RIGA TECHNICAL UNIVERSITY

Antons PATLINS

INTEGRATED SYSTEM SOLUTION DEVELOPMENT FOR PUBLIC TRANSPORT SUSTAINABILITY

Summary of doctoral thesis

Riga 2012

RIGA TECHNICAL UNIVERSITY
Faculty of Power and Electrical Engineering
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Doctoral thesis for the doctor's degree in the engineering sciences will be publicly presented on the 20-th of June 2012 at 16-00 in Riga Technical University, Kronvalda str. 1 – 117.

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CONFIRMATION

Hereby I confirm that I have worked out the present doctoral thesis, which is submitted for consideration to the Riga's Technical University for the degree of Doctor of engineering sciences. Doctoral thesis has not been submitted in any other university for obtaining the Doctor's degree.

Antons Patlins …….

Date: ……

The doctoral thesis is written in English language, contains: 173 pages, annotations in English and Latvian languages, introduction, 5 chapters, results, conclusions, 73 figures, 33 formulas, 9 tables and 199 references.

INTRODUCTION

Actuality

The control issues of large systems with control systems approach is analysed in this PhD thesis.

At this time there is no common opinion for definition of public transport system sustainable development. There is set of the best practice examples in one or another aspects defined, but not to all system in whole.

The definition parameters, techniques as well as equipment of transport system in order to keep it in sustainable position are discussed.

This PhD thesis will be primarily concerned with Riga City public transport 3-level control system solution development.

Goal

According to the thesis theme and summarizing the conclusion of literature review, it is possible to formulate the goal of the research:

Develop a system solution for keeping public transport system in sustainable and safe position.

Tasks of research:

To reach the goal of the thesis there was defined a lot of tasks to solve:

1. Research and describe the possibility to control public transport system like large scale dynamical system. Summarize definitions and interpretations of sustainable development and sustainability. Summarize principles of sustainable transport. Propose environment indicator list to assess transport impacts.

2. Suggest environmental impact aggregation procedure. Research the possibility to jointly consider indicators and offer joint consideration algorithm. Research and offer the methods for building aggregated or composite indicators.

3. Research distance measuring based sensing technology using in transport systems and offer solution for public transport safety to reduce “human factor” in the case of the need for vehicle emergency braking.

4. Offer Riga city public transport safety system solution development using camcorders and vision based traffic measurement system. Offer alarming system solution for Riga city public transport system.

5. Offer the formal integrated control tools system solution for public transport system control.

Problem definition

There are a lot of traffic tracking solutions in the world, such as LG CNS, Thinkware, Traficon, Flux, and others. But all the systems are working separately and not integrated into the common system, so the problem appears that the urban public transport development is planned in the condition of incomplete data, and therefore there is no such management system that can

provide statistical tracking, real-time monitoring, all the sub-systems harmonized working and promote sustainable development of public transport.

Scientific novelty

According to literature analysis it is possible to formulate novelties offered by current research. List of environmental criteria and parameters for evaluation of sustainability of public transport system defined. Analysed and offered methods for joint consideration of indicators. Researched and offered solutions for keeping transport system in sustainable and safe position, to decrease reaction time of system in situation of accidence in system. LIDAR technologies and equipment are researched. Sufficient experiments on light-vehicles were made. Authors mathematical calculations show that LIDAR can be successfully applied to passenger transport, for example, for a more reliable tram braking procedure in case of emergency. Three-level integrated control tool for sustainable public transport system developed, taking into account safety, ecological, security and alarming problems and reducing of „human factor effect".

Research methods

The methodological basis of research is systematic approach. It also based on scientific papers in the field of environment, transport, sustainability, multi-criteria decision making, system theory, intelligent transportation, information, microprocessor centralization systems, reliability and control. During the research were used such scientific methods and techniques as observation, scientific abstraction, description, generalization, analysis and synthesis, methods of grouping, comparisons, experiments, etc.

Work approbation and practical significancy

Authors research results are published in 22 international scientific publications (indexed in such data bases as IEEE-EXPLORE , SCOPUS...).

Research results are approbated on 22 international scientific conferences.

Research results were also approbated by participating the contest related to Riga city key transport problems solving. The competition was organized by Riga City Council. The author was among the winners. Researches of the author awarded with diplomas.

Research results were used in international scientific projects COST:

COST 356 - Towards the definition of a measurable environmentally sustainable transport (EST);

COST IC0806: Intelligent Monitoring, Control and Security of Critical Infrastructure Systems;

COST IC0902 "Cognitive Radio and Networking for Cooperative Coexistence of Heterogeneus Wireless Network";

And IZM- RTU scientific projects:

IZM/RTU Nr. ZP-2007/10 „Ekspertu sistēmu pielietojuma apgabalu izpēte regulejāmās elektriskās piedziņas sistēmas" (The expert system application areas research in regulated electric drive system), project manager J. Chaiko.

IZM/RTU Nr.ZP-2009/10 " Elektromagnētiskās savietojamības novērtējums dzelzceļa transporta sistēmu ilgtspējīgai attīstībai". (Assessment of electromagnetic compatibility for the railway transport system sustainable development) project manager N.Kunicina.

IZM/RTU Nr.ZP-2009/29 "Industriālo datortīklu konfigurāciju efektivitātes izpēte ražošanas procesa vadībai".(Researches of industrial network configuration efficiency for the production process management) project manager J. Chaiko.

And LZP fundamental research project: Nr. 06.1964 „Loģistikas lēmumu ar daudzveidīgiem kritērijiem analīze enerģētikas sistēmām" (The analysis of various criteria decisions in logistics, for energy systems), project manager N.Kunicina.

List of authors publications from year 2008 till 2012:

1. Patlins A., Kunicina N., Ribickis L. Worlds Innovative Concepts in the Field of Public Transportation Usage for Riga City Public Transport System Sustainability // Mechanics, Transport, Communications. - Iss.3, Part 2. (2011) V-58.-V-64. pages.
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8. A.Patlins, N.Kunicina. "Integrated Control Tools Development for Sustainable City Transport System". 10th International Conference October 20-23, 2010, Katowice-Ustroń, Poland.
9. Jelena Chaiko, Nadezhda Kunicina, Antons Patlins Alina Galkina. "Building of mathematical models of data transferring through the interface RS-485 in industrial networks" // Proceedings of the 51nd International Scientific Conference. RTU, 2010. 14-15 october.
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12. Patlins A., Kunicina N., Galkina A., Ribickis L. Development railway and city transport control procedure for co-modal transportation of passengers. // Revitalisation of Economy - New Challenge for European Railways, EURO - Zel 2010., Slovākija, Žilina, 2010. – pp 207.-217. ISBN:978-80-554-0197-3.
13. A.Patlins, N.Kunicina, Y.Chaiko. „Reliability of signal transmission for compatibility of two interlocking railway systems", 17th Telecommunications Forum TELFOR 2009, 24th, 25th, and 26th November 2009, in the Sava Center, Belgrade, Serbia. 4 pages.
14. A.Patlins, N.Kunicina, "Transport network development project evaluation, using decision making". "19th International Scientific Conference TRANSPORT 2009", BULGARIA, Sofia, November, 2009. // Mechanics Transport Communications, Transport 2009, Todor Kableshkov Higher School of Transport, Sofia, Bulgaria, ISSN 1312-3823. from (I-1) to (I-6) pages.
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18. A.Patlins, N.Kunicina, "Разработка процедуры контроля движения городского транспорта, для оптимизации потребления электроэнергии". "18th International Scientific Conference TRANSPORT 2008", Bulgarija, Sofija, 7.-8. novembris, 2008. // Mechanics Transport Communications, Transport 2008, Todor Kableshkov Higher School of Transport, Sofia, Bulgaria, - pp 17-21. ISSN 1312-3823 .
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22. A.Patlins, N.Kunicina, "Decision making procedure for evaluation of new transport projects, according to sustainibility of transportation" 16th International Railway Symposium EURNEX-ZEL-2008 "Towards Sustainable and Competitive Rail System"; 2008 Year. Zilina, Slovak Republic. // EURNEX - Žel 2008, Slovākija, Žilina, 4.-5. jūnijs, 2008. – pp 166-173.

I CHAPTER

The aim of first chapter of thesis is to describe what indicators are supposed to indicate, or in other terms to define what "environmental sustainability in transport" may mean and what the context of indicators is.

Large systems and large system control are also discovered during this part of thesis. Public transport system control as a large system control for system sustainability is offered.

According to automatic control, transport system functional scheme can be shown as figure 1.

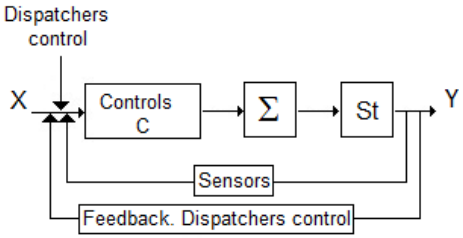

Fig.1. Transport system functional scheme

Each stage of control system, as well as the control system as a whole, describing the processes differential equations are used to link the input and output signals. Looking at the stage of the input signal x (t) and output signal y (t), the differential equation in general view can be:

$$b_m\left(\frac{dx}{dt}\right)^m + b_{m-1}\left(\frac{dx}{dt}\right)^{m-1} + \ldots + b_1\frac{dx}{dt} + b_0 x = a_n\left(\frac{dy}{dt}\right)^n + a_{n-1}\left(\frac{dy}{dt}\right)^{n-1} + \ldots + a_1\left(\frac{dy}{dt}\right) + a_0 y \qquad (1)$$

Laplace operator: $s = \frac{d}{dt}$ allows replacing the differential equations with working in operator *S* environment algebraic equations:

$$b_m x s^m + b_{m-1} x s^{m-1} + \ldots + b_1 x s + b_0 x = a_n y s^n + a_{n-1} y s^{n-1} + \ldots + a_1 y s + a_0 y \qquad (2)$$

Dividing output y (s) to the input value x (s), we obtain an algebraic transfer function for system controls:

$$C(s) = \frac{y(s)}{x(s)} = \frac{b_m s^m + b_{m-1} s^{m-1} + \ldots + b_1 s + b_0}{a_n s^n + a_{n-1} s^{n-1} + \ldots + a_1 s + a_0} \qquad (3)$$

Unlike the systems of linear equations, for systems of nonlinear equations, is not known direct methods of solution in world practice. Only in some cases, the system can be solved directly. For example, for a system of two equations is sometimes possible to express one unknown by another and thus reduce the problem to the solution of a nonlinear equation in one unknown. In world practice, there is no general analytical solution of nonlinear systems found, so in PhD thesis is offered to use the method of intervals.

As a result of the chapter it is possible to formulate what the public transport system sustainable development is and it is possible to formalize public transport system sustainable development:

$$PTSSD(\Delta T) = <E1,Qs,E2,G>(\Delta T) \quad (4)$$

Where:

PTSSD(ΔT) - public transport system sustainable development in time period *(ΔT)*; *E1* – Environmental sustainability; *Qs* – Quality of service for passengers, including safety, security and comfort level. *E2* – Economical sustainability aspects of transportation; *G* – Influence of Governance; *(ΔT)* – Time period.

As it was mentioned before, in world practice, there is no general analytical solution of nonlinear systems found, so it is possible to use the method of intervals, as the unit of measurement for each parameter using a subjective evaluation - the levels.

For example, evaluation scale can be defined as 5 levels scale. For each criteria of the system let's describe such levels system:

1-the best condition; 2-good condition; 3-normal condition; 4-bad, but still suitable condition, situation would be improved; 5-extremely bad condition; situation would be improved immediately.

For each condition it is possible to attach the color for better visual system monitoring, for example, in this sequence: (1=white; 2=blue; 3=green; 4=yellow; 5=red). Using this scaling it is possible to monitor the system also visually (Fig.2.):

E1				PO_{10}	CO_2			.....	.....
Qs				Time			Schedule	.....	.....
E2			Price					.....	.....
G						Restrictions		.....	.....

Fig.2. PTSSD visual monitoring example

In PhD thesis environmental factors are analysed in details, but classical criteria such as price and quality of service are vide analyssed in other different researches. The list of environmental indcators created to analyse public transport impact to environment.

II CHAPTER

This part deals with methods for a comprehensive joint consideration of environmentally sustainable transport indicators.

Joint consideration of indicators, is very specific process with a lot of tasks involved, so in this part of thesis it is offered an joint consideration algorithm, which can be shown also with block-diagram:

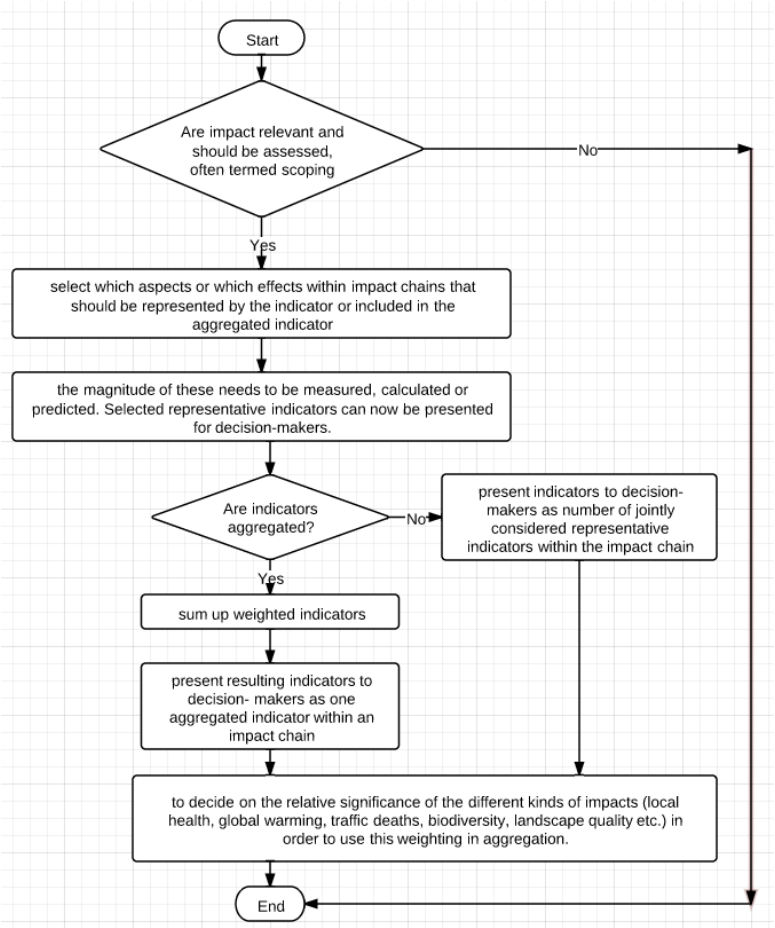

Fig. 3. Block diagram of joint consideration algorithm

As an example, working with indicators, analysis of noise-indicator is given in thesis. Noise-maps are also discussed. In similar way it is significant to analyze all the environmental impacts. Its mapping can give a possibility to analyze ecological situation in different parts of the city and react by correcting transport flow according to situation if all this data will be analyzed in one system. That is why very significant to maintain links between systems, for example, using intelligent transportation systems.

Researches in the field of Intelligent Transport Systems are also discussed in second part of thesis.

III CHAPTER

Railway and city transport procedure for co-modal transportation of passengers and automation of passenger traffic monitoring are given in third part of thesis.

System solution for automatic passenger traffic monitoring is also developed and offered during this part of thesis.

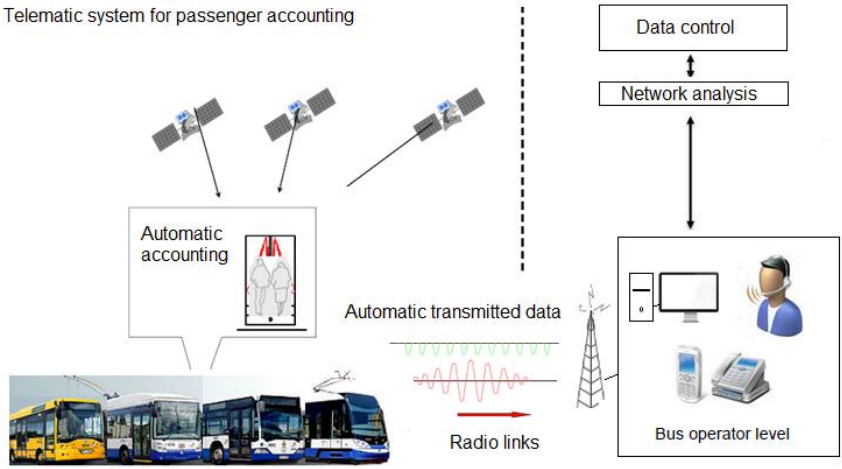

Fig.4. System solution for automatic passenger traffic monitoring – main levels

So, it is possible to offer solution for data comparison from e-ticketing system and from passenger flow monitoring system to control stowaways amount in every vehicle at each moment of time.

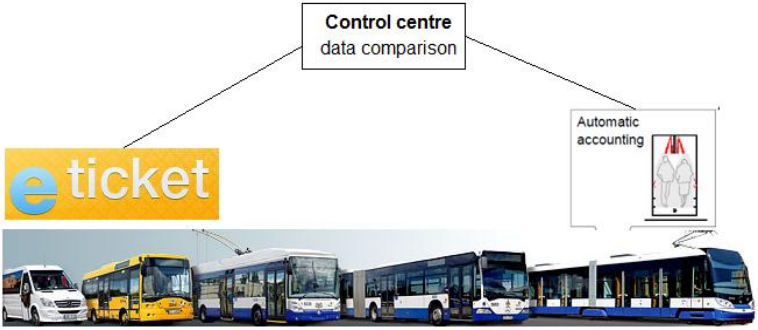

Fig.5. Data comparison from e-ticketing system and from monitoring system

The concept of three-level system solution is also given in this chapter, but total description of offered system solution is given in final part of thesis.

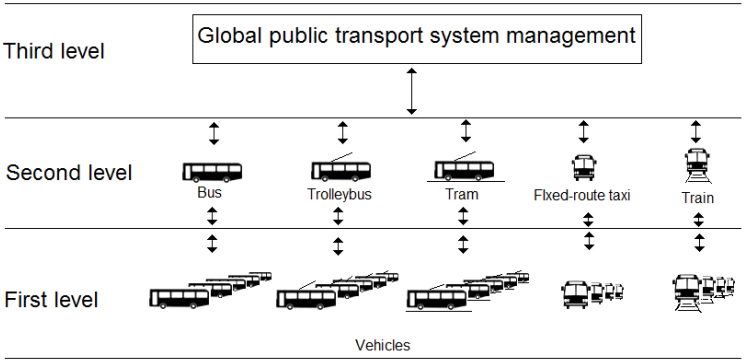

Fig.6.The concept of Riga city passenger transport three-level centralised control system solution

Three-levels integrated control tools system solution which allows to carry out the control of vehicles, to supervise work of each type of transport separately and to co-ordinate work of all transport system in city boundaries.

The development of three level control tools system solution will have to coordinate all the public transport system functionality:

- Control tool of vehicle;
- Control tool of transport mode;
- Control tool of transport modes co- modality.

IV CHAPTER

Fourth part of the thesis is more about solutions for vehicles and for public transport system sustainable development. It is discussed about possibility to use Lidar technologies in transport systems; it is offered to use them for braking control for safety system development to reduce human factor effect in transport system. There are some experiments made and results are offered and discussed.

In this chapter motion control systems Lidar sensors are examined. The work subject is quite modern because nowadays such an analysis of sensors appliance can decrease effect of human factor to traffic control. The main idea of this research is to install distance measuring sensor to trams. The Lidar systems can be used for such purpose. The control algorithm developed in scope of this work calculates tram braking path taking as input the Lidar provided signal.

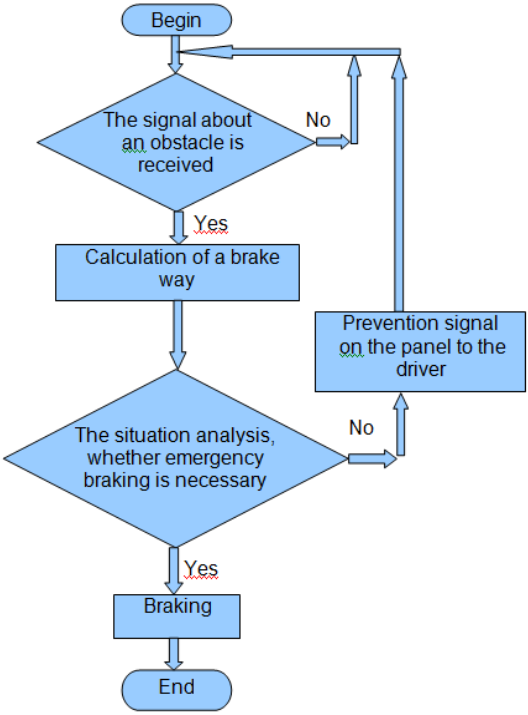

Fig. 7. The block diagram of simple trams braking systems managing algorithm

Based on “Railway Electronics” developed PGP-130 converter for tram motors control it is offered to use Lidar for tram braking control in emergency cases. The tram control equipment scheme is also offered at figure.

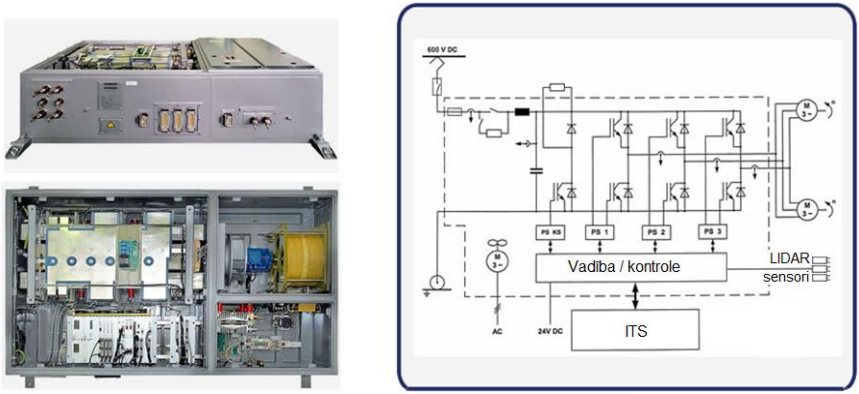

Fig.8. Scheme for tram braking control in emergency cases using Lidar

This part of the thesis also deals with WTMS system and IP-based camcorders usage for Riga city public transport safety system solution development for system safety reasons and system sustainability.

Alarming system solution for Riga City public transport system is also described and offered to use for making Riga City public transport system safer and better to use.

An alarm processing tools model is offered in this chapter. Such tool can classify alarms, as good as make decisions, crate recommendations and will be able to control alarms in real time regime.

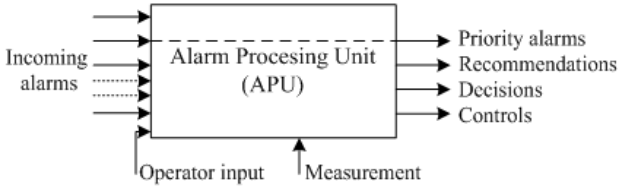

Fig.9. An alarm processing tools model with decisions, recommendations, and controls

All the public transport system objects need to communicate, so communication system solution for public transport network is also offered during this chapter.

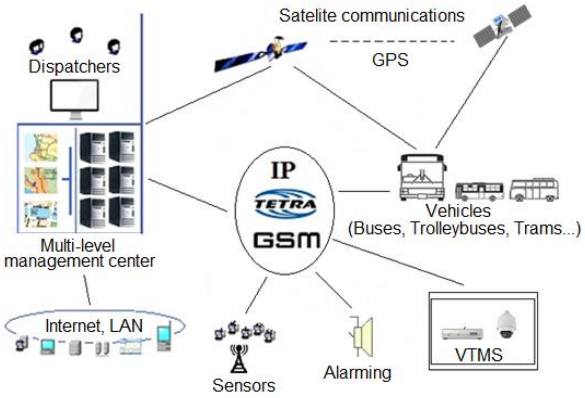

Fig 10. Communication system solution for public transport network

It is offered all the solution to integrate into three-level public transport control system solution.

V CHAPTER

Use of modern technologies of monitoring and the transport control integrated in intelligent transport system have received wide popularity all over the world. Such systems are means of considerable reduction of non-productive expenses for transport and increases of an overall performance of transport system as a whole. The first step in Riga city is bus control system ASOS. Systems of satellite monitoring of motor transport now are widely used in the transport, however the strategic development in city and implementation in tree levels of control is not just engineering issue, it is also an issue for decision makers. In article the usage of such system for passenger's transportation are discussed.

Necessity of developing of the centralized system of wireless dispatching management of city passenger transport in Riga is obvious. The centralized management of city passenger transport presumes to use more effectively transport resources and to provide higher level of service for passengers. It will be promoted also by integration of railway transportation into system of passenger transport of the city of Riga, with including into the general control system.

Analyzing world experience in designing and use of control systems of city passenger transport, it is possible to assume that introduction of similar system in the city of Riga will have a positive effect. Considering experience of other countries, it is possible also to assume approximately-necessary functionality of system.

As it was mentioned in third part of thesis, it is offered to create Riga city passenger transport three-level centralised control system solution.

At first level – vehicle equipment and processes control.

At the second level the control of each type of transport separately (something similar now well only for the Riga buses) will be carried out (ASOS system).

The third level will allow supervision system as a whole. It will allow to plan more competently work of transport system using corresponding methods of the theory of management, more effectively to transport passengers.

Thereby the system of passenger transport will work more in coordination, in the best way carrying out the main function - timely delivery of passengers in the place of a city necessary to them.

According to control theory and system theory fundamentals, it is offered scheme to global control of public transport system.

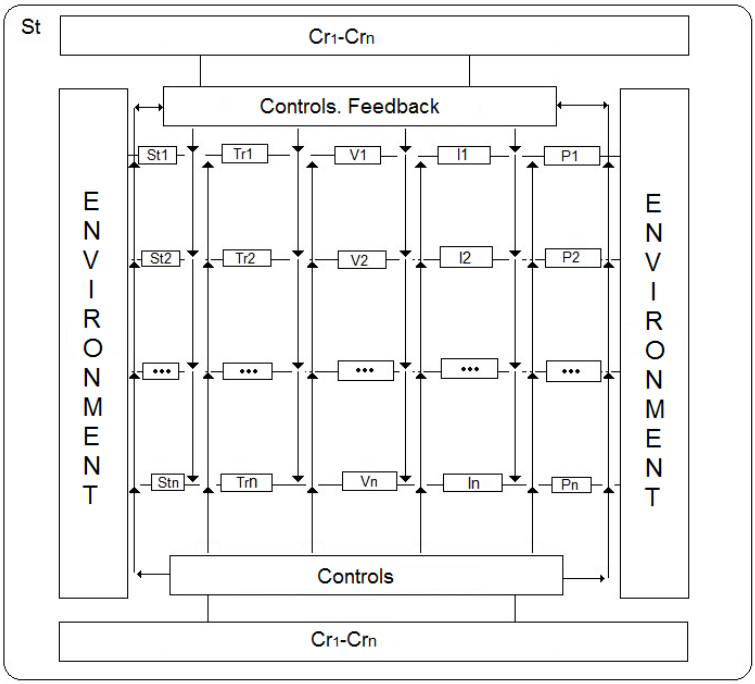

Fig. 11. Transport control system solution structure. Third (global) control level

Where: St – transport system; $\{St_1\text{-}St_n\} \in$ St – subsystems in whole transport system; $\{Tr_1\text{-}Tr_n\}$ – kinds of public transport; $\{V_1\text{-}V_n\}$ – vehicles of public transport; $\{I_1\text{-}I_n\}$ – infrastructure objects in public transport system; $\{P_1\text{-}P_n\}$ – passengers; $\{Cr_1\text{-}Cr_n\}$ – public transport system sustainable development

criteria list: (environmental sustainability; passenger safety and comfort level (quality of service); economical/technical aspects; influence of governance).

Author also has developed a computer-based model for public transport system sustainability monitoring.

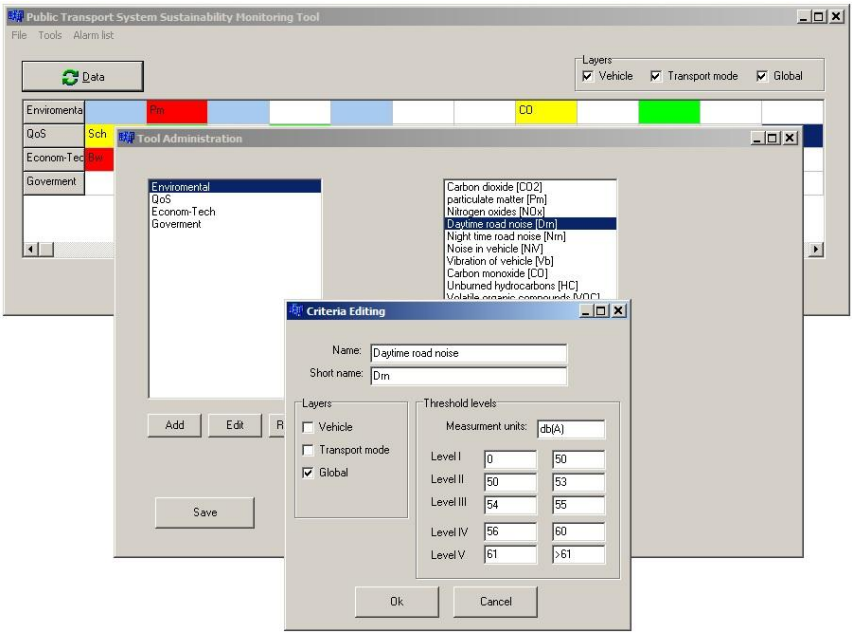

Fig. 12. Administration tool for public transport system systainability monitoring – criteria editing

The main idea of this model is, that pressing the button "Data" – all the criteria values are generated and uploaded into the system. Values for each criterion are generated randomly. After that, input values are evaluated, using 5 level scale (described in first part of thesis) for each criteria. So it is possible to receive visual results and visually monitor the system sustainability. It is possible to use checkboxes for viewing criteria only for vehicle level, only for transport mode level, only for global level, or in combination for different levels. If the criteria value is on alarm border or can damage system sustainability, then this criterion is shown in yellow or red colors and short name of this criterion is also shown. In this case it is possible to "click" the criteria short name and see full name of criteria, current value and possible comment, as good as all the system levels where this criteria is shown.

System gives the possibility to edit groups of criteria, as good as add and edit criteria for each group. It is also possible to edit values which could be used for criteria evaluation (see figure 12).

RESULTS

The main result of PhD Thesis is a three-level system solution and monitoring tool development that provides public transport system sustainable development. This is reached by formalizing the concept of public transport system sustainable development taking into account ecological problems, priorities of passengers and also economical effect, therefore, developed monitoring tool give the possibility to monitor all the sustainability criteria level to keep the system in sustainable and safe position. Developed by author monitoring tool show also all the criteria which are in critical level and can threat the system sustainability, so it is possible to react maximally fast to keep the system in sustainable position by normalizing the level of critical criteria. Other hand, increase the level of security is achieved through the use of video-cameras in vehicles, as well as outside the vehicles, emergency alerts are also sent to the system's monitoring tool, providing a response to the alarm causes and consequences. The possibility to use LIDAR technology in vehicles to provide higher level of safety in cases of emergency braking has been tested and proven experimentally. The results are positive and allow to conclude that these technologies allows to avoid the crashes, which are dependent on the "human factor", in emergency braking cases, thereby also increasing the level of public transport system safety. All the defined tasks where solved:

1. Possibility to control public transport system from large scale dynamical system view was researched and described. Different references are researched and definitions of sustainability are summarized. Principles of sustainable transport summarized and environmental indicator list to assess transport impacts proposed. As good as environmental impact aggregation procedure suggested.
2. The possibility to jointly consider indicators discovered and joint consideration algorithm offered. Methods for building aggregated or composite indicators are researched and offered. An overview towards the ITS-related aspects of development of urban transport systems provided.
3. Lidar sensing technology using in transport systems researched and solution for public transport safety to reduce “human factor” in the case of the need for vehicle emergency braking offered. Riga city public transport safety system solution development using camcorders and vision based traffic measurement system offered.
4. Vision-based traffic measurment system solution and IP-based camcorders usage for Riga city public transport safety system solution offered for system safety reasons and system sustainability. Alarming system solution for public transport system is also described and offered to use for making Riga City public transport system safer and better to use.

5. The three-levels integrated control tools system solution for public transport system control offered with the possibility to control public transport system on all three levels – vehicle, each kind of a transport separately and all the system together. Public transport system sustainability monitoring tool is offered by author and computer-based model is developed.

CONCLUSIONS

The goal of this research is reached by developing and offering the system solution for keeping public transport system in sustainable and safe position.

Concluded, that controlling of public transport system like large scale dynamical system, give the possibility for centralized control of all the public transport system.

Experimental results show, that LIDAR technologies can be successfully used in case of city conditions, when the speed of vehicles is less then 50 km/h. Results of the experiments are positive and this give a possibility to talk about using LIDAR technologies for public transport city safety for public vehicles braking control. Calculations show, that LIDAR technologies can be successfully used to reduce "human factor effect" in the case of emergency braking of public transport vehicle.

Safety and Alarming solutions developed and offered in PhD thesis, give the positive effect for people, such as immediate reaction on any alarm in system, so minimizing the risks of negative consequences.

All the researches made by author and solutions offered in first four parts of thesis will be used in three-level public transport control tool, described in fifth part of thesis, for public transport system control to keep public transport system in sustainable position, taking in account ecological problems, priorities of passengers and also economical effect.

Integrated tools offered in thesis, such as communication system solution for public transport network, alarming system solution and safety system solution will work together, as good as technologies and algorithms offered will be used for making public transport system safer and better.

Public transport system sustainability monitoring tool offered by author and computer-based model developed, show that this tool can help to monitor all the system and can help to keep it in sustainable and safe position.

Developed three-level public transport control system solution for public transport system control, can improve all the public transport system performance in Riga city.

Offered system solution is open for further researches in the whole and in each component in particular.

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