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Traffic Route Modelling and Assignment with Intelligent Transport System

Nadezhda Kunicina *(Professor, Riga Technical University – RTU)*, Alina Galkina *(Researcher, RTU)*,
Anatolijs Zabasta *(Researcher, RTU)*, Antons Patlins *(Researcher, RTU)*,
Kaspars Kondratjevs *(Doctoral Student, RTU)*

***Abstract* – The development of signal transmitting environment for multimodal traffic control will enhance the integration of emergency and specialized transport routing tools in usual traffic control paradigms - it is one of the opportunities offered by modern intelligent traffic control systems. The improvement of effective electric power use in public transport system is an advantage of Intelligent Transport System (ITS). The research is connected with the improvement of on-line traffic control and adaptation of special traffic lighting alternatives by ITS. The assignment of the nearest appropriate transport will be done by passenger request, but unlike information system, the transport planning is done on demand. The task can be solved with the help of modern technical methods and equipment, as well as by applying control paradigms of the distributed systems. The problem is solved with the help of calculations hyper-graph and scheduling theory. The goal of the research is to develop methods, which support scheduling of the emergency transport, using high performance computing.**

Keywords – Intelligent transportation systems; Communication networks; Communication system traffic control; Intelligent vehicles; Land transportation.

I. Introduction

The telematics applications are a very significant part of transport system [1] and a functional subsystem of the different transport modes, like road, rail, aviation and other systems. There is a different solution available on the market, however the final data transmission as well as functional set of control tools are variable. The first step in the standardization of control approach is railway applications. The railway application is defined for transport subsystem comprising two elements:

A. Applications for passenger services, including the systems providing passengers with information before and during the journey, reservation and payment systems, luggage management and management of connections between trains and with other modes of transport.

B. Applications for freight services, including information systems (real-time monitoring of freight and trains), marshalling and allocation systems, reservation, payment and invoicing systems, management of connections with other modes of transport and production of electronic accompanying documents.

The standardization in transport operator exchange information, like TAP TSI RCT2 standard, is a good challenge to do the traffic planning in the whole chain from customer request till the route planning.

Both these subsystems can be partly applicable not only to the railway transport system, but also to the city transport system. So, most recommended features are also applicable.

This multimodal traffic control solution is based on the extended approach of exiting telematics and ITS solutions in the surface transport segment.

II. Telematics Applications for Passenger Services

A technical specification for interoperability (TSI) for telematics applications for passenger services (TAP) has been drafted by the European Railway Agency. The Commission Regulation based on it has been adopted on 5 May 2011 [2], [3] and has been published in the Official Journal of 12 May 2011 [4] .

TAP TSI will allow the harmonization/standardization of procedures, data and messages to be exchanged between the computer systems of the railway companies, of the infrastructure managers and of the ticket vendors in order to provide reliable information to passengers and to issue tickets for a journey on the European Union railway network, in accordance with Regulation n°1371/2007 [5] on rail passengers rights and obligations.

TAP TSI refers to technical documents of the European Railway Agency. They are available on the Agency web site. Changes to these technical documents are managed by the European Railway Agency [6].

According to TAP TSI, the representative bodies from the railway sector acting at European level as defined in Article 3(2) of Regulation 881/2004/EC [7], together with a representative of ticket vendors and a representative of European passengers, shall develop the detailed IT specifications, the governance and the master plan as described in section 7 of Annex I and shall submit them to the Commission not later than one year after the publication of the Commission Regulation in the Official Journal of the European Union.

More information is available at the EU co-funded project web site [8].

It is important to foresee the interconnections of auto and rail transport modes and existing technical solution is taken as bases for future development.

III. Road Safety and Security Applications

Another task – integration of emergency and specialized transport routing tools in the usual traffic control paradigms – is one of the opportunities offered by modern intelligent traffic control systems (ITS) [11] for city transport systems. The priority area III of Directive 2010/40/EU named "ITS road safety and security applications" defines specifications and standards for ITS road safety and security applications.

The directive defined interoperable EU-wide eCall system [12]. A mandatory EU-wide system to handle emergency calls sent automatically by cars in the municipalities is under implementation in the existing traffic control systems.

The future integration of eCall system and developing of the routing for emergency transport in the case of accident may be provided due to the ITS technical capacities. There are several types of special transport categories, which could be named as special transport (e.g., ambulance, police, etc.) as well as other transport categories (military, dangerous goods) [13].

The traffic control is implemented in a number of different approaches, e.g., Distributed Intelligence Traffic Control System (DITCS) is a control system in which intersection controllers, using the timing plans, can dynamically adjust the splits to suit traffic conditions at the controller level. One of DITCS examples is Adaptive Traffic System (SCATS), which is a dynamic control system with a decentralized architecture. SCATS updates intersection cycle length using the detectors at the stop line, allows for phase skipping. The other example is a modular approach to the implementation of Urban Traffic Management Control (UTMC) systems, based on the open standards managed by Department of Transport, Local Government and the Regions (DTLR) [14].

The wide deployment of the adaptive signal control systems in USA, such as OPAC, RHODES, SCATS and SCOOT, offers different technological platform for development of the next generation of proactive traffic control systems. According to the published literature, the majority of system deployments resulted in significantly improved traffic operations in comparison to traditional time-of-day coordination plans. Besides, based on the number of system deployments, SCOOT has the largest worldwide deployments, while SCATS has the largest USA deployments. Considering the cost of the deployment, for example, ACS Lite has the lowest cost, while SCOOT has the highest one [15].

There are several studies of a realistic ad hoc network scenario, i.e., urban VANETs, which is a specialized computer application platform for transport network monitoring an on-line control in the distributive object network.

The Vehicle-to-Vehicle (V2V) Communications approach is promoted to USA department of transportation [16]. V2V contribution for Safety is the dynamic wireless exchange of data between nearby vehicles that offers an opportunity for significant safety improvements. By exchanging anonymous, vehicle-based data regarding position, speed, and location (at a minimum), V2V communications enables a vehicle to sense threats and hazards with a 360 degree awareness of the position of other vehicles and the threat or hazard they present. It calculates risk; issues to driver advisories or warnings; or takes pre-emptive actions to avoid and mitigate crashes. There are several technological development results achieved by BMW, Daimler, Honda, Audi, and Volvo available.

Modern technological solutions provide good background for transport systems control development in a frame of Latvian state research program, as well as offer valuable traffic control solutions for big cities and local authorities, that could be implemented in order to improve quality and security of municipal services.

IV. Control Challenges

The control of large-scale dynamic systems is one of the biggest challenges faced by control engineers today [9]. Large-scale infrastructure systems such as geographically distributed networks, like transport traffic network, are emerging in the contemporary society. The size and complexity of such systems make it difficult to use the tools of the classical central control approach. To manage the complexity of the large-scale infrastructure system the designers were forced to use hybrid control schemes, i.e., the design that makes use of both the discrete and the continuous controllers.

The cross impact of different transport modes and traffic conditions in route assignment should be appropriately taken into consideration which will allow to plan the route not only under normal, but also under emergency conditions, the risk conditions should be taken into account. The risk of an accident and its impact in the case of emergency auto traffic routing is a very sensitive practical issue for all traffic planners. Therefore, road safety and maintenance is a very complicated subject, which is determined by numerous aspects including human errors. Due to the degree of severity and relative infrequency, road crashes must be highly avoided. Many of the current road safety assessment techniques use comparatively mature tools. However, in many circumstances, the application of these tools may not give satisfactory results because of safety-related data being incomplete or because of high level of uncertainty involved in the safety-related data. Road accidents have continuously become a problem in the sector especially, when it involves fatalities. Various studies have been conducted in many countries, based on a range of issues associated with safety level on the roads and highways.

Let us define transport system as a dynamic system. Let us assume that X and Y are input and output signals/data. Therefore, we can also talk about the changes in the system's time, thus, such systems are characterized by changes in time. The system can be described at different time moments and the necessary parameters can be defined in order to perform continuous calculations at all times. Such control is called a dynamic process control (see Fig. 1).

For dynamic systems, knowing the set of input parameters X^1 at time t_1 , we can develop such control C to time t_2 input parameters X^2 and the set of output parameters Y^2, so we can make the technological system regulation by the following condition:

$$S(t_1) \xrightarrow{C^1} S(t_2)\,. \qquad (1)$$

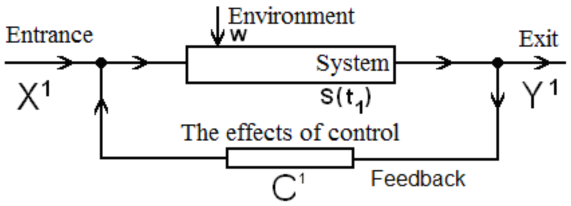

Fig. 1. Dynamic process control in transport system.

There is no analytical solution for dynamic systems control; however, for practical solutions a set of the following definitions has been set [10]:

$$TSSD = \langle V, S, E, R \rangle\ (\Delta T), \quad (2)$$

where

V environmental sustainability;

S service level, including safety and comfort;

E economic aspects;

R government and regulatory norms (incl. emergency routing);

(ΔT) time difference;

TSSD transport system sustainable development.

V. Mathematical Problem Formulation

The typical transport flow control task is related to switching the predefined alternative of the traffic plan. According to the traffic density, the relevant traffic route and traffic plan should be calculated. The HPC calculation capabilities are suitable for the evaluation of the existing traffic density and for making changes in the relevant traffic plan. The auto traffic flow evaluation is done by video monitoring of the defined route, the influence of other transport modes are taken by system multimodality supporting ITS parts. The video monitoring equipment is described in the authors' previous publication [17].

The following main parameters are utilized:

- $Psi = P1si, P2si, P3si$ the amount of vehicles per route , found as $P_1^{si} = \sum_{i=1}^{r} p_i$, where r is the time moment between the transport vehicles;
- Td^r maximum departures per road;
- $T^a d^{Z0}$ scheduled time of arrival, according to priorities;
- $Si \in S$, $s_{ij} \in s$ distance between vehicles, where value of the distance is positive;
- $K - K_j \in K$ set of crossroads;
- R, $r_i \in R$ set of roads;
- $h_i \in H$ set of the traffic lights of alternative transport schedule H;
- $B(t)$ capacity of the buffer;
- S^t transport system with vehicles; S^t_1, S^t_2, ..., $S^t_n \in S^t$; S^t_{direkt} are the minimum number of vehicles necessary to provide the emergency transportation of passengers;
- S^{te} consumption of power resources of vehicles with its components S^{te}_1, S^{te}_2, ..., $S^{te}_n \in S^{te}$, where $n = 1,2, ...$;
- t time, where t_1, t_2, .. t_i are moments of time;
- $P = (p_{ij})$ surface of hypergraph.

The purpose of the task is to minimize the transportation time – to create the traffic light schedule H, which allows to have minimum number of vehicles on the dedicated route Tm', in order to deliver emergency passenger transport p_i, along a particular route R, taking into account the possibilities of the transport changes: $\exists\ H\ \forall\ S^t_n\ (S^p_k\ S^{te}_j) \rightarrow \min$, exists when S^t_n, as for each $S^p - S^{te}_j\ (S^t_n,\ S^p_k)$ exists; $S^{te}_j \rightarrow \min$, $S^t_n \geq S^t_{\text{direkt}}$.

The task is to set the requirements for the transport information system aiming to optimize the transport system performance by using intelligent agents systems;

By means of logistics, Supra intelligent agent provides the scheduling task optimization for public transport system in the dynamic $S^{te}_j\ (t) \rightarrow \min$, $S^t_n \geq S^t_{\text{direkt}}$ taking into account the electric energy consumption efficiency increasing procedure.

VI. Technical Solutions in City Transport System

The absence of a suitable and reliable communication system frequently causes problems and interruptions in public transport network operation. It makes traffic management difficult and negatively influences the quality of public transport services. To resolve the issues, public vehicle fleet should be equipped with new communication systems that would enable better control of the large part of bus and electrical transport traffic in the city and help to create a smooth flow of the land traffic in cities.

The main objectives of the measure are:

- To improve information on traffic conditions;
- To allow the traffic management unit to promptly react to unexpected congestion and to help to better plan interventions;
- To contribute to solving operational problems, reduce risks of service interruptions, and improve traffic flow;
- To provide public transport statistics.

One of the tasks of the Latvian State Research Program project NexIT, launched in Latvia in 2014, is to provide the research in the area of city transport control optimization (Fig. 2). The auto transport flow is taken as basis for this task, as railway traffic is not so well developed in this segment in Latvia (mostly freight transit).

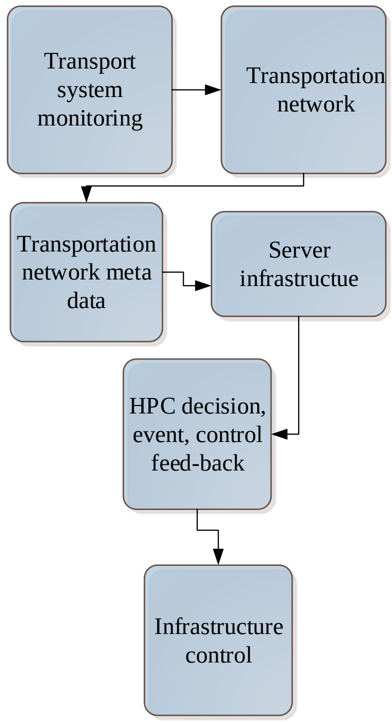

Fig. 2. City surveillance system with monitoring center.

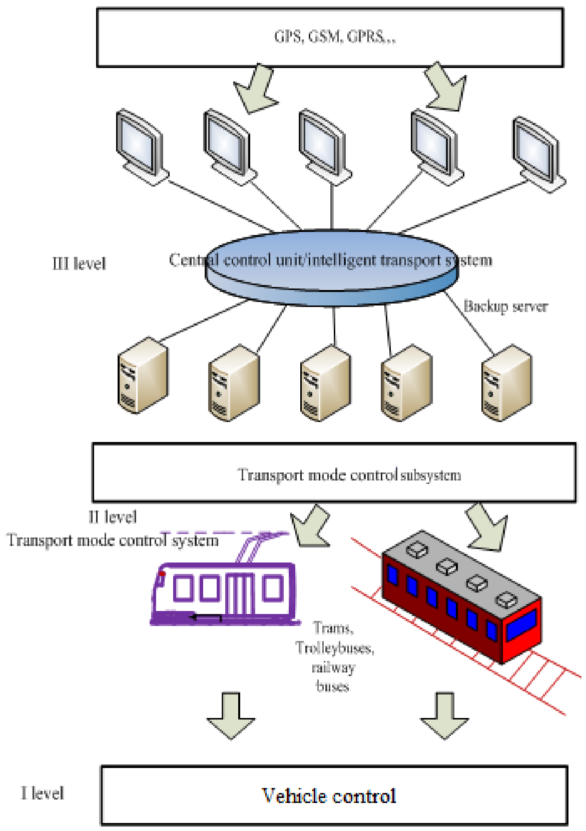

Fig. 3. Structure of 3-level intelligence transport control system.

The focus will be made on data harvesting infrastructure of the transport system monitoring; therefore, data acquisition systems, high data rate transmission infrastructure, rugged sensor systems (traffic counters), long-range data communication systems and other problem issues are under consideration.

The following functionalities are planned under ITS implementation in the existing piloting area:

- Transport system monitoring;
- Data acquisition systems;
- High data rate transmission infrastructure;
- High data rate transmission technologies;
- Rugged sensor systems (traffic counters);
- TMC – control infrastructure;
- Long range data communication systems;
- Ad-Hoc communication systems.

The next priority of the city transport control and monitoring centre is a HPC (High Performance Computing) that will ensure decision, event control and feedback from operations. One of the project tasks is to investigate the data pre- and post-processing, simulation model development, model real-time processing and output feedback analysis.

The structure of 3-level intelligent transport control system (ITS) is depicted in Fig. 3. The offered system comprises three levels: vehicle control level, transport mode control subsystem and central control unit of the ITS. ITS technical equipment usually includes GPS and GPRS applications, which have considerable influence on the environment, the speed of motion and the maintenance conditions.

In the following sections of this paper the authors provide the research method of scheduling of public transport means taking into account the purposes of passengers according to logistic criteria (costs, time, and quality of service) and suggest the procedure for effective improvement of electric power use.

The structure of the problem-solving algorithm, experimental validation of the algorithm and main conclusions are given in the article. The modeling of dynamic schedule of transport is developed and algorithm of scheduling is analyzed.

VII. Method of Problem Solution

In solving the complex task the theory of schedules is applied, as well as the theory of flows and operation investigation, further the task is solved using the elements of artificial intelligence.

The problem solution method is modeling of traffic light public schedule alternatives, using multi criteria model by energy consumption effectiveness criteria.

The traffic light alternative schedule can be modeled using intelligent actuators and elements of infrastructure as well as its interaction (Fig. 4).

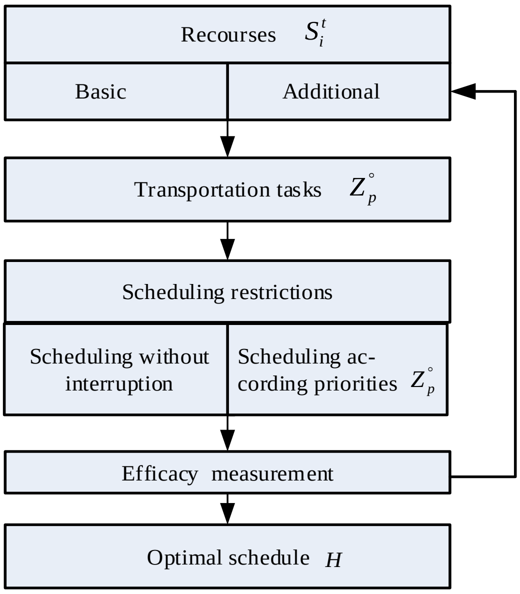

Fig. 4. General sequence model structure of public transport scheduling.

The modeling of traffic light plan schedule using multi criteria model taking in account energy consumption effectiveness criteria, is described in 13 steps below:

Step 1: Formulating the task;
Step 2: Defining the set of possible decisions;
Step 3: Defining the set of criteria;
Step 4: Defining the measurement scale of efficiency criteria. Steps 3, 5;
Step 5: Possible alternatives of efficiency measurement by criteria scales. Steps 3, 4, 6;
Step 6: Obtainig and sequencing information about priorities;
Step 7: Defining the set of decision making rules;
Step 8: Putting possible decisions in order;
Step 9: Putting result analysis in order;
Step 10: Checking the sequence of satisfactory priorities. If satisfactory, Step 12; if not satisfactory, Step 11;
Step 11: Analysis of non-satisfactory reasons, and defining of improvements. Steps 2, 3, 4, 5, 6;
Step 12: Checking the sequence of satisfactory problem decisions? If satisfactory, Step 13, if not satisfactory, Step 6 or 1;
Step 13: Completion of the decision making. .

The first step of the algorithm states the common case of the task of the transportation, defines the goal of the investigation (optimization) and conditions for the task solution – the schedule of the traffic lights and optimal transportation in the region.

The second step formulates the set of the schedule, tests its correspondence to the purpose and elaborates the procedure of testing possible schedule correspondence and the set of solutions (schedules).

The third step makes it possible to analyze the results. The schedules are compared with each other according to the efficiency indices.

The scale of the distributed criteria evaluation is elaborated in the fourth step of the algorithm. The traffic light scheduling is measured by reasonability criteria.

The corresponding schedules are evaluated in the fifth step of the algorithm with the use of identified criteria.

The sixth step defines the priorities of the city transport authority. The information on the priorities is applied in the seventh step of the algorithm to define the set of decision making regulation.

Taking into account the defined optimization conditions the variants are compared and evaluated at the eighth step.

The ninth step implements the analysis of the transportation sequence. The tenth step evaluates whether the sequence corresponds to the priorities. At the eleventh step non-satisfactory reasons are evaluated. The twelfth step evaluates whether the sequence corresponds to the problem solving.

The decision-making process is completed in the thirteenth step.

The application of high performance computing (HPC) for alternative evaluation in on-line mode as well as for decision-making, critical event monitoring and control feed-back allows to make sufficient calculations under the real time conditions. The main HPC operations are used for traffic light alternative scheduling: data storage, inter-system exchange, data pre/post-processing, model simulation, model real-time processing, model output feedback, dynamic control operations, event monitoring/generating engine, critical event recognition and handling, resource monitoring, resource optimization, inter-infrastructure decision making and control.

VIII. Experimental Part

Let us describe a route of transport scheme as a graph, where its apices are traffic lights but the routes of public transport between the apices are considered as the loops of the graph.

The HPC calculations are aimed to make such calculations in real time.

Public transport system is considered as a hyper-graph, where in Riga (Latvia) tram 4 (Fig. 5) runs from the stop „Botāniskais dārzs" till „Grēcinieku iela" $P4tr = \{ P4tr1, P4tr2, ... P4trn\}$ and trolleybus 9 runs the stops $P9t = \{P9t1, P9t2, ... P9tu\}$. The apices of the hyper-graph in this case are „Botāniskais dārzs", „Slokas iela" and „Grēcinieku iela".

The passengers take two means of public transport, first they take trolleybus and then change for tram (Fig. 6.).

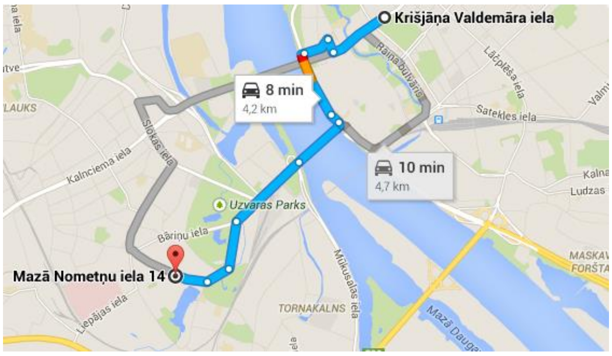

Fig. 5. Routes in the heavy traffic areas in Riga (Latvia).

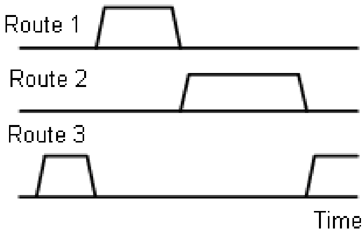

Fig. 6. Passenger route sequence.

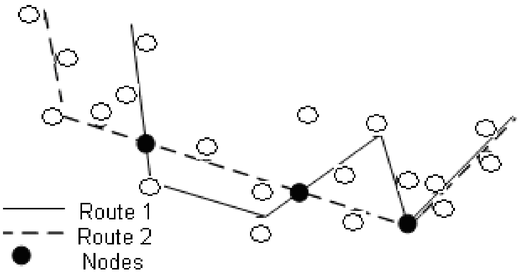

Fig. 7. Fragment of hyper-graph of transport system in Riga.

The hyper-graph of the considered example of public transport system is shown in Fig. 7.

The schedule in Table I depicts a fragment for work days and it includes only the morning time of work days.

Let us assume that S^t_{direkt} is the minimum number of vehicles to provide transportation of passengers $S^t_{direkt} = 2$ times per hour. The total number of routes per day is 71. The optimal number of routes is 71 – 36 = 35 times.

The experimentally checked time economy is 18 min in each direction which in total is 36 min per one route.

Average power consumption for a trolleybus is 1.94 kW/km; the average tariff for 1 kWh is EUR 0.1515. The efficiency $S^{te}_j\ (t)$ is calculated for 22 work days per month for 12 months per year, the average speed is 0.32 km/min.

$S^{te}_j\ (t) = 36 * 35 * 1.94 * 22 * 12 * 0.1515 * 0.32 = 31\ 285$ EUR.

With the shortening of the 9th route up to the 1st apex of the hyper-graph the economy will be 31285 euro per year, taking into account the power consumed only on work days.

Furthermore, it is necessary to take into account that the amount of passengers for transportation from the stop „Botāniskais dārzs" is increased, which means that the number of trams on route 4 should be two times increased. Finally passengers' average travel time (Fig. 6) will be decreased by 10 minutes.

Apart from the traffic light and public transport route planning the emergency and special transport route assignment planning in the existing traffic conditions is proposed.

TABLE I

THE PARAMETERS VALUE IN THE SCHEDULE, TIME (S)

	S_2	$S_{2(9)}$	$B(t)$	P_1^{si}
S_1	5	5	20	8
S_2	∞	1	40	8

IX. CONCLUSION

The improvement of on-line traffic control and adaptation of special traffic lighting alternatives by ITS can be solved with the help of modern technical methods and equipment, as well as by applying control paradigms of the distributed systems. For the solution of the task the authors analyzed the public transport schedule using a multi-criteria model based on energy consumption effectiveness criteria modelling in transport system.

The solution was achieved using the graph theory, multi-criteria decision-making, scheduling theory and intelligent transport system approach and modeling. The approbation of the suggested method was made by using energy efficiency criteria in the case of Riga public transport.

The task of procedure development for the improvement of signal planning with the aim of transport energy efficiency increasing is stated as a task of formalized model that can provide efficiency of the present transport system investigation that has a high economic importance including the situations of the city traffic congestions.

The analysis of transport control systems shows that it is possible to optimize energy consumption control by transport intelligent system.

The authors demonstrated the example of a rather simple task for traffic control optimization using a restricted set of parameters. However, for more complex calculations involving multiple transport routes and taking into account a variety of impact factors, divergent parameters and measurement data processing in a necessary dynamic mode, implementation of HPC becomes an indefeasible core of intelligent transport system.

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Nadezhda Kunicina, *Dr. sc. ing.*, Assoc. Prof., has been working in RTU since 2005. Her fields of scientific interest are: electrical engineering, embedded systems, sustainable transport systems. The research interest is related to the improvement of electric energy effectiveness in industrial electronics and electric transport. She is a project manager of Riga Technical University team "The next generation of information and communication technologies" (NexIT) project.

She is a scientific project manager of FP7 – ARTEMIS – 2012 call Arrowhead project. The aim of the project is to address the technical and applicative challenges associated to cooperative automation.

Address: 1 Kalku Str., Riga, Latvia, LV-1658.
E-mail: nadezda.kunicina@rtu.lv

Alina Galkina, *M. sc. ing.*, is a project manager with Riga Technical University. Her fields of scientific interests are: electrical engineering, electrical drives, and energy sustain able technologies. She is an author of monograph "The efficient methods of energy consumption".

The analysis and development of energy efficiency increasing methodology of electrical drive systems.

Address: 1 Kalku Str., Riga, Latvia, LV-1658.
E-mail: alina.galkina@rtu.lv

Anatolijs Zabashta, *Dr. sc. ing.*, is a Researcher with Riga Technical University since 2012. His fields of scientific interests are: electrical engineering, embedded systems, critical infrastructure. He is taking part in EU project COST Action TU1104 "Smart Energy Regions". He is taking part in project "The next generation of information and communication technologies" (NexIT).

Address: 12/1 Azenes Str., Riga, Latvia, LV-1048.
E-mail: anatolijs.zabasta@rtu.lv

Antons Patlins, *Dr. sc. ing.*, has been been a Lead Researcher with Riga Technical University since 2012. His scientific interests are related but not limited to control algorithms and devices development in the field of electrical engineering. His research is connected with the improvement of electric energy effectiveness in industrial electronics and electric transport. His current research is connected mostly with the sustainable development of public transport system. He is taking part in project "The next generation of information and communication technologies" (NexIT).

Address: 12/1 Azenes Str., Riga, Latvia, LV-1048.
E-mail: antons.patlins@rtu.lv

Kaspars Kondratjevs, *M. sc. comp.*, has been a Researcher with Riga Technical University since 2013. His fields of scientific interest are: embedded systems, critical infrastructure, and design of IT systems.

He is the main technical developer of FP7 – ARTEMIS – 2012 call Arrowhead project. His contribution is technical experiments, design and testing of control system, automatic data metering systems, as well as development of energy efficient algorithms for wireless sensor networks.

The title of his Doctoral thesis is: Development of adaptive computer control techniques for water and electricity supply infrastructure. He is taking part in the project "The next generation of information and communication technologies" (NexIT).

Address: 12/1 Azenes Str., Riga, Latvia, LV-1048.
E-mail: kaspars.kondratjevs@rtu.lv