Traffic Root Modelling and Assignment with Intelligent Transport System

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Abstract – The integration of emergency and specialized transport rooting tools in the usual traffic control paradigms is one of the opportunities offered by modern intelligent traffic control systems. The research is connected with improvement of on–line traffic control and adaptation of special traffic lighting alternatives by ITS. The task can be solved with the help of modern technical methods and equipment as well as applying control paradigms of the distributed systems. The problem is solved with the help of calculations hyper-graph and scheduling theory. The goal the research is to develop methods, which support scheduling of the emergency transport, using high performance computing.

Key words – Intelligent Transport System (ITS), emergency transport, rooting, public transport system, schedule.

I. INTRODUCTION

The development and maintenance of transport infrastructure nowadays is one of the critical tasks as in large cities as in small Latvian municipalities. The integration of emergency and specialized transport rooting tools in the usual traffic control paradigms is one of the opportunities offered by modern intelligent traffic control systems (ITS) [1] 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 [2], including:

- The availability of the required in-vehicle ITS data to be exchanged.
- The availability of the necessary equipment in the emergency call response centers receiving the data emitted from the vehicles.
- The facilitation of the electronic data exchange between the vehicles and the emergency call response centers.

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 rooting for emergency transport in 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) [3].

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 open standards managed by Department of Transport, Local Government and the Regions (DTLR) [4].

The wide deployment of the adaptive signal control systems in USA, such as OPAC, RHODES, SCATS and SCOOT, offers different technological platform for development 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 [5].

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 [6]. 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.

The modern technological solutions gives a good background for transport systems control development in a frame of Latvian state research program, as well as to 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.
II. CONTROL CHALLENGES

The control of large-scale dynamical systems is one of the biggest challenges facing by control engineers today. Large-scale infrastructure systems such as transport traffic network, power supply, water/heat supply networks etc. are emerging in the contemporary society. The size and complexity of such systems makes it difficult using tools of the classical, central control approach. To manage the large-scale infrastructure system complexity, designers were forced to use hybrid control schemes, i.e. a design that makes use of both discrete and continuous controllers.

The risk of an accident and its impact in the case of emergency traffic routing is 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 roads safety assessment techniques currently use comparatively mature tools. However, in many circumstances, the application of these tools may not give satisfactory results because the safety-related data are incomplete or there is a 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 dynamical system. Let’s assume X and Y as 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 calculations continuously at all times. Such control is called a dynamic process control (see Fig. 1).

For dynamic systems, knowing the set of input parameters $X^t$ at time $t$, can develop such control $C$ to time $t_2$ it would be an output parameters set $Y^t$, so we can make the technological system regulation by following condition.

$$S(t_1) \rightarrow S(t_2)$$  \hspace{1cm} (1)

![Fig. 1. Dynamic process control in transport system](image)

There is no analytical solution for dynamic systems control; however, for practical solutions a set of following definitions is set:

- $V$ – Environmental Sustainability;
- $S$ – Service level, including safety and comfort.
- $E$ – Economic aspects;
- $R$ – Government and regulatory norms (incl. emergency rooting);
- $(\Delta T)$ – Time difference.

$$TSIA=<V,S,E,R>(\Delta T)$$  \hspace{1cm} (2)

III. MATHEMATICAL PROBLEM FORMULATION

The typical transport flow control task is related with switching predefined alternative of traffic plan. According to the traffic density, the relevant traffic root and traffic plan should be calculated. The HPC calculation capabilities are suitable to the evaluation of existing traffic density and switching relevant traffic plan. The traffic flow evaluation is done by video monitoring of defined route. The video monitoring equipment is describing in authors previous publications [7].

The vehicle amount per route are $P_{\text{in}}=P_1, P_2, P_3, \ldots$,

- Maximum departure per road $T_d$;
- Directive arriving time, according priorities $T^{d^20}$
- Distance between vehicles $S_i \in S$, $S_j \in S$ value of the distance is positive;
- Set of crossroads $K$,$K_i \in K$;
- Set of roads $R$, $r_i \in R$;
- Set of the traffic lights alternatives transport schedule $H$, $h_i \in H$;
- Capacity of the buffer $-B(t)$;
- $S^t$ – transport system with vehicles $S_1, S_2, \ldots$, $S_n \in S^t$;
- $S^d_{\text{direct}}$ – minimum of vehicles which is necessary to provide the emergency passengers transportation;
- $S^a$ – consumption of power resources of the vehicles with its components $S^{a1}, S^{a2}, \ldots$, $S^{an} \in S^a$;
- $t$ – time, $t_1, t_2, \ldots$ – moments of time;
- $P = (p_0)$ – surface of hypergraph;

The purpose of the task is to minimize transportation time – to create the traffic light schedule $H$, which allow to make minimum number of vehicles in the dedicated route $Tm^t$, in order to deliver emergency transport passenger $p_0$ along a particular route $R$, taking into account the possibilities of the transport changes:

$$\exists H \forall S_n^t (S^P, S^e) \rightarrow \min ( exists when S_n^t as for each S^P - S_n^t (S^P, S^e) exists,\)

$$S^{d^2} \rightarrow \min, S^{d^2}{\geq}S^d_{\text{direct}}.$$

The task is to set the requirements for the transport information system aiming to optimize transport system performance with the use of intelligent agents systems.
By the means of logistics, Supra intelligent agent provides scheduling task optimization for a public transport system in a dynamic $S^{\text{opt}}(t) \rightarrow \min, S_n \geq S_{\text{direct}}$ taking into account electro energy consumption efficiency increasing procedure.

IV. TECHNICAL SOLUTIONS IN CITY TRANSPORT SYSTEM

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

The main objectives of the measure are to:

- Improve information on traffic conditions;
- Allow the traffic management unit to promptly react to unexpected congestion and help to better plan interventions;
- Contribute into solving operational problems, reduce risks of service interruptions, and improve traffic flow;
- Provide public transport statistics.

The video streaming of the transport roots in critical points may be done by several technologies. The system can be easily developed or reconfigured and image quality can be adjusted to the actual needs.

One of the tasks of the Latvian state research program project NexIT, launched in Latvia in year 2014, is to provide a research in the area of city transport’s control optimization (Fig. 2). 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 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), with will ensure decision, event control and feedback of operations. One of the project tasks is to investigate data pre and post-processing, simulation model development, model real-time processing and output feedback analysis.

A structure of 3-level intelligence transport’s control system is depicted on 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 a considerable influence on environment, speed of motion, maintenance conditions.

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

The structure of a 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.
V. METHOD OF PROBLEM SOLUTION

The solving of the complex task applies the theory of schedules; the theory of flows as well as operation investigation, further the task is solved using elements of artificial intelligence.

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

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

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

Step 1. Task formulating.
Step 2. Formalizing a set of possible decisions.
Step 3. Definition a set of criteria.
Step 4. Definition a set of efficiency’s criteria measurement scale. Steps 3, 5.
Step 5. Possible alternatives efficiency measurement by criteria scales. Steps 3, 4, 6.
Step 6. Getting and sequencing information about priorities.
Step 7. Definition a set of decision making rules.
Step 8. Possible decisions ordering.

Step 9. Ordering results analysis.
Step 10. Sequence satisfactorily priorities? If yes Step 12, if no Step 11
Step 12. Sequence satisfactorily problem decision? If yes Step 13, if no Step 6 or 1.
Step 13. Finish of problem decision.

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 – schedule of the traffic lights and optimal transportation in region.

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

The third step realizes possible analysis of 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. Traffic light scheduling is measured by reasonability criteria.

The correspondent 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 analysis of 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 problem decision is completed at the thirteenth step. The application of high performance computing (HPC) for alternatives evaluation in on – line mode as well as for decision making, critical event monitoring, control feed-back allows to make sufficient calculations in the real time conditions. The main HPC operation 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.

VI. EXPERIMENTAL PART

Let us describe a route of transport scheme as a graph, where its apices are traffic lights but routes of public transport between the apices are considered as the loops of the graph. The HPC calculations are aimed to make such calculations it the real time.

The system of the public transport is considered as a hyper graph, where in Riga (Latvia) a tram number 4 (Fig. 5) runs from stop „Botāniskais dārzs“ till „Grēcienku iela“ P4t= {P4tr1, P4tr2,... P4trn} and trolleybus number 9 runs stops P9t= { P9t1, P9t2,..., P9tu}. The apices of the hyper-graph in this case are „Botāniskais dārzs“, „Slokas iela“ and „Grēcienku iela“. The passengers use two means of public transport, first using trolleybus and then change for tram (Fig.6.)

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

![Fig. 7. Fragment of hyper-graph of transport system in Riga.](image)

The schedule at Table I depicts a fragment for working days and it includes only morning time of working days.

Let us assume \( S_{\text{direct}} \) a minimum number of vehicles to provide transportation of the passengers \( S_{\text{direct}} = 2 \) times per hour. The total number of the routes per day is 71. The optimal number of the routes is 71-36-35 times.

Experimentally is checked the time economy is 18 min in each direction that is total 36 min per one route.

An average power consumption for a trolleybus is 1.94 kW/km, an average tariff for 1 kWh, is 0.15 EUR. The efficiency \( S_j \) is calculated for 22 working days per month for 12 months per year, an average speed is 0.32 km/min.

\[
S_j(t) = 36 \times 35 \times 1.94 \times 22 \times 0.15 \times 0.32 = 30975 \text{ EUR}
\]

With a shortening of the 9th route up to the 1st apex of the hyper-graph the economy will be 30975 EUR per year, taking into account only power consumption in working days.

Furthermore, it is necessary to take into account that the amount of passenger’s for transportation from a stop „Botāniskais dārzs“ will be increased, which means that the amount of 4th trams should be increased by 2. Finally, passenger’s average travel time (Fig. 6) will be decreased by 10 minutes.

Apart of traffic lights and public transport routes planning the emergency and special transport route assignment planning in the existing traffic conditions are proposed.

### CONCLUSIONS

The topic of research is related to improvement of electric power effective use in public transport. For solution of the task, the authors analyzed public transport schedule, using multi-criteria model based on energy consumption effectiveness criteria modelling in the transport system.

The problem decision was achieved, using graph theory, multi-criteria decision-making, scheduling theory and intelligent transport system approach, modelling. 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 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 city traffic congestions. The procedure for intelligent transport system aiming the improvement of consumed electric energy use efficiency is formalized.

Analysis of transport control systems shows that it is possible to optimize energy consumption control by transports intelligent system, using intelligent system.

The authors demonstrated an example of rather simple task for traffic control optimisation 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 dynamic mode needs, implementation of HPC becomes an indefeasible core of intelligent transport system.

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