE WORK

Nowadays the industry of transport production and maintenance can be considered as one of the basic fields of economy all over the worlds. The total amount of the vehicles of different types exceeds 1 billion [104]. The industry engages more than 100 million people, each year more than 100 billion of cargo tonnes and more than 1 trillion passengers are transported [93, 91], therefore the life can not be imagined without utilization of vehicles.

Different investigations prove that a huge role in all these transportations belongs to the railway transport [71, 91]. Except for positive factors of this transport it also has drawbacks that are often related to the questions of safe utilization of this type of vehicles and possible accidents resulting in huge losses of materials and, unfortunately, human victims. This problem is being permanently considered and solved with the development of new safety systems or modernised systems of railway transport, but those do not allow fully solve all the above mentioned problems, as the development of such complex system can not always solve a particular task.

During the last years with the rapid development of technologies different intelligent control systems have taken on special significance in many fields of science. This fact is conditioned with two basic factors. The first is related to the fact that such tasks often exist the long-term solving methodologies of which (automation, manual control, etc.) do not allow to achieve an optimal solution, the second factor in its term is related to the rapid development of computer technologies, that gives an opportunity to design devices for realisation of many functional algorithms realised before in a mathematical way only.

The transport industry is not an exception, as nowadays even the simplest types of transport including railway are equipped with computer technologies of different types and complexity the basic tasks of which related to:

- increasing of efficiency factor of transport functioning;
- widening of transport functionality;
- improvement of customer comfort level;
- improvement of transport safety level, etc.

To a certain extent adaptive systems can be applied for the solution of all the above mentioned tasks.

In practice many adaptive control algorithms have been realised within the period of last twenty years only, that in its turn indicated new opportunities for the application of adaptive control systems. It proves that generally the investigation of adaptive algorithms is in its initial stage requiring significant theoretical researches as well as experiments for their practical examination. Taking into account all mentioned above we can conclude that in spite of already developed theory of adaptive algorithms, in practice they are widely applied only last years.

New control systems do not always give the opportunity to apply them with present systems. Therefore the following tasks are solved in this thesis:

- to develop accurate and soft train braking system with application of adaptive algorithm and embedded intelligent devices;
- to develop a concept of integrated system that could be able to improve safety of railway crossing territory applying the above mentioned braking system.

The thesis is related to the railway transport control system development with the aim to improve safety on the route and reduce the amount of accidents.

AIMS AND OBJECTIVES OF THE PAPER

The aim the thesis is to investigate and develop new adaptive control algorithms for the control of braking system of railway transport on the basis of embedded intelligent devices.

The following objectives are considered in the paper for the aim achievement:

- To analyse main principles and functioning algorithms of adaptive control systems;
- To analyse opportunities of intelligent embedded devices application in railway transport;
- To analyse present systems of control monitoring and safety of electric transport;
- To realise the algorithms of railway transport control and safety operation;
- To realise the valid prototypes of the devices developed on the basis of the operation algorithms;
- To examine computer models of the developed devices of different types with the aim to discover the drawbacks of the system under consideration and find new opportunities of improvement;
- To examine prototypes of the developed devices under the condition of real operation;
- Applying the method of statistical estimation to evaluate the effectiveness, reliability and other parameters of the developed algorithm and embedded devices.
- To compare the effectiveness of the developed algorithm with those currently applied;
- To compare the efficiency factor and reliability of the developed prototype with the devices currently under maintenance.

METHODS AND INSTRUMENTS OF THE RESEARCH

- Analysis of the railway control systems and processes;
- Theory of adaptive control algorithm;
- Conditions of embedded intelligent devices integration;
- Theory of probability;
- *MATLAB* software with *SIMULINK* application;
- *PLC* programming;
- Methods of statistical analysis.

SCIENTIFIC TOPICALITY OF THE RESEARCH

The following mathematical models have been developed for the adaptive system of train soft and accurate braking:

1. General mathematical model of electric, mechanic and pneumatic elements of accurate and soft braking system of the train:
2. Mathematical model of the air pressure control of the pneumatic braking system;
3. Some mathematical models of adaptive algorithms for self-learning of the train adaptive soft and accurate braking system;

4. General operation algorithm of adaptive soft and accurate braking system including the algorithms of the train pneumatic braking control system, the algorithm of the system's self-learning with that of the quality evaluation.

APPLIED SIGNIFICANCE OF THE RESEARCH

The control system and its functioning algorithms proposed in the research can be applied in railway transport including the safety of the cargo trains routes and the increasing of automation level. The above mentioned algorithms give an opportunity to avoid possible accidents applying braking regimes and providing automatic diagnostics of the pneumatic braking system. For the realization of this function a new automatic system of brakes control has been developed using embedded intelligent devices and adaptive control algorithms.

APPROBATION OF THE RESEARCH

The results of the research were presented and accepted at the following 9 international conferences:

1. International scientific conference „Topical Problems in the Field of Electrical and Power Engineering", Estonia, Pērnava, 2010, 18. June Report „Algorithm of Precise Control of Timetable for Intelligent Embedded Devices in City Electric Transport".
2. International scientific conference „Intelligent Technologies in Logistics and Mechatronics Systems 2010 (ITELMS'2010)", Lithuania, Paņeveža, 2010, 4. June Report „Modeling of embedded intelligent device for control of city electric transport".
3. International scientific conference „Transport System Telematics 10th International Conference", Poland, Katovice-Ustron, 2010, 22. October. Report „Interaction of Real and Embedded Devices for Intelligent Control of city Electric Transport".
4. International scientific conference „Intelligent Technologies in Logistics and Mechatronics Systems 2011 (ITELMS'2011)", Lithuania, Paņeveža, 2011, 5. May. Report „Adaptive random search algorithm with linear tactics for use in railway control system".
5. International scientific conference „Transport System Telematics 11th International Conference", Poland, Katovice-Ustron, 2011, 20. October. Report „Algorithm for Electronic Embedded Systems for the Protection of Railway transport from Accidents".
6. International scientific conference „Intelligent Technologies in Logistics and Mechatronics Systems 2012 (ITELMS'2012)", Lithuania, Paņeveža, 2012, 4, May. Report "Development of Adaptive Search Algorithm for Smooth Braking System of Train".
7. International scientific conference „25th European Conference on Operational Research", Lithuania, Vilnius, 2012, 11 July. Report „Use of Adaptive Control Systems in Multi-Criteria Tasks in Electric Transport Control".
8. International scientific conference „Intelligent Technologies in Logistics and Mechatronics Systems 2013 (ITELMS'2013)", Lithuania, Paņeveža, 2013, 23, May. Report "Development of neural-network based control algorithm for train adaptive and smooth braking system".

9. International scientific conference „Intelligent Technologies in Logistics and Mechatronics Systems 2014 (ITELMS'2014)", Lithuania, Paņeveža, 2014, 23, May. Report "Development control algorithm for train adaptive and smooth braking system".

As well as the results of the research were presented and accepted at the following 9 international conferences:

1. Riga Technical University Ccientific Conference "51st RTU student scientific technical conference", Latvia, Riga, April, 29, 1020. Report „Objektorientēta elektriskā transporta sistēmu modelēšana".
2. Riga Technical University "Conference in Innovations and New Technologies", Latvia, Riga, September, 24, 2010. Report „Development and modelling of the railway transport optimal control adaptive algorithm".
3. Riga Technical University, 51st International Scientific Conference, section "Power and Electrical Engineering", subsection "Electrical Engineering", Latvia, Riga, October, 14, 2010. Report „Analysis of possibilities to apply adaptive control system for railway crossing".
4. Riga Technical University, 51st International Scientific Conference, section "Industrial Technologies and Transport", subsection "Railway Transport", Latvia, Riga, October, 15, 2010. Report „Train Braking Algorithm Realization and Testing Using PLC".
5. Riga Technical University "Conference in Innovations and New Technologies", Latvia, Riga, March, 16, 2011.. Report „Ritošā sastāva jauno kustības vadības iekārtu drošuma testēšana avārijas situācijās".
6. Riga Technical University, 52nd International Scientific Conference, section "Power and Electrical Engineering", subsection "Electrical Engineering", Latvia, Riga, October, 14, 2011. Report „Analysis of possibilities to apply adaptive control system for railway crossing".
7. Riga Technical University, 51st International Scientific Conference, section "Industrial Technologies and Transport", subsection "Railway Transport", Latvia, Riga, October, 14, 2011. Report „Use of Adaptive Control Algorithms for Smooth Braking of Train Using PLC".
8. Riga Technical University "Conference in Innovations and New Technologies", Latvia, Riga, April, 3, 2012. Report „Development and modelling of the railway transport optimal control adaptive algorithm".
9. RTU 2. International Doctoral School „2nd International Doctoral School of Electrical Engineering and Power Electronics", Latvia, Ronīši, May, 24 2013.

AUTHOR'S PUBLICATIONS

The results of the presented research are published in the following 13 international conferences proceedings:

1. Potapovs A., Gorobetz M., Levchenkov A., Ribickis L. „Algorithm of Precise Control of Timetable for Intelligent Embedded Devices in City Electric Transport" // In proceedings of 9th International Symposium "Topical Problems in the Field of Electrical and Power Engineering", Estonia, Parnu, 2010. – p. 180–185.

2. Potapovs A., Gorobetz M., Levchenkov A. „Algorithm for Embedded Safety Braking Control System in City Electric Transport” // In proceedings of 51^{th} Annual Scientific Conference of Riga Technical University on Power and Electrical Engineering, Latvia, Riga, 2010. – p. 249–254.
3. Potapovs A., Gorobetz M., Levchenkov A. „Interaction of Real and Embedded Devices for Intelligent Control of City Electric Transport” // „Archives of Transport System Telematics”, Poland, Katowice-Ustroń, 2010. – p. 25–31.
4. Potapovs A., Gorobetz M., Levchenkov A., Ribickis L. „Modeling of Embedded Intelligent Device for Control of City Electric Transport” // In proceedings of 5^{th} International Conference „Intelligent Technologies in Logistics and Mechatronics Systems (ITELMS’2010)”, Lithuania, Panevezys, 2010. – p. 37–42.
5. Alps I., Potapovs A., Gorobetz M., Levchenkov A. „Algorithm for Public Electric Transport Schedule Control for Intelligent Embedded Devices” // In Scientific Journal of RTU. 4. series „Enerģētika un elektrotehnika”, Latvia, Riga, 2010. – p. 155–160.
6. Potapovs A., Gorobetz M., Levchenkov A. „Intelligent Electronic Embedded Systems for the Protection of Railway Transport from Accidents // In proceedings of 11^{th} International Conference „Transport Systems Telematics”, Poland, Katowice-Ustron, 2011. – p. 85–85.
7. Potapovs A. „Analysis of possibilities to apply adaptive control system for railway crossing” // In proceedings of 52^{th} Annual Scientific Conference of Riga Technical University on Power and Electrical Engineering, Latvia, Riga, 2011. – p 82.
8. Potapovs A., Levchenkov A., Gorobetz M. „Intelligent Electronic Embedded Systems for the Protection of Railway Transport from Accidents” // „Archives of Transport System Telematics”, Poland, Katowice-Ustroń, 2011. – p. 24–30.
9. Potapovs A., Gorobetz M., Levchenkov A., „Opportunities of Adaptive Control Algorithms Application in Railway Control Systems” // Proceedings of 7^{th} International Conference (ITELMS’2012), Lithuania, Kaunas, 2012. – p. 141–146.
10. Potapovs A., Moor-Yaroslavtsev A., Gorobetz M., Levchenkov A. „Smooth Braking of Train Using Adaptive Control Algorithms on Embedded Devices” // In proceedings of 53^{th} Annual Scientific Conference of Riga Technical University on Power and Electrical Engineering, Latvia, Riga, 2012. – p 135.
11. Potapovs, A., Gorobecs, M., Ļevčenkovs, A. „Development of Neural-Network Based Control Algorithm for Train Adaptive and Smooth Braking System” // Proceedings of 8^{th} International Conference (ITELMS’2013), Lithuania, Kaunas: Technologija, 2013. – p. 7–13.
12. Potapovs, A., Gorobecs, M., Ļevčenkovs, A. „Adaptive System of Smooth and Accurate Braking of Railway Transport” // Proceedings of 8^{th} International Conference (ITELMS’2013), Lithuania, Kaunas: Technologija, 2013. – p. 2–6.
13. Potapovs, A., Gorobecs, M., Ļevčenkovs, A. „Mathematical Modelling of Smooth and Precise Adaptive Train Braking System” // Proceedings of the 3^{rd} International Conference on Simulation and Modeling Methodologies, Technologies and Applications (SIMULTECH 2013), Island, Reykjavik, 2013. – p. – 204–209.

One publication is in the reviewed conference theses:

1. Potapovs A. „Intelektuālās elektroniskās iebūvētās sistēmas sadursmju novēršanai Latvijas dzelzceļā” // Rīgas domes Satiksmes departamenta starptautiskais konkurss „Par labāko doktorantu, maģistrantu, studentu un skolēnu pētniecisko darbu saistītu ar Rīgas pilsētas satiksmes problēmām”, Rīga, 2011. g.

Textbook is published:

1. Anatolijs Ļevčenkovs, Andrejs Potapovs, Ivars Raņķis „Programmēšanas tehnoloģijas pamati studiju projektam (EEI345 3 kr. p.)”, RTU – 2011. g., 111 lpp. ISBN-978-9934-10-194-6

PATENTS

The results of the presented research are patented. The following patent certificates:

1. A. Ļevčenkovs, M. Gorobecs, I. Raņķis, L. Ribickis, P. Balckars, A. Potapovs „Vilcienu pretsadursmju iekārta ar satelītu navigāciju”, patent No. LV14384B of 26.05.2011.;
2. A. Ļevčenkovs, M. Gorobecs, I. Raņķis, L. Ribickis, P. Balckars, A. Potapovs, I. Alps, I. Korago, V. Vinokurovs „Iekārta drošai autotransporta pārbrauktuvju šķērsošanai izmantojot satelītu navigācijas sistēmas”, patent No. LV14405B of 20.09.2011.;
3. A. Potapovs, A. Ļevčenkovs, M. Gorobecs, S. Holodovs, I. Birjuļins „Vilcienu automātiskas laidenas un precīzas bremzēšanas iekārta”, patenta pieteikuma No. P-13-43 of 03.04.2013.

Kā arī tika iegūta Eiropas patentu valdes apliecība par veikto pētījumu novitāti:

A. Ļevčenkovs, M. Gorobecs, I. Raņķis, L. Ribickis, P. Balckars, A. Potapovs, I. Alps, I. Korago, V. Vinokurovs „Device for safe passing of motor vehicle over level crossings using satellite navigation systems”, patent No. WO/2013/013728 A3 of 20.05.2014.

STRUCTURE OF THE THESIS

The thesis is devoted to the investigation and development of the transport control system applying adaptive control algorithms and embedded intelligent devices. The introduction contains the basis of the topicality of the subject in accordance with which the aim and objectives of the thesis are determined.

The 1st chapter of the thesis is devoted to the investigation of the control system of the present rolling-stock unit of railway transport, description of adaptive, accurate and soft braking systems (*APBS*) elements and scheme of their interaction, general algorithm of this system operation as well as to the developed target function and hypothesis.

The 2nd chapter of the thesis contains the development of adaptive self-learning algorithm for the rolling-stock physical motion parameters determining, investigation and development of adaptive searching algorithm for the motion parameters calculation, development of the mathematical model of rolling-stock motion and development of automatic control algorithm for train braking system and its description.

The 3rd chapter of the thesis is devoted to the analysis of microprocessor devices application safety requirements in the railway control systems, to the development and application of embedded intelligent devices interface, elaboration of electric circuit of the suggested system and the computer model of interaction of the elements.

The 4th chapter considers the examining of the developed mathematical and computer model in laboratory and then of the prototype under real operation conditions.

The experimental results are statistically analysed in the 5th chapter.

The final part of the thesis are the conclusions and recommendations for further research.

ELEMENTS OF RAILWAY TRANSPORT ADAPTIVE, ACCURATE AND SOFT BRAKING SYSTEM (*APBS*) AND DESCRIPTION OF THEIR INTERACTION SCHEME

The author of the promotional paper suggests to describe the systems *APBS* under consideration at different levels distinguishing the existing elements of the railway transport control systems and those which are suggested to apply. *APBS* system description is realised applying separate definitions of mechanical and electrical elements of the system. The first level contains basic existing elements of the railway rolling stock control system. The system contains:

- GVC – basic control centre;
- $DC = \{Dc_1, Dc_2, ..., Dc_n\}$ – dispatcher centre;
- $ST_i = \{St_1^i, St_2^i, ..., St_{m_i}^i\}$ – stations;

  where $i = \overline{1,n}$ – index of the dispatcher centre, m_i – number of the stations, i – control of that dispatcher centre.
- $PB_i = \{Pb_1^i, Pb_2^i, ..., Pb_{q_i}^i\}$ – crossings,

  where $i = \overline{1,n}$ – index of the dispatcher centre, q_i – number of the crossings, i – control of that dispatcher centre.
- $RSO_i = \{Rso_1^i, Rso_2^i, ..., Rso_{k_i}^i\}$ – objects of the rolling stock,

  where $i(t) = \overline{1,n}$ – index of the dispatcher centre changing in time t according to the rolling stock.

Among the defined elements of the system information flows exist providing functioning of these elements and their interaction. The interaction of these elements as well as their functioning are closer described in [106, 107, etc.].

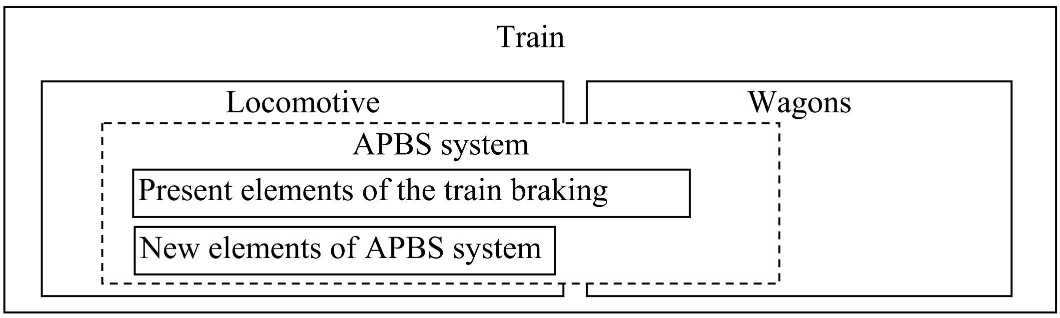

Fig. 1. General integration scheme of *APBS* system of the train

Figure No. 1. demonstrates principal scheme of *APBS* embedding into the present braking control system of the train. For the detail description of *APBS* the author divides the elements of this system into two following basic groups:

- Present elements of the train braking control system (the elements included into the control system before the application of *APBS* system);
- *APBS* system new elements (the elements included into the control system after the application of *APBS* system).

APBS system elements suggested by the author are divided into the following basic functional modules groups (the functions of the suggested elements are available in the promotional paper version):

Electrical blocks (in Fig. 2. marked with yellow):

- *ADIIM* – module of the analogue and digital input/output;
- *BB* – module of the supply block;
- *BSM* – module of the wireless connection;
- *GPM* – module of the global positioning;
- *IIM* – module of the information output;
- *DGM* – module of the data storage;
- *MKTVM* – control module of the driver controller;
- *MKKM* – control module of the driver valve position;
- *EPVM* – module of electric pneumatic valve (electric part);
- *AMN* – analogue manometer (electric part);
- *GKM* – module of the basic controller.

Mechanic and pneumatic blocks (in Fig. 3. marked with yellow);

- *BMP* – new parts of braking main and their connections (in the figure they are marked with dash line);
- *EPVM* – module of electric pneumatic valve (mechanical part);
- *AMN* – analogue manometer (mechanical part);
- *DrVM* – module of safety valve;
- *AVM* – module of emergency valve.

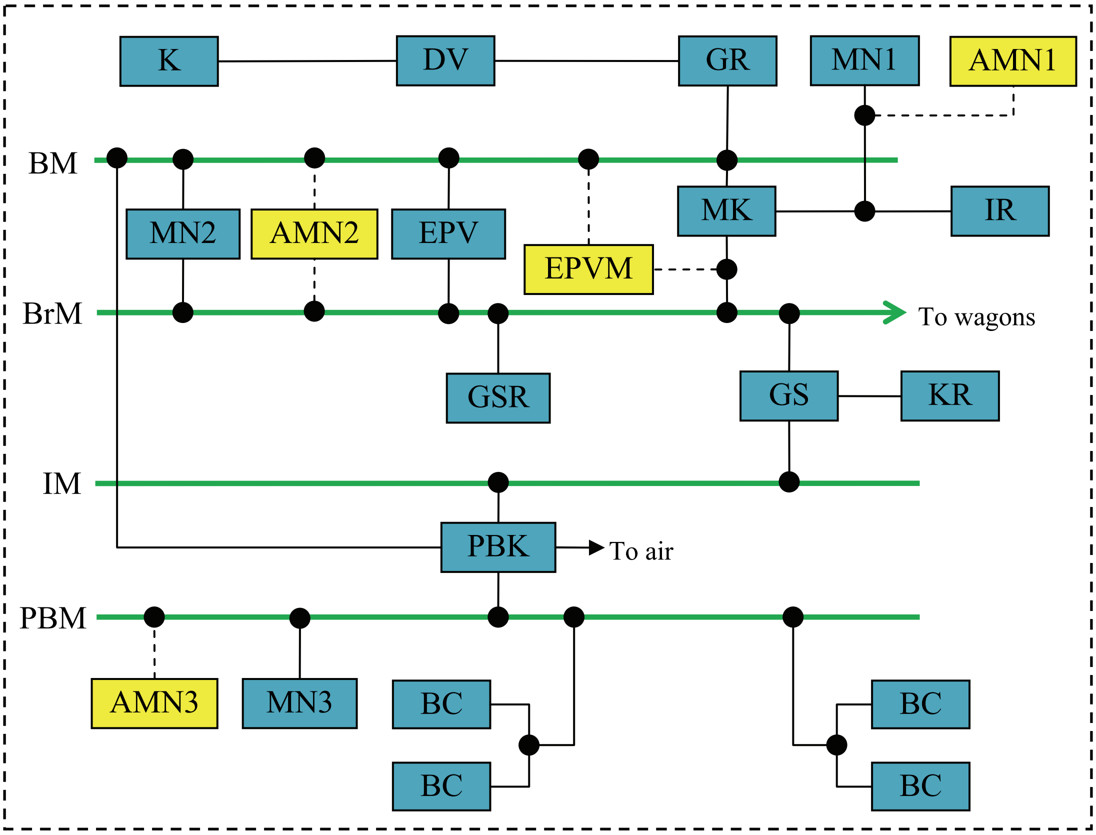

Fig. 2. General block scheme of APBS system electric elements

The basic part of the fourth system elements contains *PLC* control program, that applies *PLC* functioning algorithm. The basic components of this program are the following:

- Initialising subprogram;
- Subprogram of global positioning data processing;
- Subprogram of wireless connection data exchange processing;
- Subprogram of *PLC* input information;
- Subprogram of the obtained data processing applying adaptive control algorithms with its self-learning elements;
- Subprogram of PLC outputs control (including such peripheral control elements as text display).

Subprogram of adaptive data processing provides application of adaptive searching algorithm giving a possibility to realise more effective self-learning during its functioning time analysing the work of driver with braking system and generating of the control signals for the outside actuating device.

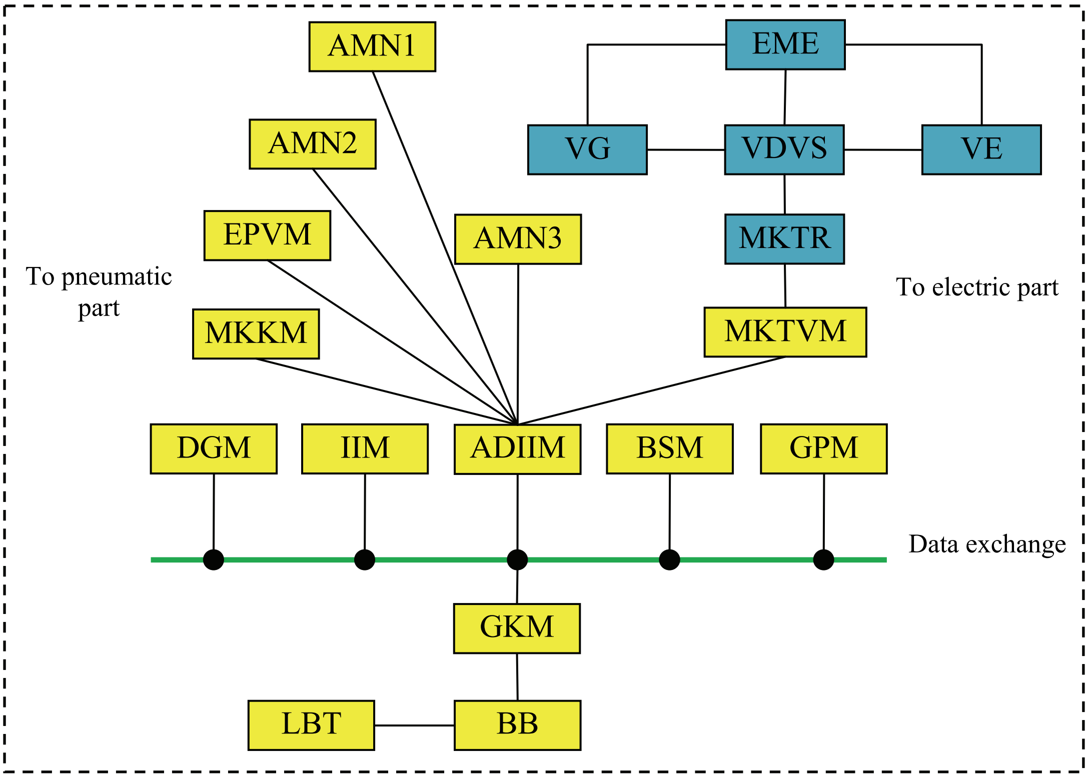

Fig. 3. General block-scheme of mechanic and pneumatic components of APBS system

Target function and suggested hypothesis

Such statement has been assumed that applying *APBS* system allows to improve and automate braking process of the railway transport.

APBS target function of the system operation is expressed as a set of separate criteria. The most important criteria of the task solution are the following:

- S_{obj} – distance to the object in from of which it is necessary to stop or achieve a preset speed;
- $BM_{gs\_\max}$ – braking main maximum air pressure BM_{gs} criterion (determines BM_{gs} value);
- $BM_{gs\_izm\_atr}$ – braking main air pressure BM_{gs} changing speed criterion (determines BM_{gs} value);
- $V_{vilc\_\max}$ – criterion of the maximum speed of the train (determines maximum speed of the train at the present segment of the way under particular operation conditions);
- t_{adapt} – *APBS* criterion of the system adaptation time (determines how long *APBS* the system can define parameters after data input).

In accordance with particular criteria the target function of the task is

$$S_{obj} = GKM_1(DP_{in}, DR_{in}, DGKM_{out}) \xrightarrow[\Omega]{} \min . \qquad (1)$$

The set of the target function restrictions is

$$\Omega:\begin{cases} V_{beig} = V_{merk} \\ BM_{gs} \le BM_{gs\_\max} \\ BM_{gs\_izm\_atr\_\min} < BM_{gs\_izm\_atr} < BM_{gs\_izm\_atr\_\max} \\ BM_{gs} \\ V_{vilc} \le V_{vilc\_\max} \\ t_{adapt} \le (t_4 - t_2) \end{cases}, \quad (2)$$

where V_{beig} – is an actual V speed of the train after the finishing of the braking process, V_{merk} – preset V speed of the train after the finishing of the braking process, $BM_{gs\_\max}$ – maximum acceptable air pressure in the braking main BM, $BM_{gs\_izm\_atr\_\max}$ – maximum speed of changing of the air pressure in the braking main BM, $BM_{gs\_izm\_atr\_\min}$ – minimum speed of changing of the air pressure in the braking main BM realising service brake application and t_{adapt} – $APBS$ adaptation time of the system.

Function of the adaptive algorithm quality evaluation is also determined as a separate set of criteria. Important criteria are the following:

- M – criterion of the error determination of an average wagon mass of the train;
- N – criterion of the error determination of the train number of wagons;
- K – criterion of the error determination of force pressure for one braking block.

Function for the evaluation of adaptive algorithm quality is

$$Q = \begin{cases} M = |\, m_{vag} - m_{vag\_f} \,| \longrightarrow \min \\ N = |\, n_{vag} - n_{vag\_f} \,| \longrightarrow \min \\ K = |\, k_k - k_{k\_f} \,| \longrightarrow \min \end{cases}, \quad (3)$$

where m_{vag_f} – actual mass of wagon, n_{vag_f} – actual number of the wagons and k_{k_f} – actual force pressure for one brakin block.

Normalized function for the evaluation of adaptive algorithm quality is

$$Q = \alpha_1 M' + \alpha_2 N' + \alpha_3 K' \longrightarrow \min, \quad (4)$$

where α_1 – the factor of criterion of error determination of the train wagons number, α_2 – the factor of criterion of error determination of the train average wagon mass, α_3 – the factor of the error determination of force pressure for one braking block, $M' = \dfrac{M_{\max} - M}{M_{\max} - M_{\min}}$ – criterion of the error determination of the train average wagon mass, $N' = \dfrac{N_{\max} - N}{N_{\max} - N_{\min}}$ – normalized criterion of the error determination of the number of train wagons and $K' = \dfrac{K_{\max} - K}{K_{\max} - K_{\min}}$ – normalized criterion of the error determination of the force pressure for one braking block.

Besides the following connection takes place

$$\alpha_1 + \alpha_2 + \alpha_3 = 1 . \qquad (5)$$

The author of the paper suggests to apply the law of normal distribution for the calculations of normal error probability and iteration of adaptive searching algorithms target function calculation as a simple and acceptable from the time point of view. Normal distribution is one of the most important distributions of probability as the state is proved that about 68 % of all the elements are at the same standard distance from that average, about 95 % of all the elements are at the two standard distances from the arithmetic average, but 99.7 % of all the elements are at three standard distances [103].

Analysing the developed criteria for the target function the author of the paper suggests the following basic hypotheses:

- APBS system can determine parameters of the train and its braking system:
  H01 hypothesis: $m_{vag\_teor} = m_{vag\_fakt}$, $n_{vag\_teor} = n_{vag\_fakt}$, $k_{k\_teor} = k_{k\_fakt}$;
  H11 hypothesis: $m_{vag\_teor} \neq m_{vag\_fakt}$, $n_{vag\_teor} \neq n_{vag\_fakt}$, $k_{k\_teor} \neq k_{k\_fakt}$.
- APBS system can automatically stop the train as close as possible to the preset stop point:
  H02 hypothesis: $X_{apst\_teor} = X_{apst\_fakt} \pm kluda$;
  H12 hypothesis: $X_{apst\_teor} \neq X_{apst\_fakt} \pm kluda$.
- The selected adaptive searching algorithms (see Chapter 2.3. of the promotional paper) are more effective than ordinary algorithms and can determine minimum of the target function with lower number of iterations i_{sk}:
  H03 hypothesis: $i_{sk}^{adapt} < i_{sk}^{parlas}$;
  H13 hypothesis: $i_{sk}^{adapt} \geq i_{sk}^{parlas}$.
- Number of searching iterations and expected error for algorithm No. 2. will be lower than algorithms No. 3. and No. 4.:
  H04 hypothesis: $i_{sk}^{2.algoritms} < i_{sk}^{3.algoritms}$;
  H14 hypothesis: $i_{sk}^{2.algoritms} \geq i_{sk}^{3.algoritms}$;
  H05 hypothesis: $i_{sk}^{2.algoritms} < i_{sk}^{4.algoritms}$;
  H15 hypothesis: $i_{sk}^{2.algoritms} \geq i_{sk}^{4.algoritms}$.

DEVELOPED OPERATIONAL ALGORITHMS OF *APBS* SYSTEM ELEMENTS

APBS – general operational algorithm of the system consists of the following sub-algorithms and functions:

- *RVMA* – the algorithm of the rotating units interaction with other elements in accordance with which data exchange is provided among particular *APBS* and other railway system elements (other *APBS*, *GVC*, *DC*, *ST*, *PB* etc.);
- *APA* – adaptive self-learning algorithm according to which the process of determining of the train variables physical parameters is provided (for more information see Chapter 2.2 of the promotional paper);

- *AMA* – adaptive searching algorithm according to which the process of determining of the train variables physical parameters is provided within a limited time interval (for more information see Chapter 2.3 of the promotional paper);
- *NA* – the algorithm of the evaluation of modelled parameters accuracy, that evaluates *AMA* the value of the parameters comparing them with actual;
- *BSAVA* – the algorithm of automatic control of the train braking system that is used *EPVM* according to *APBS* the control signals and norms of the railway transport control (for more information see Chapter 2.5 of the promotional paper);
- *VKM* – the model of train motion that provides the theoretical data modelling *APA* and *AMA* during its functioning (in more details described in Chapter 2.4 of the promotional paper).

Flow-chart of these sub-algorithms and functions interaction is given in the following figure.

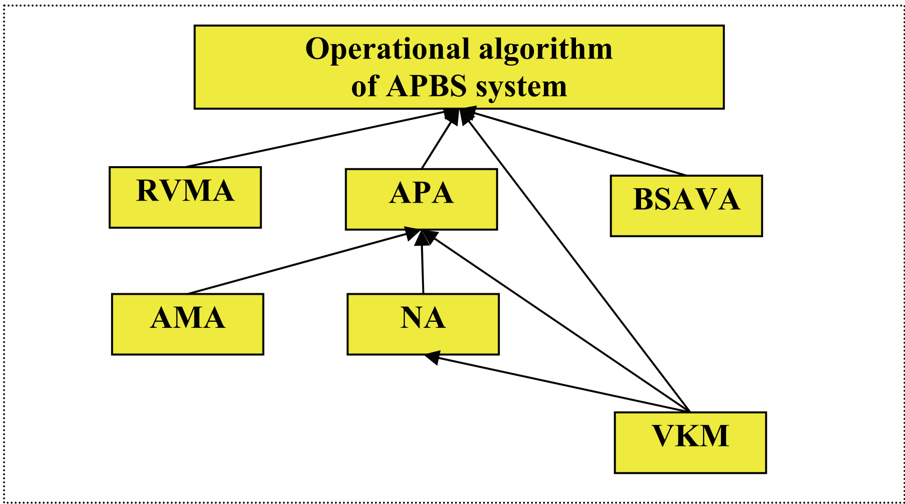

Fig. 4. General structure of APBS system's operation algorithm

APBS system is functioning in two basic regimes:

1. *APBS* self-learning and adaptation of the algorithm;
2. Automatic control of the train braking with the help of *APBS* system.

APBS system general operational algorithm contains the following basic steps:

1. Step – when voltage is supplied *APBS* of the system *GKM* is switched on;
2. Step – when *GKM* is switched on the following functions are activated:
   - The presence of the signal of the global positioning system is examined using *GPM* ;
   - The presence of the wireless connection is examined using *BSM* ;
   - Obtaining of the signals from outside sensors is checked (*AMN* , *MKTVM* , *MKKM*);
   - The information is input into *IIM* about the determined data at the previous points.
3. Step – if the data from the previous steps are correct *APBS* continues its operation mode, if not step No. 1. is repeated. 1. If after more experiments in step No. 1. all the described data are not obtained, *APBS* system is switched off and *IIM* obtains error information.

4. Step – using the information from data base DB, GKM defines the following train identification parameters:
   - $DINIT$ – identification number of the train (n), number of the train type (n), number of the route (sector of the way) (n).
5. Step – using $APBS$ system's outside sensors (GPM, $MKTVM$, $MKKM$ and AMN), the service of the data set fixation of the following parameters for data base formation:
   - $V_{vilciena}(t)$ – speed of the train (km/h);
   - $X_{vilciena}(t)$ – geographic latitude of the train location (˚);
   - $Y_{vilciena}(t)$ – geographic longitude of the train location (˚);
   - $VRN(t)$ – number of the train regime (n);
   - $BRN(t)$ – number of the braking regime (n);
   - $BrM_{gs}(t)$ – air pressure in the braking main BrM (atm);
   - $BM_{gs}(t)$ – air pressure in the supply main BM (atm);
   - $BC_{gs}(t)$ – air pressure in the locomotive braking cylinders BC (atm);
6. Step – from data base DB using the electronic route maps $MKRT$ and data about the train location from the previous step the parameters of the present railway sector are defined:
   - i_{prom} – steepness of the railway profile (‰);
   - V_{vilc_max} – maximum speed of the train at the current sector of the way (km/h);
   - N_{cp} – number of the way sector (n).
7. Step – the control centre GVC, using the module of the wireless connection BSM, obtains the information about the parameters of the train motion (defined in the algorithm steps No. 4. and No. 5.);
8. Step – using wireless connection module BSM, the main control centre GVC supplies the information about the nearest objects of the railway transport system:
   - VIN_{tuv} – identification number of the nearest train in the route (n);
   - DC_{tuv} – identification number of the nearest dispatcher centre DC in the route (n);
9. Step – using the identification numbers obtained in the previous step of the algorithm with BSM data exchange between the nearest trains is established according to $RVMA$ algorithm that is described in literature [105]);
10. Step – train starts the motion. Further $APBS$ system's general operational algorithm proposes two different functioning plans (driver realises braking after the starting of the motion or not).
11. Step – if the driver realises braking the next step of the algorithm is started, if not then the algorithm realises step No. 13.
12. Step – APA, using AMA, NA and VKM defines physical parameters of the train and it can continue the motion until the next necessity to stop. The algorithm goes to step No. 17.
13. Step – if the driver does not realise the braking then the algorithm checks whether the speed of train $V_{vilciena}$ exceeds the safe value $V_{drosibas}$ of the speed. If yes, then the algorithm goes to the next step.

14. Step – states *BSAVA* realising the automatic operation braking until it is fully completed.
15. Step – at the same time *APA*, using *AMA*, *NA*, *VKM*, defines the physical parameters of the train.
16. Step – *BSAVA* realises the trip of the brakes after the full operation of the brakes is fixed.
17. Step – *APBS* system, using the obtained data, *VKM* and data *MKRT*, constantly theoretically calculates the braking way of the train S_{bremz_teor}.
18. Step – at the same time *APBS* system, using *RVMA*, *GPM*, *MKRT* defines possible distance S_{dist} till the nearest object on the route that requires stop of the train or decreasing of its speed.
19. Step – if $S_{bremz\_teor} > S_{dist}$, the basic *APBS* operational algorithm of the system states *BSAVA* realising automatic operational braking.
20. Step – at this moment the self-learning of the system *APBS* is repeatedly made and the algorithm realises step No. 11. and No. 12.
21. Step – at the moment when the calculated braking way S_{br_2pak} is equal to the distance till the nearest object requiring stop *V* of the train using *BSAVA* (the algorithm of the automatic control of the train braking system) the automatic braking of the train *V* is started.
22. Step – when the train V is fully stop the algorithm continues step No. 7.

The system completes the steps of the described algorithm until *GKM* is switched off from the supply. Full version of the algorithm under consideration is provided in the promotional paper.

DEVELOPMENT OF THE ELECTRIC AND PNEUMATIC SCHEMES OF *APBS* SYSTEM ELEMENTS

In this chapter the author of the promotional paper describes basic schemes *APBS* system elements that are used in the development of *APBS* system devices prototypes.

The paper (Fig. 5.) reflects the scheme of the *IIM* inputs switching that is configuration of *IIM* analogue and digital inputs and the list of the elements connected to it.

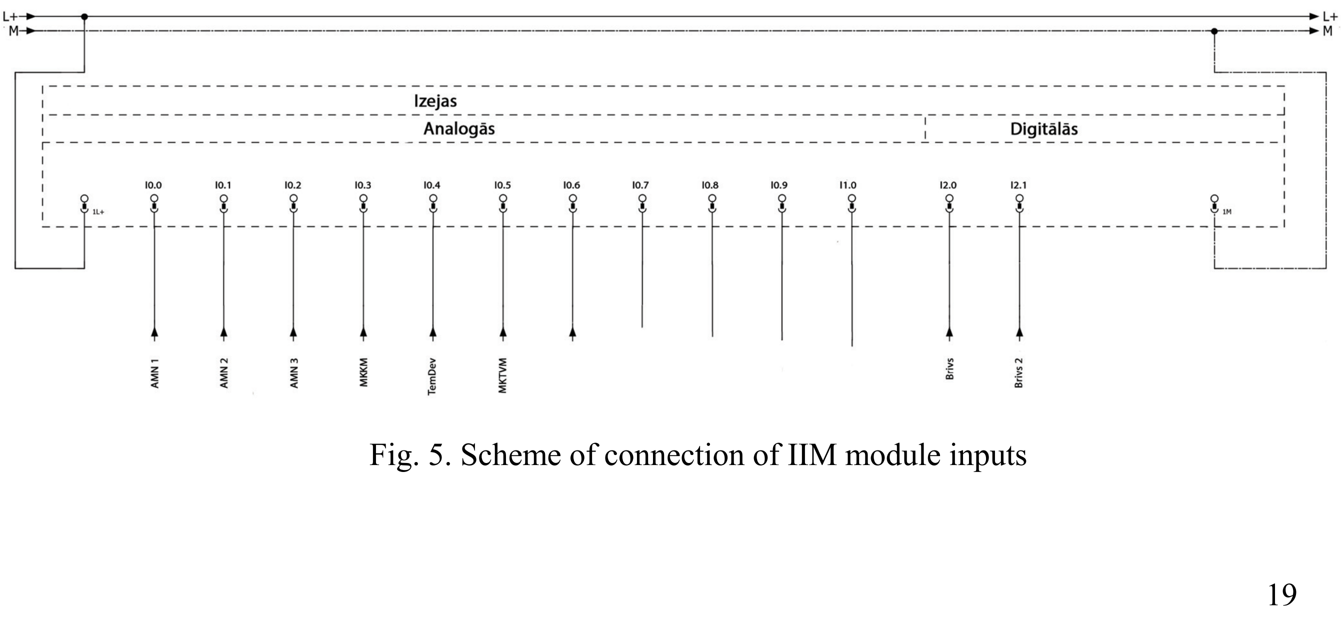

Fig. 5. Scheme of connection of IIM module inputs

In its turn *IIM* outputs connections scheme is Fig. 6. The scheme foresees more electro-pneumatic valves, as well as control relays and connections of *APBS* system lamps of its operation indication.

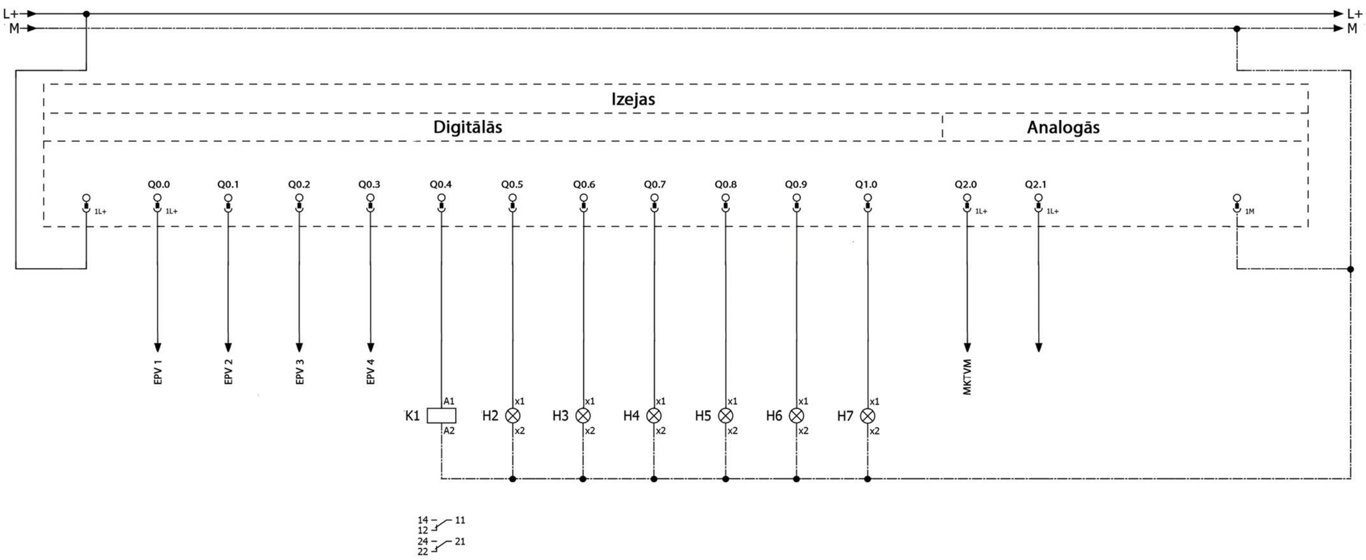

Fig. 6. Scheme of connection of *IIM* module outputs

In its turn Fig. 7. contains the scheme of device *SAFE-R 5* for the control of locomotive *M-62* pneumatic braking with the aim to realise the emergency braking regime. With the help of relay R1 the emergency braking is started, relay R2 opens the supply circuit.

Further Fig. 8. scheme of the pneumatic elements is given, according to which the prototype of *APBS* system device *SAFE-R 5* is switched to the locomotive realising the experimental testing of it under the real conditions. This scheme meets the needs of *M-62* pneumatic brakes control with the following additional elements:

- *V1, V2* – electro-pneumatic valves;
- *18, 19* – safety valves;
- *DRV* – safety valve;
- *AMN* – analogue manometer.

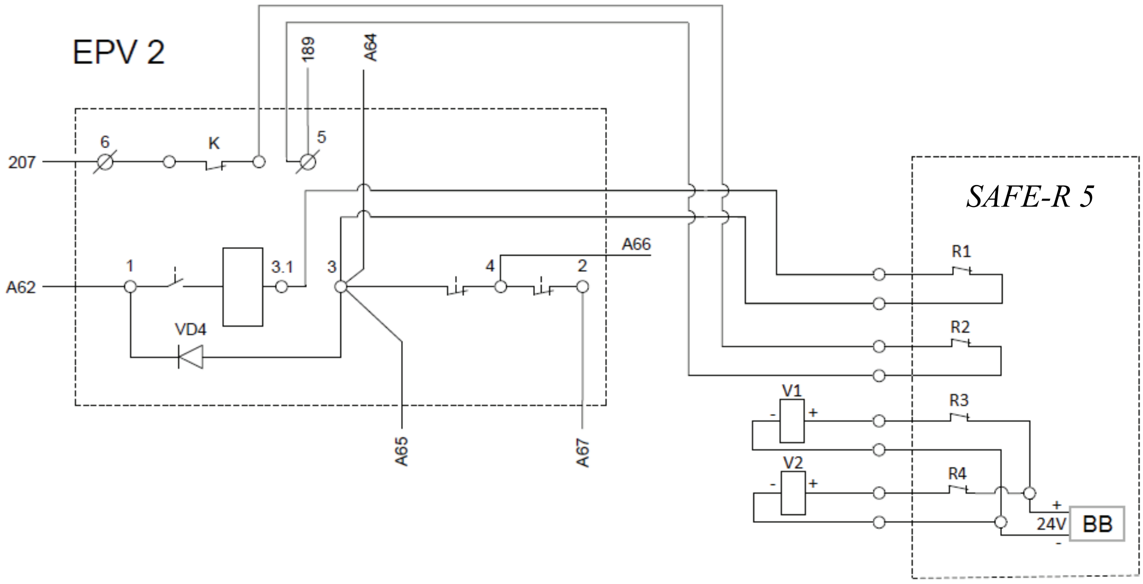

Fig. 7. The scheme of the locomotive *EPV* connection

Because of economic circumstances no possibility was to realise experiments with *APBS* system for a whole train with more wagons therefore the developed circuit is for the control of the locomotive pneumatic braking only as the system is connected in parallel to the auxiliary braking cock *PBK* but not to the driver tap *MK*.

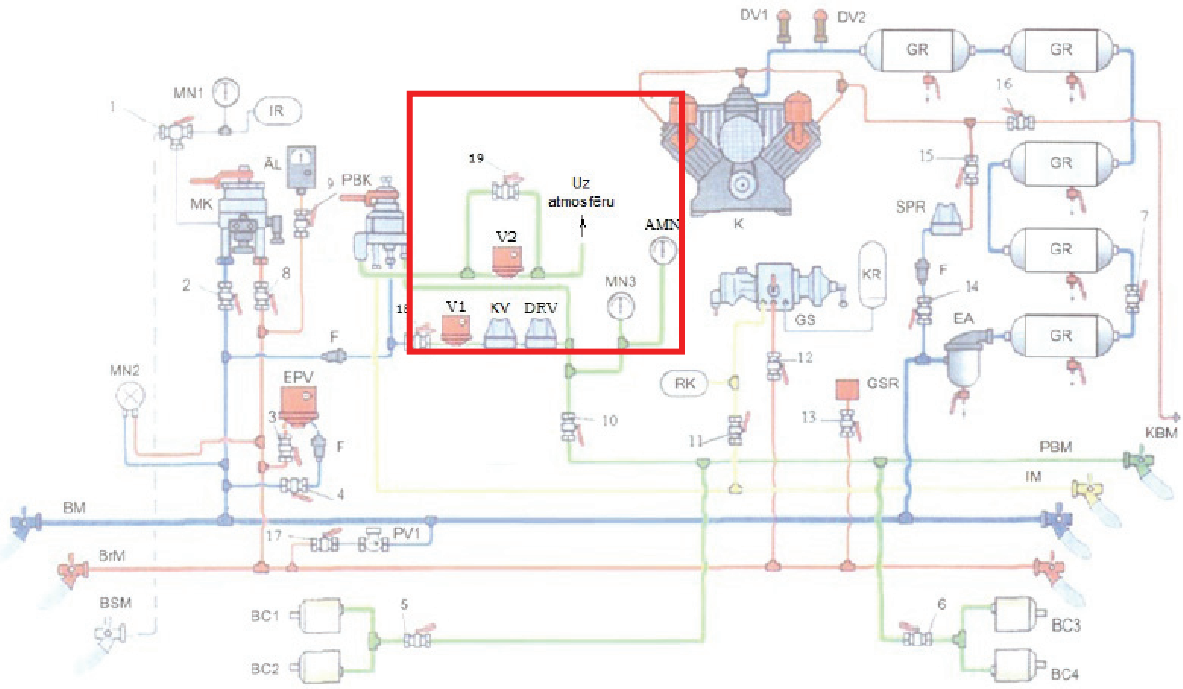

Fig. 8. Scheme of pneumatic *APBS* system elements connection

EXPERIMENTAL TESTING OF THE DEVELOPED *APBS* SYSTEM AND ITS CONTROL ALGORITHM

Testing of the developed *APBS* system operation algorithm under the laboratory conditions

The of this promotional paper describes the experiments under the laboratory conditions in this chapter. In these experiments a *VKM* computer model, the selected adaptive searching algorithms and methods are applied. As a result of the experiments set of data is obtained for the further statistical analysis, the aim of which is to discover the most effective searching algorithms and prove the general ability of *APBS* system functioning.

Table 2 demonstrates the list of algorithms containing the following searching algorithms and methods (in more details it is described in the second chapter of the promotional paper):

1. Algorithm – Reading method;
2. Algorithm – Method with returning in the case of incorrect step;
3. Algorithm – Method of the best experiment;
4. Algorithm – Method of the repeating searching;
5. Algorithm – Genetic algorithm;
6. Algorithm – Method of the case searching with a particular searching radius and random direction;
7. Algorithm – Gauss-Seidel method;
8. Algorithm – Monte-Carlo method.

As it is seen a simple reading method is mentioned as the first type of searching algorithms. This method always gives an opportunity to find a searched minimum of the target function, but it is characterised with high losses of the machine time as the number of iterations of target function calculation is practically maximum possible. The aim of the application of the rest of algorithms is to find minimum of the target function with lower number of iterations.

The following input data are applied in the completed experiments:

- m_{vag_fakt} – average actual mass of a train wagon, t;
- n_{vag_fakt} – actual number of the train wagons, n;
- k_{k_fakt} – average actual pressure force of the braking chocks, kN;
- $V_{vilciena}$ – actual speed of the train, km/h.

For the realization of the mentioned experiments the following values of the input data are selected:

1. Table

Input values of the experiments data

Parameters	Values								
	1.	2.	3.	4.	5.	6.	7.	8.	9.
m_{vag_fakt}	20	40	60	80	100				
n_{vag_fakt}	2	10	20	40	60				
k_{k_fakt}	1	1.4	1.8	2.2	2.6	3	3.4	3.8	4.2
$V_{vilciena}$	20	40	60	80	100				

With yellow colour those parameters values are marked that further are accepted as low, with blue colour – the accepted average values, and with red – the high values.

The total number of the experiments is determined with all possible number of the parameters values combinations taking into account the following exceptions:

- If $3{,}8kN \le k_k$, then $m_{vag} \ge 60t$;
- If $2{,}3kN \le k_k$, then $m_{vag} \ge 35t$.

The result of each experiment is data table (Table No. 2.) containing the following input data (with yellow):

- Number of the algorithm – order number of the tested algorithm facing a particular selected searching algorithm;
- Values $m_{vag\_fakt}, n_{vag\_fakt}, k_{k\_fakt}, V_{vilciena}$ – given values of the train physical parameters;
- S_{br_fakt} – actual braking way of the train calculated in accordance with the selected physical parameters if the train.

The data table contains also the following output data (with blue):

- Values $m_{vag\_\mathrm{mod}}, n_{vag\_\mathrm{mod}}, k_{k\_\mathrm{mod}}, V_{vilciena}$ – modelled values of the train physical parameters;
- S_{br_mod} – modelled braking way of the train calculated in accordance with the modelled physical parameters if the train;
- Number of iterations – number of the target function calculations for the evaluation of the tested algorithm response speed;
- Error – average mean-square error of practical and defined characteristics of the train movement parameters (minimum of the target function);
- Total error – parameter of the evaluation of searching algorithm operation accuracy calculated using S_{br_fakt} and S_{br_mod}.

During the computer experiment MySQL data base if developed. The data base contains 4 basic tables.

The first one contains (Fig. 9.) the data of the completed experiments. The table has combinations of all the values of the modelled experimental parameters used for the each particular experiment. The table contains the following data:

- exp – the order number of the experiment;
- nvag – actual number of the wagons accepted in each experiment;
- mvag – actual mass of the wagons accepted in each experiment
- kbr – actual pressure force of the braking chocks;
- vkmh – initial speed of the train.

Lauks	Tips	Atribūti	Nulle	Noklusēts
exp	int(11)		Nē	0
nvag	int(11)		Nē	0
mvag	int(11)		Nē	0
kbr	double		Nē	0
vkmh	int(11)		Nē	0

Fig. 9. Structure of the experiments data table

exp	nvag	mvag	kbr	vkmh
1	2	20	1	20
2	2	20	1	40
3	2	20	1	60
4	2	20	1	80
5	2	20	1	100
6	2	20	1.4	20
7	2	20	1.4	40
8	2	20	1.4	60
9	2	20	1.4	80
10	2	20	1.4	100
11	2	20	1.8	20
12	2	20	1.8	40

Fig. 10. Fragment of the experiments data table

The second table (Fig. 11.) contains modelling results of each particular experiment reflecting the following braking parameters of the train:

- exp – the order number of the experiment;
- sbr – calculated actual braking way;
- tsag – preparation time of the train braking system (time during which the braking system of the train achieves its maximum braking effectiveness).

Lauks	Tips	Atribūti	Nulle	Noklusēts
exp	int(11)		Nē	0
sbr	double		Nē	0
tsag	double		Nē	0

Fig. 11. Structure of the modelled data table

		exp	sbr	tsag
Labot	Dzēst	629	1734.6904659692	17
Labot	Dzēst	626	116.85075938389	15
Labot	Dzēst	1	93.496147612253	21
Labot	Dzēst	2	317.51723193215	21
Labot	Dzēst	3	695.20703314679	21
Labot	Dzēst	4	1222.3485607473	21
Labot	Dzēst	10	1530.3722961562	21
Labot	Dzēst	800	4069.0737441403	21
Labot	Dzēst	5	1878.4114201995	21
Labot	Dzēst	6	82.334192373692	21
Labot	Dzēst	7	265.06301967427	21
Labot	Dzēst	8	568.53552997764	21
Labot	Dzēst	9	994.08286044612	21
Labot	Dzēst	11	75.790755053279	19
Labot	Dzēst	12	234.63774815703	21

Fig. 12. Fragment of the modelled data table

The third table contains (Fig. 13.) the data about the practical braking characteristics of the train obtained in each experiment. The table contains such values like:

- exp – the order number of the experiment;
- dt – time moment;
- acc – the value of the train deceleration at each particular moment of time;
- vkmh – the value of the train speed at each particular moment of time;
- sp – braking way of the train at each particular moment of time.

Lauks	Tips	Atribūti	Nulle	Noklusēts
exp	int(11)		Nē	0
dt	float		Nē	0
acc	double		Nē	0
vkmh	double		Nē	0
sp	double		Nē	0

Fig. 13. Structure of the data table of the train parameters braking characteristics

exp	dt	acc	vkmh	sp
176	0	0	20	0
176	1	0.00924	19.966736	5.5463155555556
176	2	0.009237738933195	19.93348013984	11.083393372178
176	3	0.0092354801894226	19.900232411159	16.611235708611
176	4	0.0092332237668162	19.866992805598	22.129844821277
176	5	0.0092309696635117	19.833761314809	27.63922296428
176	6	0.0092287178776474	19.80053793045	33.139372389405
176	7	0.0092264684073643	19.767322644183	38.630295346122
176	8	0.040239540263596	19.622460299234	44.080978762576
176	9	0.07267604952614	19.36082652094	49.458986129504
176	10	0.10133409711651	18.996023771321	54.735659399315
176	11	0.12727815236122	18.53782242282	59.885054516766
176	12	0.15127234029977	17.993241997741	64.883177293916
176	13	0.17388945055125	17.367239975757	69.707410620515
176	14	0.17572087534286	16.734644824523	74.355923071771
176	15	0.17763702813293	16.095151523244	78.826798494895

Fig. 14. Structure of the data table of the train parameters braking characteristics

The fourth table (Fig. 15.) contains the data about the operation results of the searching algorithm. In accordance with the fact that all adaptive algorithms have random character more experiments are necessary with the same data for the statistical accuracy obtaining. Therefore value "trial" is introduced that reflects the order number of the experiment within each particular searching algorithm. The table contains the following data:

- exp – the order number of the experiment;
- trial – order number of the particular experiment;
- alg – the order number of the algorithm;
- steor – particular braking way;
- nvag – particular number of the wagons;
- nvag – mass of the wagon;
- kbr – actual pressure force of the braking chocks;
- iterations – number of the calculations of the searching algorithm target function;
- error – average mean-square error of practical and defined characteristics of the train movement parameters (minimum of the target function);
- Total_error – difference of the practical and calculated braking way.

Lauks	Tips	Atribūti	Nulle	Noklusēts
exp	int(11)		Nē	0
trial	int(11)		Nē	0
alg	int(11)		Nē	0
steor	double		Nē	0
nvag	int(11)		Nē	0
mvag	int(11)		Nē	0
kbr	double		Nē	0
iterations	int(11)		Nē	0
error	double		Nē	0
Total_error	double		Nē	0

Fig. 15. Structure of the results data table

exp	trial	alg	steor	nvag	mvag	kbr	iterations	error	Total_error
31	1	5	116.81259372711	4	40	1.4	101	5.9426154167747e-026	0
46	10	5	90.232626988203	7	40	2.6	101	6.75116629019e-026	0
48	10	5	677.29039106487	4	40	2.6	101	6.638028490252e-024	0
50	8	5	1916.6809365921	13	40	2.6	101	7.5209424413032e-024	-2.2737367544323e-013
51	7	5	181.21720076483	4	60	1	101	1.5788073224907e-024	0
89	1	5	1369.1159847801	13	60	3.8	101	7.1441698511952e-024	0
92	5	5	317.98890953165	12	60	4.2	101	5.9221607268189e-024	0
98	3	5	2218.7739739594	4	80	1	101	7.4853736497199e-024	0
113	3	5	1319.400714267	12	80	2.2	101	6.4513171046719e-024	2.2737367544323e-013
117	10	5	506.89506803425	12	80	2.6	101	6.5144095687828e-024	0
125	10	5	3229.9617197709	3	80	3	101	5.5545349789069e-024	4.5474735088646e-013
139	8	5	1650.0949929511	12	80	4.2	101	8.0083593998001e-024	4.5474735088646e-013
9	9	5	994.08286044612	11	20	1.4	201	6.0703414636609e-024	0
16	4	5	71.559948730869	2	20	2.2	201	1.0314262658532e-025	0
17	9	5	214.59265636532	2	20	2.2	201	3.392496322903e-024	0
34	6	5	1787.6680512332	9	40	1.4	201	7.9278097594011e-024	0
36	10	5	104.3076422113	12	40	1.8	201	5.5134750843345e-026	-1.4210854715202e-014
52	6	5	737.86487634839	12	60	1	201	3.138231464793e-024	0
60	8	5	4031.6082724913	11	60	1.4	201	6.0585855429069e-024	-2.7284841053188e-012

Fig. 16. Fragment of the results data table

Examining of the developed prototype in the real conditions

APBS system's prototype examining in the real conditions runs in more steps, testing different *APBS* system operational functions and units of the prototyps with separate experiments. Among the functions those *APBS* system basic (adaptive and accurate braking of the train) as well as additional are tested (e. g. braking of the train in the emergency regime).

The prototype is examined using JSC LDz equipment and those at station *„Bolderāja"* in the real conditions with locomotive *M62* and track machine *ADM1*.

In these experiments the prototypes of the devices $SAFE-R5$, $SAFE-R6$ and $SAFE-R7$ are utilised with the names historically came from the previous investigations of RTU scientists, but the functions of each of them (being defined with the number in the name of the device) are significantly changed or improved (the development and functions of the previously developed equipment is described in literature [106, 107]).

The prototypes contain as *GKM Siemens* programming controllers and peripheral devices.

The connection of *PLC* central processor to the computer is realised with *PC/PPI* cable, *USB/PPI* (*Universal Serial Bus /Programmable Peripheral Interface*) cable, communication processors *CP 5511*, *CP 5611*, *PCMCIA – Personal Computer Memory Card International Association* – card, *PCI* – Peripheral component interconnect – card with *IMP* cable embedded into *SIMATIC* interface.

Fig. 17. *Pneumatic part of the SAFE-R 5* prototype device connection to the locomotive *M62*

Experiments under the real operation conditions

Further in the promotional paper this experiment is assigned with order No. 1.

In accordance with testing program [102] experiment No. 1. is made $SAFE-R5$, $SAFE-R6$ and $SAFE-R7$ prototypes. They correspondingly realise blocks $PLC1$, $PLC2$ and $PLC3$ seen in Fig. Fig. 18. During the time of the experiment the fact is examined whether all the mentioned prototypes interacting with each other can realise the following basic functions:

- Ability to stop the locomotive automatically in front of the switching off traffic light applying extreme braking regime. The stop point of the locomotive is foreseen at the distance of 50 m from the input traffic light of *„Bolderāja"* station;
- Ability to stop the locomotive automatically in front of a track machine applying extreme braking regime. The stop point of the locomotive is foreseen at the distance of 150 m from the track machine;
- Ability to stop the locomotive automatically in front of the input traffic light of *„Bolderāja"* station applying extreme braking regime.
- Ability to stop the track machine automatically in front of the locomotive applying extreme braking regime.
- Ability to provide inter exchange of data using *GSM* connection channel;
- Ability to determine variable in the space of situation using *GPS*, etc. functions.

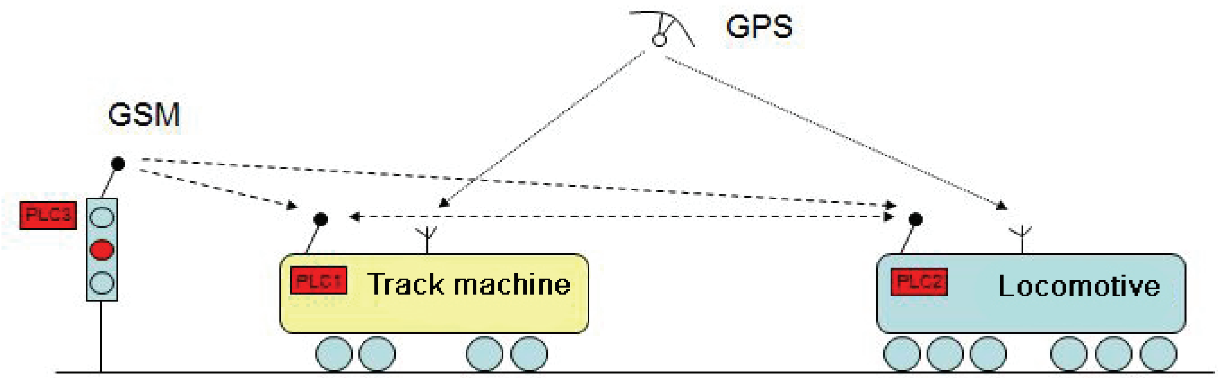

Fig. 18. Experiment No. 1. principal scheme

APBS system device $SAFE-R5$ prototype is electrically connected to the locomotive using scheme (see supplementary material No. 2.). For the opportunity to use the locomotive voltage 75V DC the $SAFE-R5$ prototype is especially provided with a converter the input voltage of which is from 48V DC to 110V DC but the output voltage meet the regular *PLC* operation voltage 24V DC. The connection of the $SAFE-R5$ prototype control relay to the locomotive *EPV* control system is realised by means of scheme (see supplementary No. 3.). Regularly closed contacts of relay R1 are used for this connection No. 11. and No. 12. The connection of the $SAFE-R5$ prototype to the locomotive is realised in accordance with testing program point 3.1. (see [102]), but after the connection readiness is tested in accordance with testing program instruction point 4.1.

Device $SAFE-R6$ prototype is electrically connected to the track machine using scheme (see supplementary material No. 4.). In this no type of converters are used as it can cause connections to the voltage of track machine with value of 24V DC. The connection of the $SAFE-R6$ prototype control relay to the track machine *EPV* control system is realised by means of scheme (see supplementary No. 5.). Regularly closed contacts of relayR1 are used for this connection No. 11. and No. 12. The connection of the $SAFE-R6$ prototype to the track machine is realised according to the testing program instruction point 3.2, but readiness after the connection – according to the testing program instruction point 4.2.

In its turn system device $SAFE-R7$ prototype is electrically connected to the locomotive using scheme (see supplementary material No. 6.). Standard power supply block *„LOGO!POWER"* of *Siemens* production is connected in the relay enclosure *ESD* No. 2. to the socket with voltage 220V AC. Device $SAFE-R7$ prototype inputs are connected to the correspondent relay contacts using scheme (see supplementary material No. 6.). When the yellow colour of traffic light is on a signal is supplied to the device $SAFE-R7$ prototype PLC input 11.0 that means permission of motion. When the red colour of traffic light is on the signal is supplied to PLC input 10.7 restricting the motion. Connection of the device $SAFE-R7$ prototype in relay enclosure ESD No. 2. is realised according to the testing program instruction point 3.3, but readiness after the connection – according to the testing program instruction point 4.3.

Realisation of the experiment

When the prototype has been installed and its functions have been tested the locomotive leaves "Bolderāja" station and runs away from its input traffic light for a pre-set distance (see table of results No. 1.). So does the track machine. When both vehicles are situated at the experimental initial points the examining of the $SAFE-R5$, $SAFE-R6$ and $SAFE-R7$ prototypes functioning starts.

The track machine starts movement in the direction to the "Bolderāja" station traffic lights. Coming closer to the traffic light $SAFE-R6$ prototype at a particular moment of time using lamp No. 2. (see Fig. 20.) and text display $TD400C$ starts generating an emergency signal that defines the necessity of braking process start. Then when the driver ignores the signal contacts of the $SAFE-R6$ prototype control relay No. 11. and No. 12. are disconnected and the emergency braking process is started (lamp No. 3. is on) when the track machine is stopped at the defined point.

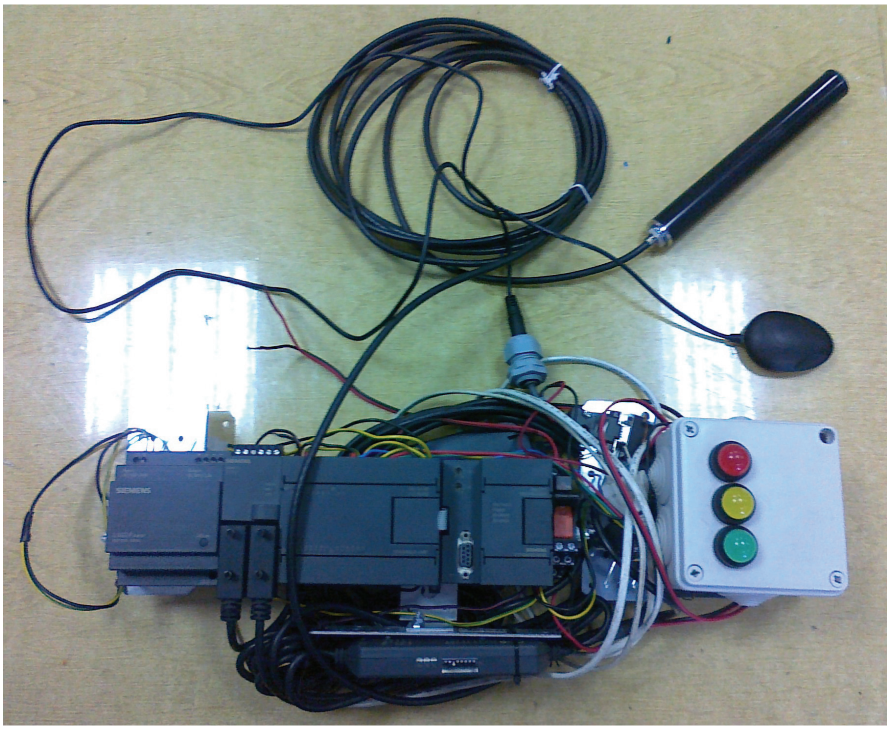

Fig. 19. Device $SAFE-R6$ prototype

After that when the track machine is fully stop the locomotive starts movement in the direction of "Bolderāja" station traffic lights. Being closer to the track machine at the particular moment of time $SAFE-R5$ prototype using lamp No. 8. (see Fig. 20.) and text display $TD400C$ starts generating an emergency signal that defines the necessity of braking process start. Then when the driver ignores the signal contacts of the $SAFE-R5$ prototype control relay No. 11. and No. 12. are disconnected and the emergency braking process is started (lamp No. 9. is on) when the locomotive is stopped at the defined point.

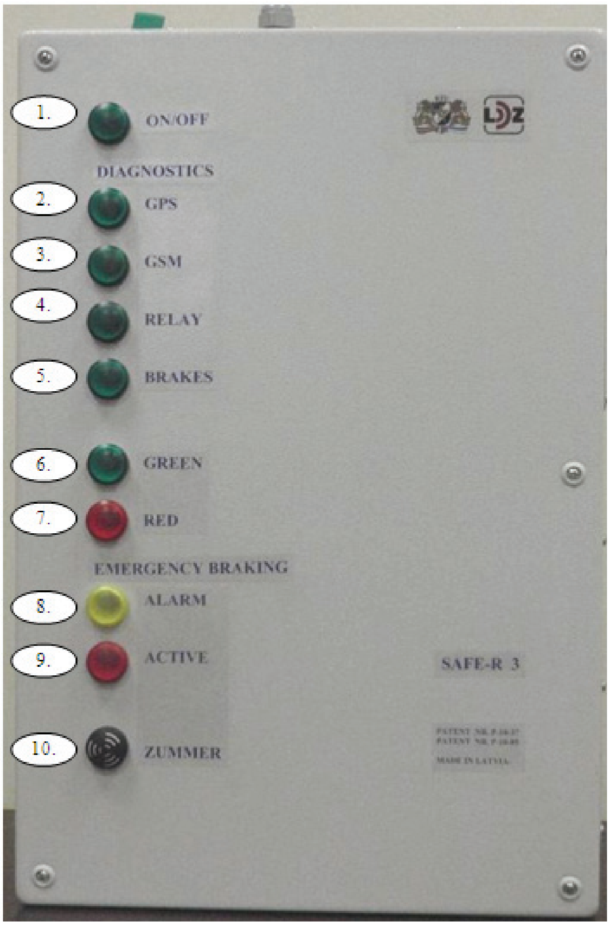

Fig. 20. Front panel of $SAFE - R5$ prototype device

The results of the testing and some notes are given in table No. 2. The development, installation and control process of Siemens two hundred *PLC* control program is described in [46]. The rest of the results are available in promotional paper full version.

2. Table

Experiment No. 1. results

Initial distance of the locomotive from traffic lights, m	**Initial distance of the track machine from traffic lights, m**	**Speed of the track machine, km/h**	**Speed of the locomotive, km/h**	**Distance between the station traffic lights and track machine after its full stop, m**	**Destance between track machine and locomotive after its full stop, m**	**Notes**
600	300	15	15	42	165	
700	400	24	25	76	158	
1100	600	35	35	130	201	
1100	659	35	35	131	219	

1000	600	30	30	289	341	The locomotive and tack machine started movement almost simultaneously
			8		28	run to the locomotive
			28 (decreased to 23)		89	run to the locomotive

STATISTICAL ANALYSIS OF THE TESTING RESULTS

The proposed hypothesis states that the selected adaptive searching algorithms can increase operational speed of APBS system AMA algorithm if to compare with the case when simple reading method is used, that with the given configuration of the input parameters (containing only a part of all possible input parameters, level of its discretion, VKM complexity, etc.) always requires 280000 searching iterations. Such high number of iterations of the searching algorithm is inadmissible for effective operation of APBS system as the accepted maximum iteration number is significantly restricted by the GKM performance and limited time.

For the proving of the searching algorithm operation character 3 different computer experiments are selected from thier total number (experiment No. 5., No. 260. and No. 495.). The results of 10 these experiments are graphically shown in Fig. 21., Fig. 22. and Fig. 23.

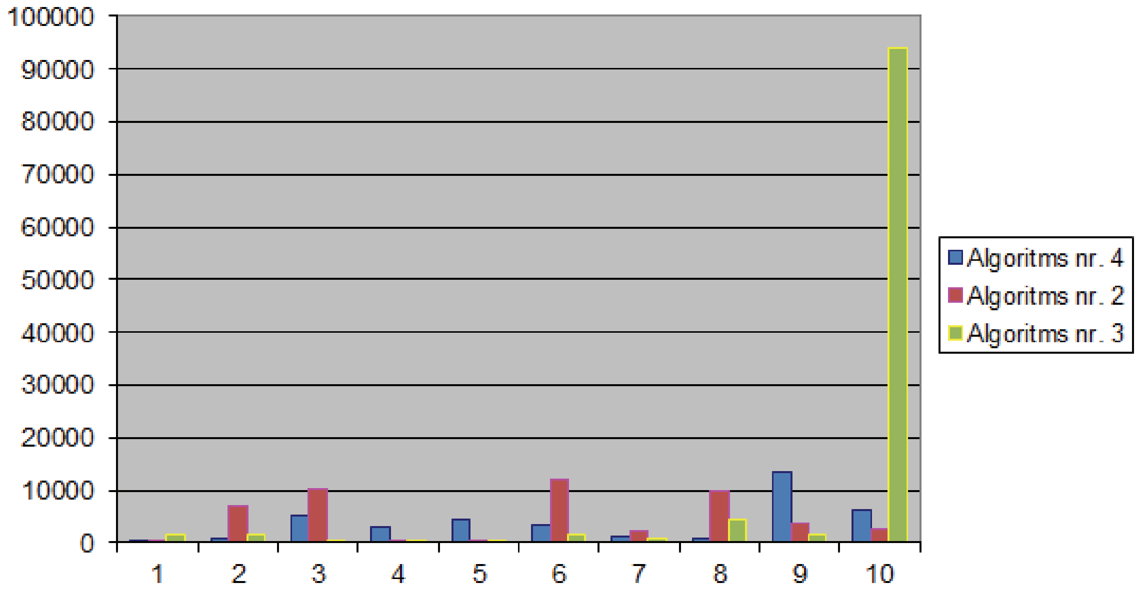

Fig. 21. Experiment No. 5. of each algorithm searching iteration number according to the number of experiment order

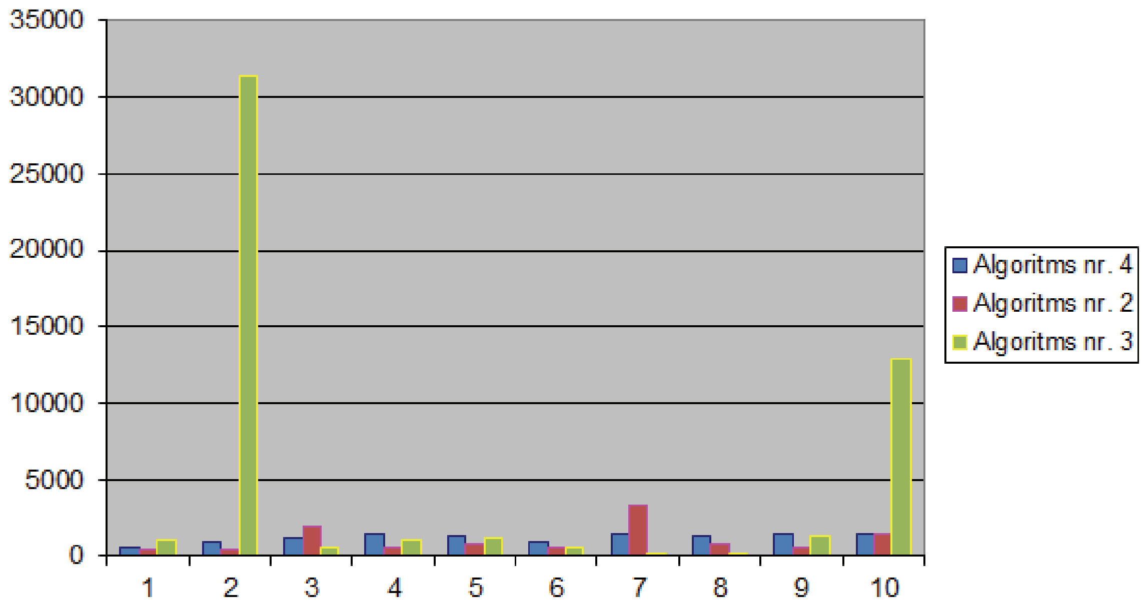

Fig. 22. Experiment No. 260. of each algorithm searching iteration number according to the number of experiment order

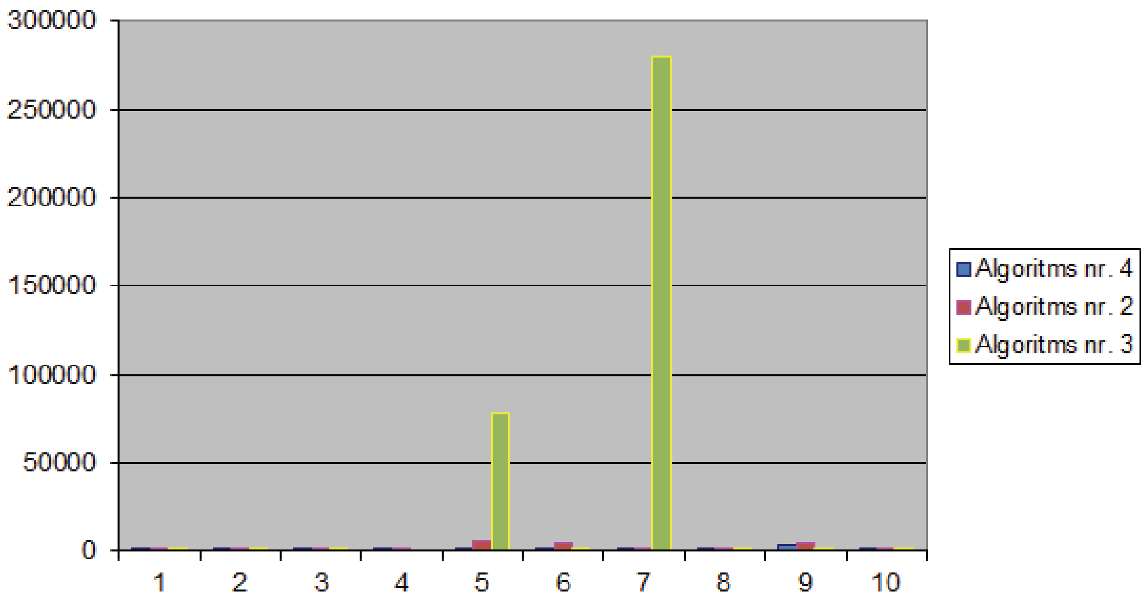

Fig. 23. Experiment No. 495. of each algorithm searching iteration number according to the number of experiment order

The following are the results of the hypothesis Z-testing divided into separate groups of the searched parameters.

3. Table

Table of average experiments results for a long train

No. of alg.	**Iteration**		**Error**		**Difference**	
	Number	Standard deviation	Value	Standard deviation	Value	Standard deviation
2	1530.5	61.6	0	0	0	0
3	5861.8	277.2	0	0	0	0
4	1722.1	60.2	0	0	0	0

Table No. 4. presents the results of searching algorithms operation modelling for the average length of the trains.

4. Table

Table of average experiments results for a train of average length

No. of alg.	Iteration		Error		Difference	
	Number	Standard deviation	Value	Standard deviation	Value	Standard deviation
2	4325.9	202.6	0	0	0	0
3	12947.4	1218.2	0	0	–1.6	0.6
4	4509.5	212.5	0	0	0	0

Table No. 5. presents the results of searching algorithms operation modelling for the long trains.

5. Table

Table of average experiments results for a long train

No. of alg.	Iteration		Error		Difference	
	Number	Standard deviation	Value	Standard deviation	Value	Standard deviation
2	4784.5	357.4	0	0	0	0
3	no	no	no	no	no	no
4	3859.9	247.6	0	0	0	0

Table No. 6. presents the results of searching algorithms operation modelling for the light trains.

6. Table

Table of average experiments results for a train of light vagons

No. of alg.	Iteration		Error		Difference	
	Number	Standard deviation	Value	Standard deviation	Value	Standard deviation
2	5001	309.7	0	0	0	0
3	9455.3	1215.4	0	0	–1.3	0.6
4	4333.3	225.4	0	0	0	0

Table No. 7. presents the results of searching algorithms operation modelling for the average heavy trains.

7. Table

Table of average experiments results for a train of average heavy wagons

No. of alg.	Iteration		Error		Difference	
	Number	Standard deviation	Value	Standard deviation	Value	Standard deviation
2	2967.9	185.9	0	0	0	0
3	7915.4	1094.7	0	0	–0.5	0.3
4	3243.3	213.8	0	0	0	0

Table No. 8. presents the results of searching algorithms operation modelling for the heavy trains.

8. Table

Table of average experiments results for a train of heavy wagons

No. of alg.	Iteration		Error		Difference	
	Number	Standard deviation	Value	Standard deviation	Value	Standard deviation
2	2519.9	135.2	0	0	0	0
3	6254.7	694.4	0	0	–0.4	0.3
4	2681.5	147	0	0	0	0

Table No. 9. presents the results of searching algorithms operation modelling for the low pressure force of the braking chocks of the trains.

9. Table

Table of average experiments results for a train of for the low pressure force of the braking chocks

No. of alg.	Iteration		Error		Difference	
	Number	Standard deviation	Value	Standard deviation	Value	Standard deviation
2	4341.6	226.8	0	0	0	0
3	9941	1062.3	0	0	–1.5	0.6
4	3902.1	177	0	0	0	0

Table No. 10. presents the results of searching algorithms operation modelling for the average high pressure force of the braking chocks of the trains.

10. Table

Table of average experiments results for a train of for the average high pressure force of the braking chocks

No. of alg.	Iteration		Error		Difference	
	Number	Standard deviation	Value	Standard deviation	Value	Standard deviation
2	2693.2	145	0	0	0	0
3	6718.7	728.2	0	0	–0.1	0.1
4	2753.6	132.5	0	0	0	0

Table No. 11. presents the results of searching algorithms operation modelling for the high pressure force of the braking chocks of the trains.

11. Table

Table of average experiments results for a train of for the high pressure force of the braking chocks

No. of alg.	Iteration		Error		Difference	
	Number	Standard deviation	Value	Standard deviation	Value	Standard deviation
2	2438.3	213.5	0	0	0	0
3	4657.7	788.4	0	0	0	0
4	2940.2	273.4	0	0	0	0

Table No. 12. presents the results of searching algorithms operation modelling for the trains with low speed.

12. Table

Table of the average experimental results with low speed of train

No. of alg.	**Iteration**		**Error**		**Difference**	
	Number	Standard deviation	Value	Standard deviation	Value	Standard deviation
2	5589.9	366.8	0	0	0	0
3	7976.5	1272.9	0	0	0	0
4	5446.4	365.5	0	0	0	0

Table No. 13. presents the results of searching algorithms operation modelling for the trains with average speed.

13. Table

Table of the average experimental results with average speed of train

No. of alg.	**Iteration**		**Error**		**Difference**	
	Number	Standard deviation	Value	Standard deviation	Value	Standard deviation
2	2627.8	162.3	0	0	0	0
3	6656.5	824.1	0	0	–0.4	0.2
4	2396.4	97.7	0	0	0	0

Table No. 14. presents the results of searching algorithms operation modelling for the trains with high speed.

14. Table

Table of the average experimental results with high speed of train

No. of alg.	**Iteration**		**Error**		**Difference**	
	Number	Standard deviation	Value	Standard deviation	Value	Standard deviation
2	2942.2	203.4	0	0	0	0
3	8775.6	1303	0	0	–1.9	1.1
4	3327.2	238	0	0	0	0

Further see the graphical summary of the previous data tables

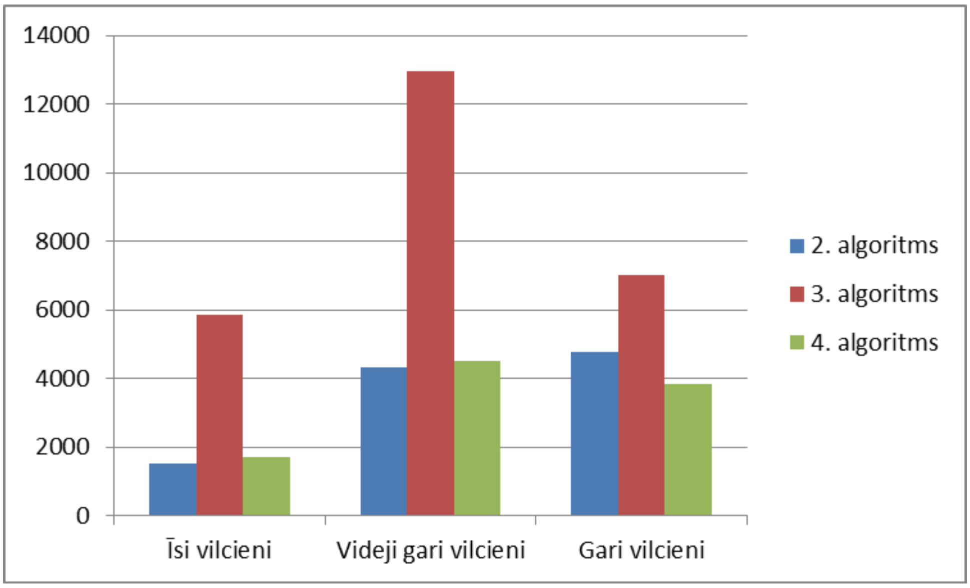

Fig. 24. Distribution of the searching algorithms iteration number according to the length of the train

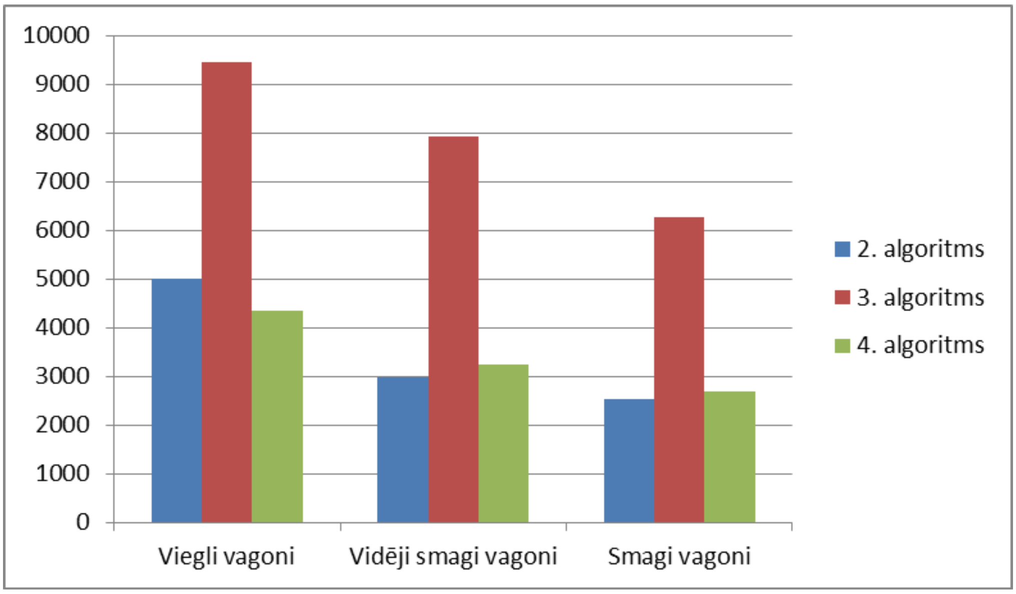

Fig. 25. Distribution of the searching algorithms iteration number according to the mass of the train wagons

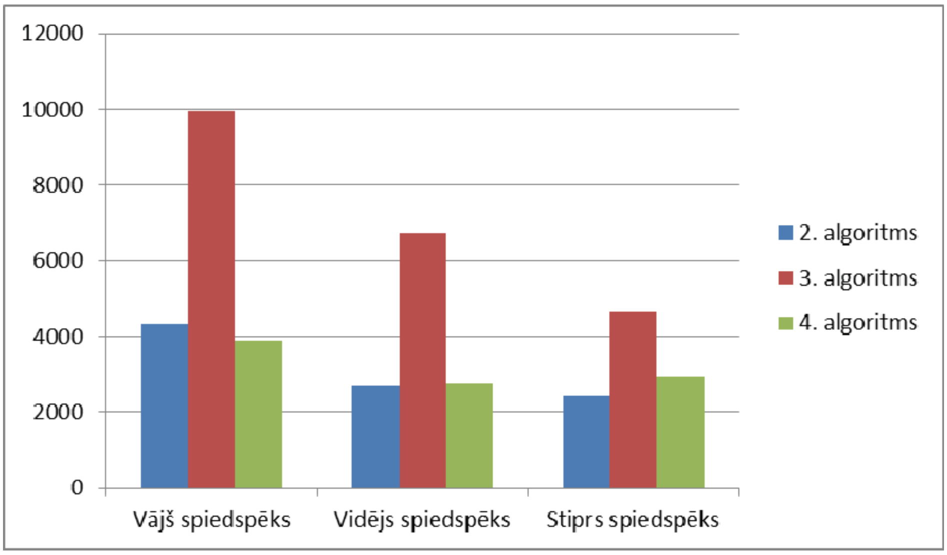

Fig. 26. Distribution of the searching algorithms iteration number according to the pressure force of the braking chocks

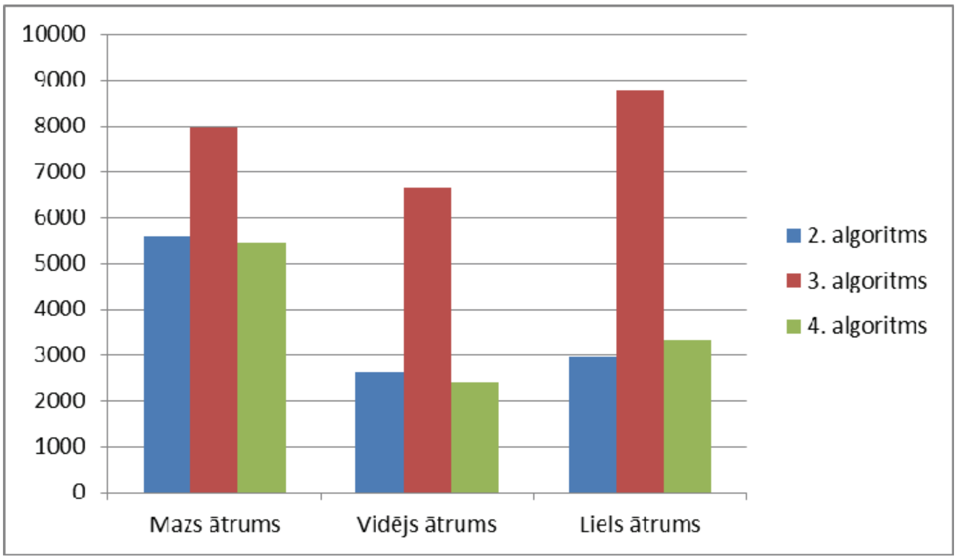

Fig. 27. Distribution of the searching algorithms iteration number according to the speed of the train

The following are the results of the hypothesis Z-testing divided into separate groups of the searched parameters.

The first group contains testing of H03 hypothesis for each of the adaptive searching algorithms searching for the number of the train wagons (Table 15). Results of the hypothesis testing according to the groups of parameters are reflected in the full version of the promotional paper.

15. Table

Results of H03 hypothesis testing searching for the number of train wagons

Criterion	**Level of reliability**	**Interval of testing**	**Examined value**	**Results**
Number of wagons nvag=2 alg=3	99.90 %	(8.619 ; 8.6707)	2	H03 can be rejected with probability of 99.90 %

Number of wagons nvag=2 alg=4	99.90 %	(9.4086 ; 9.4282)	2	H03 can be rejected with probability of 99.90 %
Number of wagons nvag=2 alg=5	99.90 %	(8.3681 ; 8.4146)	2	H03 can be rejected with probability of 99.90 %
Number of wagons nvag=10 alg=3	99.90 %	(8.5863 ; 8.6353)	10	H03 can be rejected with probability of 99.90 %
Number of wagons nvag=10 alg=4	99.90 %	(9.3447 ; 9.3688)	10	H03 can be rejected with probability of 99.90 %
Number of wagons nvag=10 alg=5	99.90 %	(8.3535 ; 8.3968)	10	H03 can be rejected with probability of 99.90 %
Number of wagons nvag=20 alg=3	99.90 %	(20 ; 20)	20	H03 can not be rejected with probability of 99.90 %
Number of wagons nvag=20 alg=4	99.90 %	(14.6608 ; 14.8268)	20	H03 can be rejected with probability of 99.90 %
Number of wagons nvag=20 alg=5	99.90 %	(20 ; 20)	20	H03 can not be rejected with probability of 99.90 %
Number of wagons nvag=40 alg=3	99.90 %	(40 ; 40)	40	H03 can not be rejected with probability of 99.90 %
Number of wagons nvag=40 alg=4	No data	No data	No data	No data
Number of wagons nvag=40 alg=5	99.90 %	(40 ; 40)	40	H03 can not be rejected with probability of 99.90 %
Number of wagons nvag=60 alg=3	99.90 %	(60 ; 60)	60	H03 can not be rejected with probability of 99.90 %

Number of wagons nvag=60 alg=4	No data	No data	No data	No data
Number of wagons nvag=60 alg=5	99.90 %	(60 ; 60)	60	H03 can not be rejected with probability of 99.90 %

CONCLUSIONS

Analysing the results of the thesis one can conclude that finally the aim of the research is achieved. During the work on the promotion paper the following has been made:

1. The analysis of the information given in literature about adaptive control systems and algorithms of their functioning, embedded intelligent devices and present safety systems of railway transport.
2. Development of the mathematical model of the suggested APBS objects, determination and description of the constants and variables of the system.
3. Investigation of application opportunities of different adaptive searching algorithms and methods for the realization of ABPS system learning process during its functioning.
4. Definition of basic APBS impact criteria and total target function for accurate and soft railway transport braking.
5. Development of general algorithm for the calculation of the value of target function.
6. Development of the prototypes of APBS system on the basis of intelligent devices, using the programming controllers for the control of braking system of railway.
7. Development of the computer model of cargo train motion and its its pneumatic braking system operation for the examining of the suggested system in laboratory.
8. Some experiments for the developed control algorithm approbation.
9. Analysis and hypothesis testing of the modelling results, proving the effectiveness of the adaptive searching algorithms application if to compare it with simple rereading method.
10. Different algorithms are compared taking into account accuracy and effectiveness of the operation.

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

1. Application of the developed railway transport control algorithms gives an opportunity to realise smooth and accurate Braking at a given point using minimum number of the braking stages with average accuracy +/–10 m;
2. APBS system allows realisation of the locomotive braking opportunely at the necessary stop points as well as at unexpected calculated stop points in the emergency situation with different initial speeds of of the locomotives;
3. APBS can opportunely react to unexpected switching of traffic light proving the operation performance and mobility of the system;

4. Testing of the selected adaptive searching algorithm gives the conclusion that according to the average mass of the wagon and criterion of pressure force of the braking chocks of 99 % APBS learning and calculation of train parameters are faster to be realised.
5. According to the criterion of wagon number in 99 % the adaptive searching algorithms do not allow faster realise APBS system self-learning in comparison with simple reading methods;
6. Comparing two more effective searching algorithms the conclusion is in the case of repetition searching method is in average 1.2 times more effective than that with returning in the case of unsuccessful step with less values of the searching train parameters;
7. In its turn the method with returning in the case of unsuccessful step is in average 1.1 times more effective than the method of repeating searching with higher searching parameters of the train.

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