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DEVELOPMENT AND MODELLING OF SCHEDULING THEORY ALGORITHMS FOR INTELLIGENT ELECTRIC TRANSPORT SYSTEM

SARAKSTU TEORIJAS ALGORITMU IZSTRĀDE UN MODELĒŠANA INTELEKTUĀLĀ ELEKTRISKĀ TRANSPORTA SISTĒMĀ

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Introduction

This work is based on research in a field of scheduling theory [1,2, 3], intelligent agent systems [4], negotiation algorithm [5] solving tasks of energy saving [6], optimal electric vehicle control [7] and transport flow control in traffic jam.
The research includes analysis of different control modes for city traffic and public electric transport. It is devoted to improve control of public electric transport motion and traffic using scheduling theory algorithms. Solutions for following tasks are proposed in research: reducing consumption of electrical energy using intelligent control system for electric transport; increasing of motion speed of public electric transport and reducing of idle time of public electric transport in traffic jams, taking in account schedule criteria and optimal electric transport control using scheduling theory algorithms.
Public electric transport should have higher priority than private cars, by criterion of transported passenger number, electric energy consumption and service level evaluated by schedule fulfilment. Public electric transport, such as trams and especially trolleybuses, which are more sensible to traffic jams, uses more electric energy during frequent acceleration and braking in traffic jam and infringe scheduled time. Also traffic lights are not synchronized and working independently from transport flow. Computer experiment of modelling of traffic dynamics is described.

Problem Formulation

The purpose of research is to develop new mathematical models and new algorithms for optimal electric transport flow control using scheduling theory and taking in account dynamic parameter of city transport system.
Main goals are

- Research of scheduling theory algorithms for optimal control of electric transport in conveyor and parallel job processing systems and development of procedures for optimal schedule of traffic control.
- Research of using of developed procedures in computer modelling of electrical transport systems' optimal control [2], taking in account criteria of minimization of electrical energy consumption, maximization of processing speed and minimization of processing time.

Following object classes are defined for problem formulation in electric transport control system (fig. 1):

- Set of electric transport vehicles: $T = \{t_1, t_2,...,t_n\}$
- Set of traffic lights: $L = \{l_1, l_2, ..., l_m\}$
- Intelligent control system : S
- Set of electric drives for each vehicle: $D_T = \{d_1, d_2 ..., d_n\}$
- Sets of sensors for transport and traffic lights - M_T, M_L
- Sets of transmitters for transport, traffic lights and control system: R_T, R_L, R_S

- Sets of actuators for transport and traffic light: A_T, A_L
- Electronic control devices for transport, traffic lights and control system : V_T , V_L, V_S
- Database for transport, traffic lights and control system: Db_T, Db_L, Db_S
- Software with artificial intelligence procedures for transport, traffic lights and control system: Pg_T, Pg_L, Pg_S
- Power supply for transport, traffic lights and control system: B_1, B_2, B_3

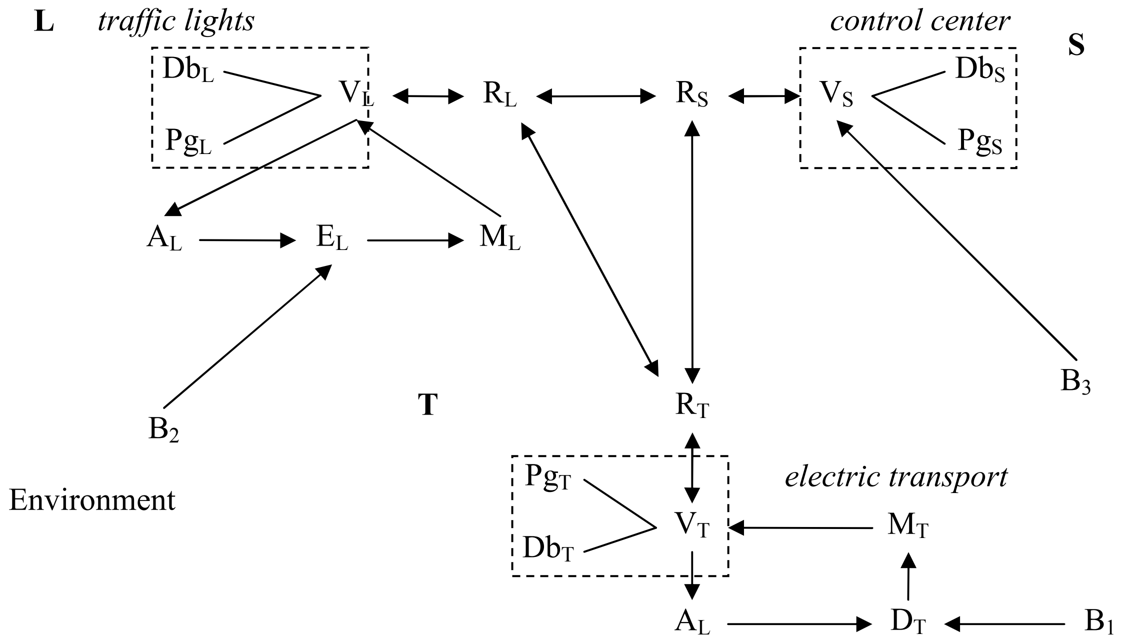

Fig. 1. Structure of electric transport system with intelligent control.

Mathematical Model

Following mathematical model of optimal schedule is proposed.
Let us assume that are given:

- Set of M identical parallel processors
- Set of N tasks
- $d_k \geq 0$ time moment of arrival of k-th task for processing
- $t_k > 0$ time units are needed to process k-th task,

where each k = 1,2, ..., N

- Schedule $s = s(t) = \{s_1(t), s_2(t), ..., s_M(t)\}$, a set of partly continuous functions
  where
  $s_L = s_L(t), s_L(t) = [0, n]$
  $L = 1,2,...,M$, $0 \leq t < \infty$
  with constraints:
  - If $s_L(t') = k \neq 0$, $t = t'$, then $s_H(t') \neq k$ for each $1 \leq L \neq H \leq M$ i.e. each processor performs only one job in one time interval.
  - If $s_L(t') = 0$ and $t = t'$, then processor is free.
  - Completeness constraint: summary length of intervals, where $s_L(t') = k \neq 0$, is tk
  - Readiness constraint: $s_L(t') \neq k$, $t \leq d_k$, $t = 1,2,...,n$

- Vector $\bar{t}(s)=\{\bar{t}_1,\bar{t}_2,...,\bar{t}_n\}$ of processing ending time moments for each schedule s, where $\prod_{L=1}^{M}(s_L(t)-k)=0$.
- Monotone increasing functions $F(x)=F(x_1,x_2,...,x_n)$, $\bar{x}=\bar{t}(s)$ for quality characterised of the schedule.
- Cost function $\varphi_k(x_k)$ that depends on job processing ending moment $x_k=t_k$.

Optimal schedule in general case is defined as

$$F(\bar{x})\rightarrow \min .$$

In case of cost function optimal schedule s* is characterized by summarized function $\varphi_k(x_k)$ value:

$$F(\bar{t}(s)) = \sum_{k=1}^{n} \varphi_k(\bar{t}_k) \rightarrow \min ,$$

$$F(\bar{t}(s)) = \max_{1\le k\le n} \{\varphi_k(\bar{t}_k)\} \rightarrow \min ,$$

where $k=1,2,...,n$.

Additional parameters and functions are defined for traffic flow modelling.

Constants:

- L – vector of street lengths;
- M_{max} – vector of maximal number of vehicles;
- V_{max} – vector of maximal speed;
- R – matrix of priorities, which defines priority of directions;
- T – matrix of possible transitions, which defines next section for transition.

Variables:

- t – current time;
- dt – time of iteration;
- $M^1(t)$ – vector of number of vehicles – describes number of cars in each section;
- $M^2(t)$ – matrix of number of vehicles – describes possible transitions of vehicles to next section;
- B(t) – number of free space – describes free space (possible number of vehicles to move) in possible directions;
- G(t) – matrix of light durations of the traffic lights – describes duration of lights in each direction; M2(t) – matrix of number of moved vehicles in each direction; V(t) – matrix of vehicles current speed; D(t) – matrix of moving distances.

Algorithms for Problem Solution

Authors have developed and proposed for the first time new flow algorithm (REIT GL-1) for scheduling, taking in account specifics of optimal control of electric transport. Algorithm for traffic light scheduling takes in account intensity of traffic flow and priority of electric transport routes. Algorithm consists of the following steps:

Initialization. t = 0.
Step 1: Defining the vector M^1 of number of vehicles for each section.
Step 2: Transforming the vector M^1 into matrix M^2, where

$$m_{ij}^2 = r_{ij}\cdot m_j^1 . \qquad (1)$$

Step 3: Calculating free space vector B^1 for each section:

$$b_j^1 = m_{\max j} - m_j^1 \quad (2)$$

Step 4: Transforming vector B^1 into matrix B^2, where

$$b_{ij}^2 = r_{ij} \cdot b_j^1 \quad (3)$$

Step 5: Calculating of possible transition matrix H(t) of number of vehicles using free space on the next section:

$$h_{ij} = \begin{cases} m_{ij}^2 \cdot r_{ij}, & b_{ij}^2 > m_{ij}^2 \\ b_{ij}^2 \cdot r_{ij}, & b_{ij}^2 \le m_{ij}^2 \end{cases} \quad (4)$$

Step 6: Finding matrix of costs Z(t), which is maximal number of possibly transited vehicles for each crossroad:

$$z_{ij} = \max_k h_{ij} \quad (5)$$

Step 7: Calculating a matrix traffic light's duration G (t):

$$g_{ij} = \begin{cases} t_a + (z_{ij} \cdot c \cdot d - s_a)/v_{\max}, & z_{ij} \cdot c \cdot d \ge s_a \\ \sqrt{2 \cdot z_{ij} \cdot c \cdot d / a}, & z_{ij} \cdot c \cdot d < s_a \end{cases} \quad (6)$$

Step 8: Selecting minimal time interval from matrix (G (t):

$$dt = min(G).\ t = t + dt; \quad (7)$$

Step 9: Running procedure of traffic flow modelling using the schedule for time period dt.
Step 10: Repeat from step 1.

Procedure of traffic flow control schedule modelling is used on step 9 of REIT scheduling algorithm and consists of following steps

Initialization: Time interval dt, M^1 number of vehicles on each edge; initial speed matrix V^0 for each vehicle on each section, where $v^0{}_{jc} \in V^0$, current distance from crossroad – D^0, where $d^0{}_{jc} \in D^0$, where j–index of the street section, c – vehicle's number. If traffic light on crossroad is green $g_j > 0$, then start the algorithm.
Step 1: Calculating of maximal possible distance to move s_{jc} and maximal speed v_{jc} without hindrances:

$$t_{a_{jc}} = (v_{\max} - v_{jc})/a_{jc} \quad (8)$$

$$s_{jc} = \begin{cases} a_{jc} \cdot dt^2/2 + (dt - t_{a_{jc}})v_{\max}, & dt \ge t_{a_{jc}} \\ a_{jc} \cdot dt^2/2, & dt < t_{a_{jc}} \end{cases} \quad (9)$$

$$v_{jc} = \begin{cases} v_{\max}, & dt \ge t_{a_{jc}} \\ v_{jc}^0 + dt \cdot a_{jc} & dt < t_{a_{jc}} \end{cases} \quad (10)$$

Step 2: Calculating of each car maximally possible transition according to it's position before crossroad:

$$d_{jc} = d_{jc}^0 - s_{jc} \quad (11)$$

Step 3: Calculating of number of vehicles, which have passed the crossroad:

$$C_j = |\{D^1 : d_{jc}^1 < 0\}| \quad (12)$$

Step 4: Calculating a current position of each car before crossroad after transition taking in account hindrances.

$$d^1{}_{jc} \in D^1;\ j = r_i; \quad k = r_{i-1}; \quad i = \overrightarrow{|r|, 2} \quad (13)$$

Step 5: Calculating of each vehicle's actual speed

$$v^1{}_{jc} \in V^1 . \quad (14)$$

6. Step: Calculating average speed of each vehicle

$$\overline{v}_{jc} \in \overline{V} : \overline{v}_{jc} = (d^0_{jc} - d^1_{jc}) / dt . \quad (15)$$

Step 7: Repeat from step 1 with new *dt*.

Computer Experiment

Computer experiment includes modelling of scheduling theory algorithm and flow (REIT GL-1) algorithm in comparison with existing traffic light schedule. Three series X-type crossroads with traffic lights are selected. In Riga it may be streets, where traffic jams are usually creating and public electric transport is moving (Fig. 2.).

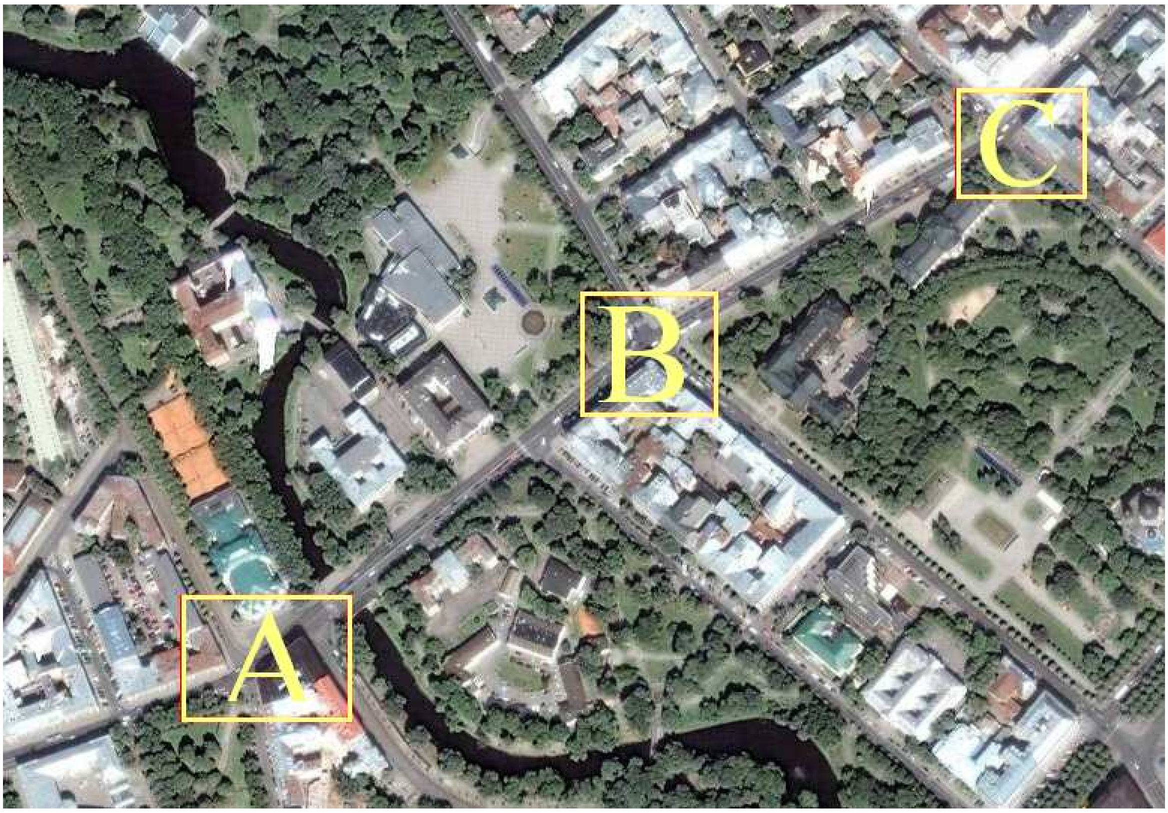

Fig. 2. Example of Riga crossroads of experiment

Transport network graph model is created. Nodes, subnodes and edges are defined (Fig. 3.). Transport flow routes are calculated and priorities are set up.

Following factors are used in calculations during the simulation: maximal number of vehicles on streets, current number of vehicles on streets; free space on the streets, defining number of possible transited vehicles to next section, green and red light duration, current speed of vehicles, current distance to crossroad, maximally possible transition distance for each vehicle, maximal current speed before crossroad after transition, average speed of each vehicle. Iteration results are number of vehicles moved away from the street and number of cars left on the street.

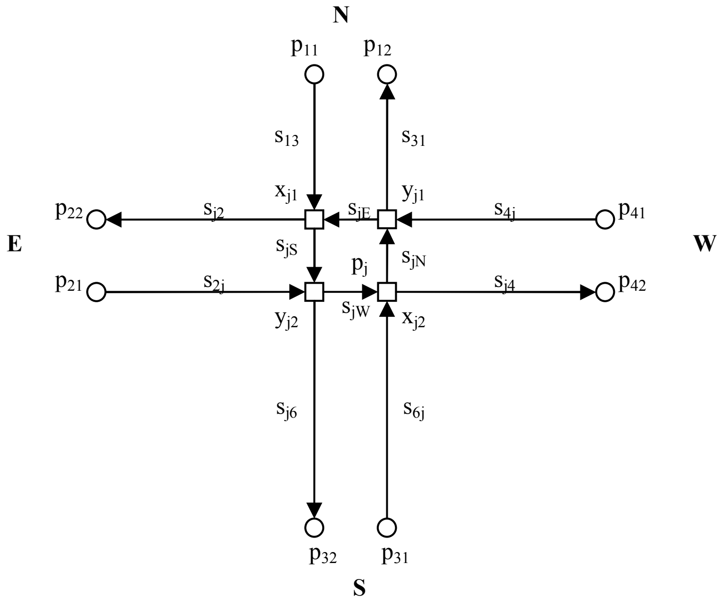

Fig. 3. Example of graph model of j-th crossroad's traffic flows

Following parameters are used for simulation to compare scheduling theory algorithm and REIT GL-1 algorithm with really existing traffic light schedule.

- green light duration limits,
- relative number of electric transport in the traffic flow,
- initial street fullness,
- average length of a vehicle,
- minimal distance between vehicles in traffic jam,
- maximal speed,
- driver's reaction time,
- acceleration time to maximal speed,
- weather, that has influence on driver's reaction and acceleration time:
  - clear,
  - cloudy with rain
  - heavy rain with reduced visibility,
- weights if optimization criteria,
- distributions for time interval between new vehicles and for number of new vehicles:
  - normal
  - uniform,
  - Poisson,
  - exponential,
  - lognormal
  - Weibull.

The computer model is created to work in web-environment and it's graphical user interface is presented on figure 4.

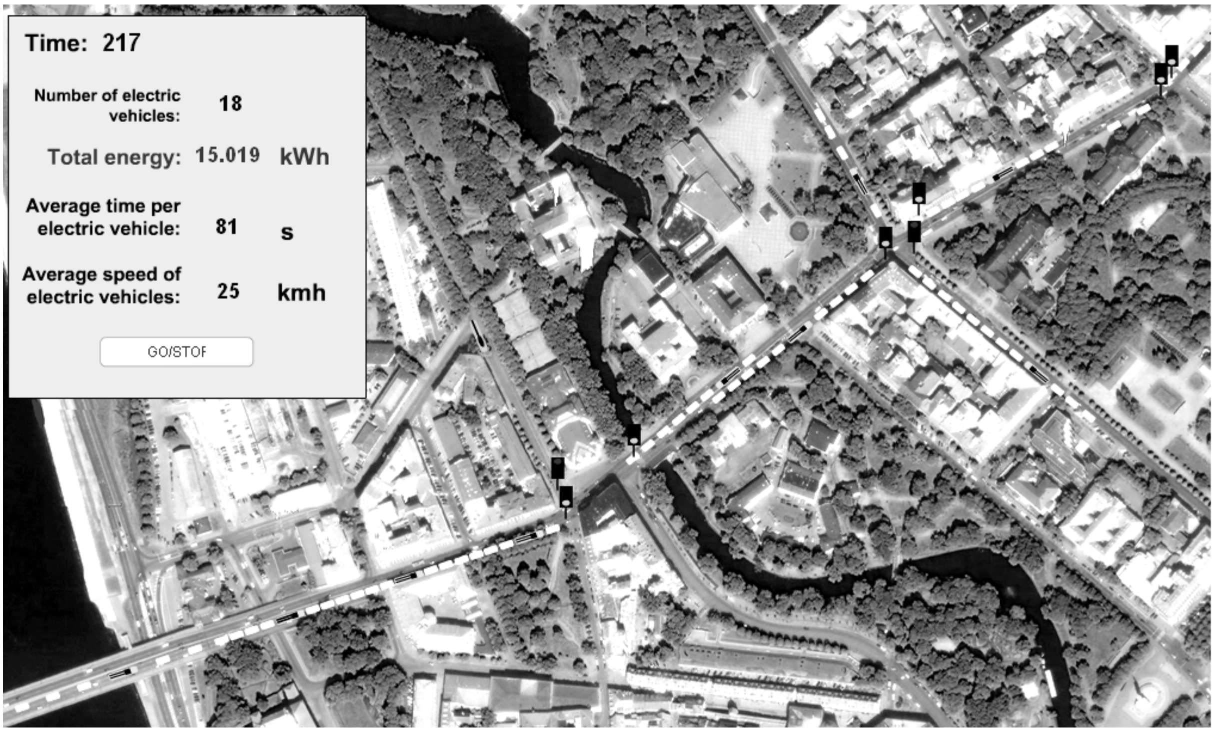

Fig. 4. Interface of the computer model.

Traffic light 3E schedule

0	128	300	394	451	514	600	738	814	847	880	930	997	1038
-128	172	-94	-57	-63	86	138	-76	-33	-33	-50	-67	41	189

Traffic light 3N schedule

0	128	300	394	451	514	600	738	814	847	880	930	997	1038
128	-172	94	57	63	-86	-138	76	33	33	50	67	-41	-189

Fig. 5. Example of graph model of j-th crossroad's traffic flows.

Figure 6 presents the result of modelling of existing traffic light mode and schedule created by REIT GL-1 algorithm. Results of computer modelling shows that REIT GL-1 algorithm gives possibility:

- in case of normally distributed incoming transport flow to reduce consumption of electrical energy up to 32%, to reduce idle time of electric transport up to 13% and to increase motion speed of electric transport up to 53%.
- in case of incoming transport flow distributed by Poisson distribution to reduce consumption of electrical energy up to 31%, to reduce idle time of electric transport up to 9% and to increase motion speed of electric transport up to 24%.
- in case of uniformly distributed incoming transport flow to reduce consumption of electrical energy up to 27%, to reduce idle time of electric transport up to 10% and to increase motion speed of electric transport up to 22%.
- in case of lognormal distributed incoming transport flow to reduce consumption of electrical energy up to 32%, to reduce idle time of electric transport up to 13% and to increase motion speed of electric transport up to 39%.
- in case of exponentially distributed incoming transport flow to reduce consumption of electrical energy up to 26%, to reduce idle time of electric transport up to 20% and to increase motion speed of electric transport up to 31%.

- in case of incoming transport flow distributed by Weibull distribution to reduce consumption of electrical energy up to 7%, to reduce idle time of electric transport up to 14% and to increase motion speed of electric transport up to 12%.

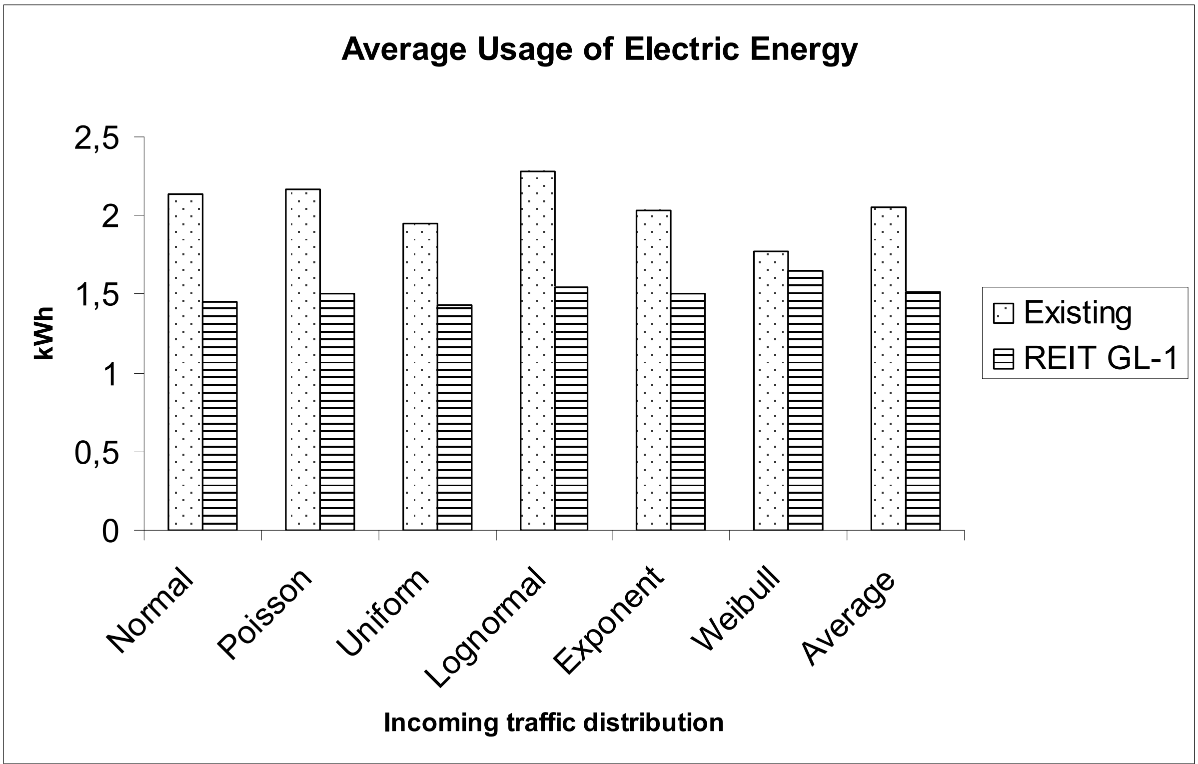

Fig. 6. Comparison of existing situation and work of REIT GL-1 algorithm by electric energy consumption criteria

Total results shows that REIT GL-1 algorithm give possibility to reduce consumption of electrical energy up to 26%, to reduce idle time of electric transport up to 13% and to increase motion speed of electric transport up to 28%.

Conclusions

Algorithm developed in this work may be used for modelling of public electric transport motion and traffic. Developed procedures may be realized in intelligent electric transport control system. Results of modelling of these procedures propose solution for the following tasks: to increase motion speed of public electric transport and to reduce idle time of public electric transport in traffic jams; to reduce consumption of electrical energy using intelligent control system for electric transport, taking in account schedule criteria.

Developed procedures gave possibility to realize algorithm of optimal speed control for modelling of intelligent agents to reduce consumption of electrical energy; to realize modelling of algorithm of negotiation for intelligent agents with a purpose to reduce idle time in traffic jams, to increase average movement speed and to reduce consumption of electrical energy for public electric transport, as well as to optimize traffic flow control.

The result of computer modelling does not include costs for installation of necessary devices. Realistic value should be about 10% of reduction of electric energy consumption. As for Riga 70 000 000 kWh of electric energy is used for electric transport it costs about 3 500 000 Ls. Saving of 10% of this energy may give economy in 350 000 Ls. The economical effect is obvious, as well as traffic jams may be reduced using developed algorithm.

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Gorobecs M., Levčenkovs A., Ribickis L., Balckars P. Sarakstu teorijas algoritmu izstrāde un modelēšana intelektuālā elektriskā transporta sistēmā

Pētījuma mērķis ir izstrādāt jaunus matemātiskos modeļus un jaunus algoritmus intelektuālām iekārtām, lai vadītu elektriskā transporta sistēmu, ņemot vērā dinamiskos parametrus pilsētas transporta sistēmā. Modeļi un algoritmi tiek piedāvāti daudzkriteriālai optimizācijai.

Pētījuma galvenais mērķis ir samazināt pilsētas elektriskā transporta elektroenerģijas patēriņu. Matemātiskais modelis un sarakstu teorijas algoritms izstrādāts un piedāvāts, lai atrisinātu daudzkritēriju optimizācijas uzdevumu elektroenerģijas patēriņa minimizēšanai, stāvēšanas laika minimizēšanai un vidējā transporta plūsmas kustības ātruma maksimizēšanai ceļu sastrēgumos.

Sabiedriskā elektrotransporta sistēmas matemātiskajā modelī ir dinamisko parametru kopa. Visi mainīgie nepārtraukti mainās. Līdz ar to ir nepieciešams izmantot sarakstu teorijas algoritmu, lai adaptētu optimālo risinājumu tekošo dinamisko parametru vērtībām. Sarakstu teorijas algoritmu ar dinamiskiem parametriem var pielietot luksoforu darbības grafika sastādīšanai, ņemot vērā transporta plūsmu un sabiedriskā transporta sarakstu, lai izvairītos no dīkstāves, direktīvo termiņu pārkāpumiem un pasažieriem piedāvātu labāku servisu. Rakstā tiek apskatīts arī praktisks piemērs, lai pārbaudītu piedāvāto modeli un noteiktu algoritma efektivitāti.

Gorobetz M., Levchenkov A., Ribickis L., Balckars P. Development and modelling of scheduling theory algorithms for intelligent electric transport system

The purpose of research is to develop new mathematical models and new algorithms for intelligent devices to control in electric transport system taking in account dynamic parameter of city transport system. Models and algorithms are proposed for multi-criteria optimization.

Main goal of research is energy saving for public electric transport. Mathematical model and scheduling theory algorithm is developed and proposed in the paper to solve multi-criteria optimization task minimizing idle time and electric energy used by public electric transport and maximize average speed of the flow in traffic jam.

Mathematical model of public electric transport system has a set of dynamic parameters. All these variables are changing continuously. That is why scheduling theory algorithm is necessary to adopt optimal solution to current input dynamic parameters. Scheduling theory algorithm with dynamic input parameters can be very useful to create schedule for traffic lights according to transport flows and public electric transport schedule to avoid idle time, directive term infringements and to provide faster service to passengers. Paper presents a practical example to test proposed mathematical model and workability of developed algorithm.

Горобец М., Левченков А., Рибицкис Л., Балцкарс П.. Разработка и моделирование алгоритмов теории расписаний для интеллектуальных электротранспортных систем

Цель исследования разработать новые математические модели и алгоритмы для интеллектуальных устройств для управления системой электротранспорта принимая во внимание динамику городского транспорта. Модели и алгоритмы предложены для многокритериальной оптимизации.

Главная цель исследования это уменьшение затрат электроэнергии для городского электротранспорта. Математическая модель и алгоритм теории расписаний разработаны и предложены для решения многокритериальной задачи оптимизации для минимизации затрат электроэнергии, минимизации времени простоя и максимизации средней скорости движения во время затора.

Математическая модель системы общественного электротранспорта содержит ряд динамических параметров, которые непрерывно изменяются. Поэтому возникает необходимость использовать алгоритмы теории расписаний для адаптации оптимального решения под текущее значение динамических параметров. Алгоритм теории расписаний может быть применен для составления графика работы светофоров, учитывая поток транспорта и расписание общественного электротранспорта, чтобы уменьшить время простоя, нарушения директивных сроков и предложить лучшее качество сервиса для пассажиров. В статье рассмотрен также практический пример для проверки эффективности модели и разработанного алгоритма.