KAUNAS UNIVERSITY OF TECHNOLOGY

Mindaugas Juraška

TRANSPORT STREAM MODELING USING COLORED PETRI NETS

Summary of doctoral dissertation

Technological Sciences, Electrical and Electronics Engineering (01T)

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The research was accomplished during the period of 2000 – 2004 at Kaunas University of Technology

Scientific supervisor:

Assoc. Prof. Dr. Kastytis Kiprijonas ŠARKAUSKAS (Kaunas University of Technology, Technological Sciences, Electrical and Electronics Engineering - 01T).

Council of Electrical and Electronics Engineering Sciences trend:

Prof. Dr. Habil. Danielius EIDUKAS (Kaunas University of Technology, Technological Sciences, Electrical and Electronics Engineering - 01T) - **chairman**;
Prof. Dr. Jonas DAUNORAS (Kaunas University of Technology, Technological Sciences, Electrical and Electronics Engineering - 01T);
Prof. Dr. Habil. Vilius Antanas GELEŽEVIČIUS (Kaunas University of Technology, Technological Sciences, Electrical and Electronics Engineering - 01T);
Dr. Rimantas KALNIUS (JSC "Ekranas", Technological Sciences, Electrical and Electronics Engineering - 01T);
Prof. Dr. Habil. Jonas STANKŪNAS (Vilnius Gediminas Technical University, Technological Sciences, Electrical and Electronics Engineering - 01T).

Official opponents:

Prof. Dr. Habil. Algimantas, Juozas POŠKA (Vilnius Gediminas Technical University, Technological Sciences, Electrical and Electronics Engineering - 01T);
Prof. Dr. Habil. Algimantas FEDARAVIČIUS (Kaunas University of Technology, Technological Sciences, Transport Engineering - 03T).

The official defense of the dissertation will be held at 11 a.m. on June 28, 2005 at the Council of Electrical and Electronics Engineering Sciences trend, public session in the Dissertation Defense Hall at the Central Building of Kaunas University of Technology (K. Donelaičio g. 73, room N 403, Kaunas).

Adress: K.Donelaičio g. 73, LT-44029 Kaunas, Lithuania.
Tel.: (370) 7 300 042, fax: (370) 7 324 144, e-mail: mok.skyrius@ktu.lt

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KAUNO TECHNOLOGIJOS UNIVERSITETAS

Mindaugas Juraška

TRANSPORTO SRAUTŲ MODELIAVIMAS SPALVOTAIS PETRI TINKLAIS

Daktaro disertacijos santrauka

Technologijos mokslai, elektros ir elektronikos inžinerija (01T)

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***Disertacija rengta 2000-2004 metais Kauno technologijos universitete*.**

Mokslinis vadovas:

doc. dr. Kastytis Kiprijonas ŠARKAUSKAS (Kauno technologijos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T).

Elektros ir elektros inžinerijos mokslo krypties taryba:

prof. habil. dr. Danielius EIDUKAS (Kauno technologijos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T) – *pirmininkas****;***
prof. dr. Jonas DAUNORAS (Kauno technologijos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T);
prof. habil. dr. Vilius Antanas GELEŽEVIČIUS (Kauno technologijos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T);
dr. Rimantas KALNIUS (AB "Ekranas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T);
prof. habil. dr. Jonas STANKŪNAS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T).

Oficialieji oponentai:

prof. habil. dr. Algimantas, Juozas POŠKA (Vilniaus Gedimino technikos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T);
prof. habil. dr. Algimantas FEDARAVIČIUS (Kauno technologijos universitetas, technologijos mokslai, transporto inžinerija – 03T).

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Adresas: K.Donelaičio g. 73, LT-44029 Kaunas, Lietuva.
Tel.: (8-37) 300042, faksas: (8-37) 324 144, el. paštas: mok.skyrius@ktu.lt

Disertacijos santrauka išsiųsta 2005 m. gegužės 23 d.

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General characteristics of the research

Presently, in the countries of the EU, 44 % of the load market and 79 % of the passengers market fall to the road traffic; accordingly to railway traffic – 8 % and 6 %.

It should be admitted that at present the road transport is better applied to the needs of new economy. However, the increasing vehicle traffic flows raise rather serious problems, such as:

- traffic jams;
- air pollution;
- high accident level.

Among the main means for improvement of the state, the European Commission provides the increase of the railway role.

In order to achieve this aim it is necessary to solve a lot of rather serious problems among which the most urgent are the following:

1. The lack of information and its wrong use (poor level of the customers' information, insufficient or ineffectively applied information of technological character);
2. Unsatisfactory quality of traffic control.

European Rail Traffic Management System (ERTMS) is being developed and implemented in the EU for the solution of the further mentioned problems. It provides a qualitative leap both in the system of economic railway activity organization and in the system of train traffic management.

Optimal train traffic scheduling and control of these schedules execution (train management) are the most important future tasks. Since it will not be possible to avoid certain disorganizations of the target traffic schedule, the other important task is *optimal adjustment of the disorganized traffic schedule*.

The problem of the traffic schedule optimal adjustment is based on the determined data.

The purpose of the research:

To create traffic optimal adjustment methods and algorithms based on the theory of Petri nets.

To investigate the functionality of created algorithms.

The goals of the research

To create the methodic of effective stops minimization.

To create the imitational road section model using Petri net modeling means that enables to solve the problems of unplanned stops according the proposed methodic.

Relevance of the research

According to the requirements for transport it is needed

To increase the economical efficiency of transit creating and introducing methods and algorithms enabling to avoid forced and unscheduled stops causing extra energy input.

In this research the author ***presents and defends:***

1. Train stream optimal adjustment methodology and algorithm that are used in order to pass the already collected equipment in the shortest time and with the minimal input, and move into the normal traffic schedule.
2. Stream modeling method reasoned by the theory of colored Petri nets.
3. The stream adjustment algorithm reasoned by the use of colored Petri nets theory was devoted for the input minimization and created by traffic modeling method.

The originality of the research:

1. The stream imitational model is created on the base of colored Petri nets, enable prognosticate conflicts situations them resolution minimize input.
2. The analogical methods and algorithms reasoned by colored Petri nets theory use was not obtained in the literature sources.

Approbations:

Topic of the dissertation was published in:

4 articles of periodical scientific publications from the list approved by Lithuanian Ministry of Education and Science;

4 articles in the materials of the papers of scientific conferences (in Lithuania)

Content of the dissertation:

The research problem, its relevance and the formulated goals are described in the ***Introduction***.

Chapter 1 ("Stream organization and traffic schedule optimization and adjustment. Literature review and analysis") consists of 6 sections.

Optimization criterion of the passengers trains in the first section. The so-called *source and purpose matrixes* formed processing data of sociological questionnaires and statistical research (including the investigations of the flows) are used for description of the clients' needs.

The problem of the passenger train traffic schedule optimization most often is converged into the *periodic event scheduling problem* for solution of which the programming methods of linear, non-linear or composite *whole number* are used.

The formulations of all three types of problems are presented in this work.

Freight train traffic schedule optimization methods are reviewed in the second section.

The analysis of optimization methods and algorithms reviewed in the first section evaluating the possibilities of their adaptability to the stream optimal adjustment are given in the third section.

It is pointed that the discussed train traffic schedule optimization algorithms can be adapted for the problem of traffic schedule optimal correction, but there are two essential shortcomings:

1. Minimizing the transit cost price it is manipulated by the time of arrival and departure underestimating that this time can be frequently changed only by the method of train *speed change*; but in this case in the already mentioned problem phrasing, the input of the energy are evaluated not enough exactly, as they depend on speed;
2. A lack of attention is paid to the practical ***realization accuracy*** of the planned traffic schedule in the discussed algorithms. But the researches show that this schedule can be fully disordered even in the path of not intensive traffic because of insufficient exactness of traffic schedule practical realization.

The fourth section ("Comparative electric energy input going by electric locomotive") deals with the train fuel input with the electric pull. After investigation it was set that train fuel input with the electric pull depends on the road decline and character, on the bearings used in the carriages, and also on the environmental temperature, train mass, speed, etc.

The fifth section ("Comparative fuel input within the thermal powering") deals with the train fuel input within the thermal powering. After investigation it was set that train fuel input within the thermal powering (similarly as in the case of electric locomotive) depends on the road decline and character, on the bearings used in the carriages, and also on the environmental temperature, train mass, speed, etc.

Short Petri net history and the spheres of their application are described in the sixth section. The results of train station modeling using colored Petri nets by various authors are analyzed there also.

Chapter 2 ("The transport theory of speeds") consists of 3 sections. Calculation methods of fuel input with thermal powering are given in the first section, train passing in the stations is given in the second section, the train traffic schedule modeling possibilities using black–and-white Petri nets are given in the third section.

The fist section ("Fuel input calculation with thermal powering") deals with the fuel input calculation with thermal powering that consists of fuel input on purpose to reach the proper speed (racing), fuel input for the support of constant speed (i.e., train drive). The reliance of train mass on fuel input in racing and driving are also investigated there.

The passing of the trains going vis-à-vis in the stations is analyzed in the second section ("Streams passing in the stations").

The question of passing without forced stops is relevant only in single-line railway sectors, or in such sectors where a part of line blocks are single line, and the other part are dual gauge railway. The pass can be made in single line roadways only in the stations (if there is enough length for passing).

In all the cases the railway sector where the trains can pass (no matter without stops or if one of them stops) is called ***overlaking***.

The train pass in the overlaking is shown in Fig. 1.

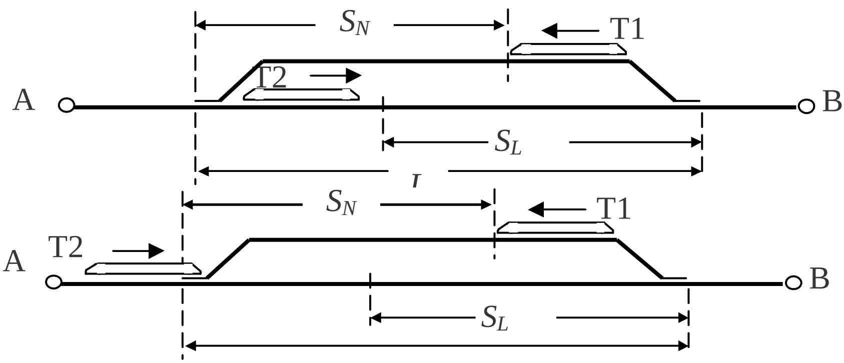

Fig. 1. The scheme of train pass in overlaking

The odd and even trains are marked as T1 and T2 (Fig. 1).

S_N and S_L are respectively the braking distance of odd and even trains;

L is the length of the overlaking.

The rules of undisturbed (without forced stops) train pass are (Fig. 1):

1. The train that came the first into the overlaking (Fig. 1, let it be T1) must constantly get the information about the distance that is left till the end of the overlaking (such information can be given by the radio blocking center RBC, or the distance can be measured by the processor of T1 locomotive according to T1 starting coordinates x_1 that are measured by itself, and the overlaking end coordinates X_n that are already known in advance) and the signal '*section behind the overlaking is busy/empty*' (the train T2 has not came/came into the overlaking) (such information can be given by the systems RBC or ALSN).

2.In time moment, when the distance to the overlaking end is equal to the train braking distance:

$X_N - x_1 = S_n$, the train going in the opposite direction in all its length must already be in the overlaking (Fig. 1a). It this condition is not fulfilled (Fig. 1b), the train T1must be stopped because the undisturbed pass has failed.

The second rule is fully understood: if the train T1 will not begin to brake in the certain time moment, when $X_N - x_1 = S_n$ it will not stop on the section of the overlaking. At this time train T2 has not vacated the section behind the overlaking and (even if T2 is partly in the overlaking) there is no warranty that this section will be vacated in time.

So, the minimal overlaking length L must meet the condition:

$$L \geq \max\{S_N + l_N + \Delta S\ ,\ S_L + l_L + \Delta S\}\ . \qquad (1)$$

Where ΔS is the *distance of the reaction*, i.e. the distance which the train goes during the time from the decision to begin the stop till the brake moment;

I_N and I_L are respectively the lengths of odd and even trains;

L is the overlaking length for the average weight trains.

It must be noted that the longer paths are needed for the undisturbed pass than ordinary station overlaking paths that have the condition $L \geq l$.

The condition (1) is applied only for the trains that are going according mobile blocked sections (ETCS 2 level, or ETCS 3 level). But this is rather distant future.

The trains going according to the fixed blocked sections need longer overlaking for passing. Five chains of the railings must “go” into overlaking for the train going under the green signal. The overlaking length L must be 8 km as the railings chain length is 1,6 km. The overlaking can be shortened to 5 km using shorter railing chains, but no longer, because shorter than 1 km length chain can be fully “re-covered” by the longer trains. The scheme of overlaking with fixed blocked sections is shown in Fig. 2.

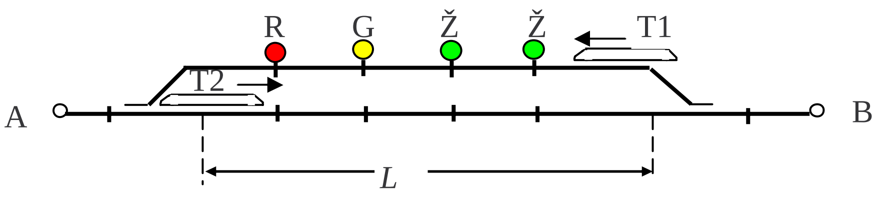

Fig. 2. The scheme of overlaking with fixed blocked sections

Minimal overlaking lengths can be used only in the cases when the trains from the different sides synchronically come to the overlaking. This can be done using EVC system: the trains moving in the line must get the orders to correct (increase or slow down) the speed. The processor equipment of locomotive can do these adjustments, if it has the information about the trajectory (speed, coordinates) of the trains going in the opposite direction.

The train traffic schedule modeling possibilities using black–and-white and colored Petri nets are researched in the third section ("Train traffic schedule modeling using black-and white Petri nets")

The model of line blocks (Fig. 4) was created using program package *Centaurus* (black-and-white Petri nets) (Fig. 3) for the modeling that allows modeling the analogues processes also. While composing the model it was admitted:

1. Place tokens model the trains, and the places – the stations and events.
2. Transitions model traffic conditions.
3. Analogue blocks model the going in the line block.

Four stations (A, B, C, D) (Fig. 3) were taken into account. Dual gauge railway line block is between the side A-B and C-D stations, and between the middle B-C stations is the single line roadway line block.

The principal scheme of those line blocks is given in Fig. 3.

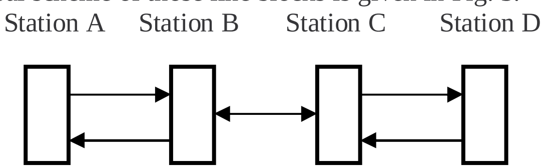

Fig. 3. The principal scheme of the line blocks

It is set that the semiautomatic road block is equipped between those stations, i.e. when only one train can be let into the line block and no one train can be let into the next station (neither after, nor before) till it has not reached the next station.

The program packet *Centaurus Plius* created by the scientific group "Hybrid system modeling" at Kaunas University of Technology was applied for this version to establish the train traffic schedule using black-and-white Petri nets.

The program packet *Centaurus Plius* allows modeling the systems using black-and-white Petri nets. But they are not adapted for the transport system modeling.

The railroad model, modeling the given fragments of stations and line blocks (Fig. 3) is given in Fig.4.

Fig. 4 shows the structure of Petri nets (Fig. 3) for the railroad model.

The following conclusions are made trying to model train traffic schedule using black-and-white Petri nets:

1. The traffic schedules cannot be depicted.

2. The train going speed (freight, passenger trains) cannot be changed dynamically.

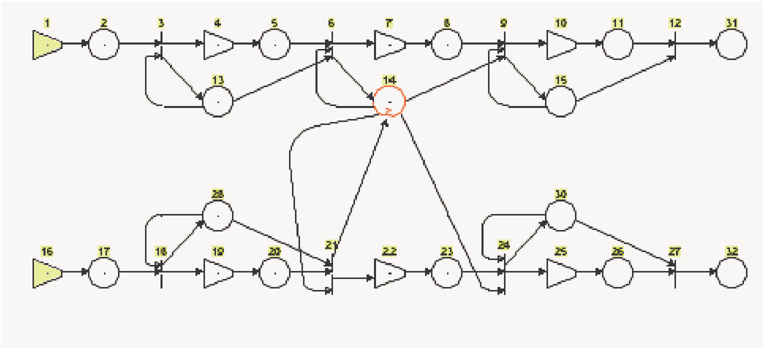

Fig. 4. Petri net structure

The dissolution of those questions clearly shows that the desirable purposes cannot be distinguished by modeling in this way (using black-and-white Petri nets).

Chapter 3 ("Consummate adjustment methodic and algorithm of train stream") is the man chapter of the work. It consists of five sections. Traffic schedule quality criterions are researched in the first section. Train traffic schedule modeling is analyzed in the second section, traffic schedule optimization methodic and algorithms – in the third, algorithms of unscheduled stop search and adjustment – in the four; possibilities of train traffic schedule modeling using colored Petri nets are researched in the fifth section.

In the first section ("The streams quality criteria") it is shown that traffic schedule optimization (adjustment) algorithm essentially depends on the raised purposes and their criteria. At first if there is time limit for the destination station (criterion T_{min}), and the second, if it must be done with the least input not overcoming certain limits (criterion W_{min}).

The algorithm of the schedule optimization according the criterion T_{min} is rather simple: w^{th} train takes given line block without delay, no matter how many times it will stop and how long it will take to stand in order to pass "planned" trains.

Criterion T_{min}can be modified into input that are necessary to reach the station of destination. It includes all the money components connected with the time, such as: exploitation expenses of the locomotive and the carriage, expenses of the crew (crew salary, insurance, etc.).

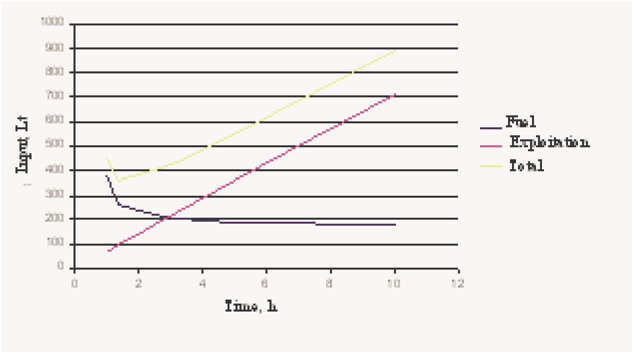

Fig. 5. Train input and their components for the 100 km path

Fig. 5 shows the change of train input on time. Three curves are depicted there: the first (fuel) curve shows only fuel input for the train going 100 km distance that depends on speed; the second (exploitation) curve shows the input of the train exploitation; and the third (total) curve depicts the total input of the fuel and exploitation.

As it can be seen (Fig. 5), the train goes the necessary distance through the shorter time (going more quickly), but at this time it uses more fuel and so the input increases. The train exploitation input increases because of its outage and the going time.

Unnecessary stops and racings and also unnecessary goes in a high speed raises bigger input. So, further we will analyze the situations that allow minimizing those losses of the energy.

Total input algorithm of schedule optimization according complex criterion is more important and more advanced.

Optimization problem can be formulated so:

Minimizing expenses

$$W = T_w W_T + W_w W_q \,. \qquad (2)$$

When

$$T_{w\max} \geq T_w \,. \qquad (3)$$

Where T_w is the time during which the train goes to the destination station (S_n), calculated from the departure of the w^{th} train from the home (S_1) station, h;

W_T are the expenses depending on time, Lt/h;

W_w is the amount of conditional fuel (energy) necessary to overpass the route, kg;

w_q is the cost of conditional fuel unit, Lt/kg;

$$T_w = \sum_{z=1}^{n-1} \frac{l_z}{v_{wz}} + \sum_{i=2}^{n-1} \tau_{wi} \; . \qquad (4)$$

Where v_{wz} is the technical speed of w^{th} train in z^{th} line block, km/h;

L_z is the length of z^{th} line block, km.

$$W_T = L + n_j V + E \; ; \qquad (5)$$

where

W_T is the exploitation expenses, Lt;

L is one hour exploitation expenses of locomotive, Lt;

n_j is the number of carriages in the train;

V is one hour exploitation expenses of the carriage, Lt;

E is one hour expenses of crew keeping (salaries, insurance, etc.), Lt;

W_w depends on the kind of powering (electric or thermal powering).

In not electrified roads

$$W_w = W_{wo} + W_{ws} + W_{wp} \; ; \qquad (6)$$

where

W_{wo} is the fuel used for the train movement, kg;

W_{ws} is the input of fuel used for the braking and racing to the initial speed, kg;

W_{wp} is the input of fuel standing or moving in idle run (further it is disregarded), kg;

W_{wo} depends on many factories, such as: train weight, speed, road profile (uphill, slope), curves, carriage type, locomotive type, road characteristics (with junctions or without).

W_{wo} in all cases in straight and smooth road can be very adequately expressed by formula

$$W_{w0} = \sum_{z=1}^{n-1} \left(\alpha_0 + \alpha_1 v_{wz} + \alpha_2 v_{wz}^2 \right) l_z \; ; \qquad (7)$$

where a_0, a_1, and a_2 are the coefficients evaluating the previously mentioned factors and used for the calculation of w^{th} train;

v_{wz} is the speed of the train run that is bigger that the technical speed, if the train must stop even in one line block bordering the station.

Line block is divided into shorter sections with even road characteristics if there are curves in the line block and the decline is not even and double sums occur in (7).

So, the problem of w^{th} train optimal traffic schedule is formulated so: the management influence u U must be find such that the functional can be minimized, and the underwritten restrictions must be met:

$$T_{w\max} \geq T_w + T_{w1} \; ; \qquad (8)$$

$$v_{wz}^{\max} \geq v_{wz} \geq v_{wz}^{\min} \,. \tag{9}$$

The problem in common case is non-linear and rather complicated.

The railroad traffic schedule modeling methodic is researched in the second section ("Modeling of stream traffic schedule").

One of the main problems of Lithuanian railroads is that there are a lot of single-line line blocks. This single-line roadway line block appeared when the stream of trains has increased, because only one train can be let into single-line line block with semiautomatic road block, and no one other train can come into this line block from no one side till the full train vacates this line block. So, there are unplanned train stops in the stations before single-lane roadways with the intensive train movement.

One of such unplanned stops that occurred in single-line line block between the trains Nr. 1 and Nr. 2 (Fig. 6) is researched properly. The semiautomatic road block is appointed in single-lane roadway line block.

The train N 1 going from the station A to the station C was forced to make unscheduled stop in the station B and pass the train N 2 that was going from the station C to the station A (Fig. 6).

The line block must be free (this line block is single line), i.e, without any trains (this is required by the Instructions of Railway Signalization and Instructions of Railway traffic), when the train N 1 arrives to the station B and wants to go to the line block B-C. So, the train N 1 must wait for the train N 2 will vacate the line-block B-C.

Train N 1 comes into the line-block B-C, when the line block B-C is vacated, i.e. train N 2 vacates this line-block.

Relational fuel input, when the train N 1 goes from the station A to the station C (Fig. 6), is expressed by formula:

$$W = W_1 + W_2 + W_3. \tag{10}$$

Where:

W_1 is the relational fuel input overcoming the line-block A-B;

W_2 is the relational fuel input standing in the station;

W_3 is the relational fuel input overcoming the line-block B-C.

$$W_1 = \int_{v_0}^{v_1} n_T(v)dv + n_{pM}(L_{AB} - l_{TM}) \,. \tag{11}$$

The train fuel input W_1 consists of fuel input for the racing to achieve the desired speed v_1 and fuel input for the remained distance after the racing.,

where:

L_{AB}- is the distance of line block A-B, km;

l_{TM}- is the distance while racing to the maximal speed;

n_T – is the fuel input for the train quickening for 1 km/h;

n_{pM} – is the fuel input for the train to ride 1 km, when the speed is maximal.

The train fuel input W_2 consists of: n_{st} (fuel input connected with the stops) and n_x (idle run fuel input, when the locomotive is standing and the sums are multiplied from the train standing time, i.e., train N 1 fuel input will depend on train n_{st} standing time, because time influences the keep of the crew (salaries, insurance, etc.), the input of train expenses, locomotive expenses, etc. and on the idle n_x run, fuel input, when the locomotive is working.

The situation when the train N1 will be forced to stop in the station B and let the train N 2 pass is shown in Fig. 6; so the train N1 fuel input will be obtained according:

$$W_2=(n_{st}+n_x)t.; \tag{12}$$

where:

t- is the time spent in the station.

The fuel input of the train N1 when it goes from the station B to the station C will be:

$$W_3 = \int_{v_0}^{v_1} n_T(v)dv + n_{pM}(L_{BC} - l_{TM}). \tag{13}$$

Train fuel input W_3 consists of fuel input for the racing in order to distinguish the desired speed v_1 and the fuel input for overcoming the remained distance after the racing.

where:

L_{BC}- is the distance of line block B-C, km;

l_{TM}- is the distance while racing.

In order to avoid those unplanned fuel input, the train traffic must be organized so that all the trains could pass in the stations and come into the line block when the road is empty.

The critical places (the train traffic schedule places where the train was forced to stop for passing or when he came and the line block was engaged and he had to wait for the empty line block) must be found (Fig. 6).

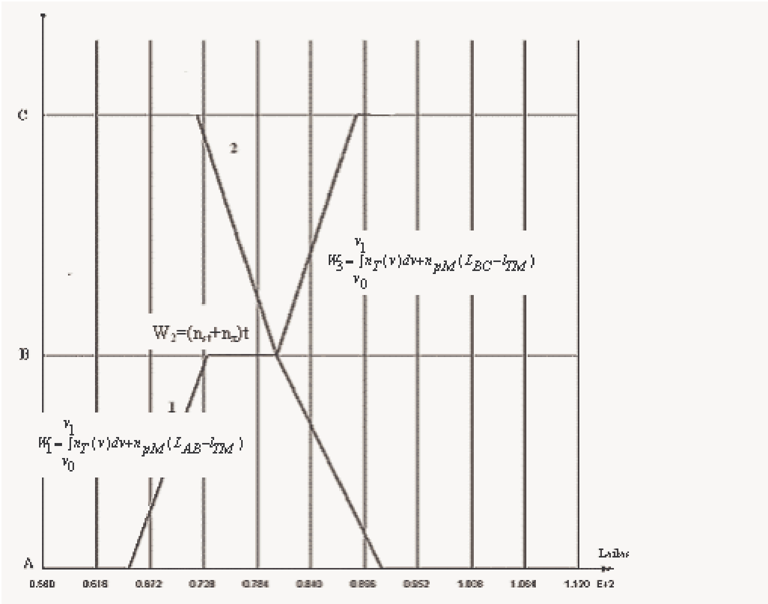

Fig. 6. The fragment of train traffic schedule

The question how to adjust the train traffic after having find those critical places in order to avoid the unscheduled train stops and do not change the already existing traffic arise.

The only solution is to adjust the speed of the unscheduled train stop in order to come the train in time and the trains could pass in the station, and come into line block when it is empty.

The speed of unscheduled train stops must be adjusted only by minimizing it, because the biggest allowed speed does not permit to increase (the trains go in several maximal allowed speeds in Lithuanian Railways that are limited by the maximal allowed speed of the road and the train).

If the train N 1 will go by the adjusted speed (Fig. 7), the researched schedule will be:

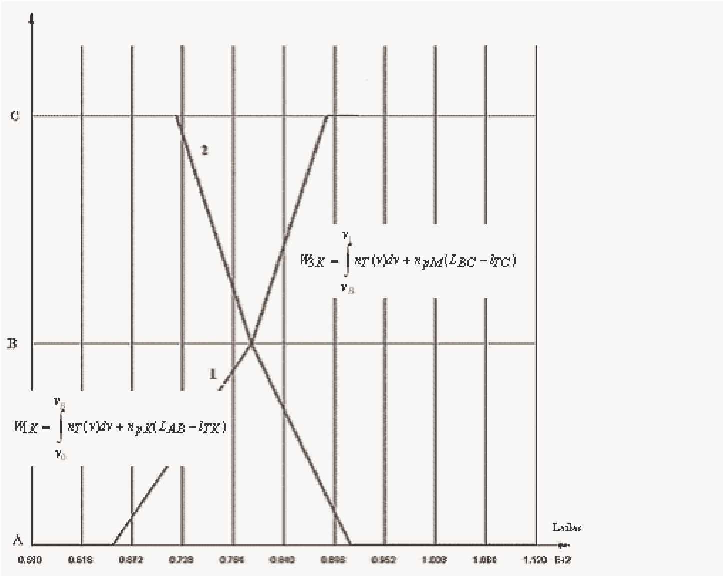

Fig. 7. The fragment of the adjusted train traffic schedule

The train traffic schedule with no forced stops and so the unnecessary fuel input can be avoided is obtained when the trains go by recommended speed in critical places.

The train N 1 will turnout the train N2 in B station and so the unscheduled stop will be avoided.

The train traffic schedule without forced stops and so avoiding the unnecessary fuel input are obtained when the trains are going by the recommended speed in critical places.

The fuel input when the train N 1 is going from the station A to the station C (Fig. 7) will be:

$$W_K=W_{1K}+W_{3K}; \quad (14)$$

where:

W_{1K} – is the fuel input passing the line-block A-B;

W_{3K} - is the fuel input passing the line block B-C.

The fuel input when the train is going from the station A to the station B are obtained according formula:

$$W_{1K} = \int_{v_0}^{v_B} n_T(v)dv + n_{pK}(L_{AB} - l_{TK}) . \quad (15)$$

Train fuel input W_{1k} consists of fuel input for the racing in order to achieve adjusted speed v_B and fuel input for the passing the rest distance of line block after the racing.

where:

L_{AB}- is the distance of line block A-B, km;

l_{TK}- is the distance while racing to the adjusted speed.

n_T – is the fuel input for the train quickening for 1 km/h

n_{pK} – is the fuel input for the train to ride 1 km, going by adjusted speed.

The fuel input when the train goes from the station B to the station C is obtained according formulae:

$$W_{3K} = \int_{v_B}^{v_1} n_T(v)dv + n_{pM}(L_{BC} - l_{TC}) . \quad (16)$$

Train fuel input W_{3k} consists of fuel input for the train racing from the speed v_B to the speed v_1 speed difference and fuel input for going the line block distance after the racing.

where:

L_{BC}- is the distance of line block B-C, km;

l_{TC}- is the distance while racing from the speed v_B to v_1, km

So, if the forced stop is made, the expenses are:

$$W= \int_{v_0}^{v_1} n_T(v)dv + n_{pM}(L_{AB} - l_{TM}) + n_{st} + n_x + \int_{v_0}^{v_1} n_T(v)dv + n_{pM}(L_{BC} - l_{TM}) \cdot$$

In the second case if the speed is adjusted, the expenses are the following:

$$W_K = \int_{v_0}^{v_B} n_T(v)dv + n_{pK}(L_{AB} - l_{TK}) + \int_{v_B}^{v_1} n_T(v)dv + n_{pM}(L_{BC} - l_{TC}) .$$

In those expressions it can be observed that the expenses for racing of adjusted traffic schedule are twice less , because only the one race to the maximal speed remains, because: $\int_{v_0}^{v_B} n_T(v)dv + \int_{v_0}^{v_B} n_T(v)dv = \int_{v_0}^{v_1} n_T(v)dv$.

The fuel input to ride 1 km with the forced stop are higher than the fuel input going by adjusted smaller speed.

So, as it can be seen from Fig. 7 that when the train N 1 is going by adjusted speed, the fuel input is becoming smaller depending on the four components mentioned above.

So, W_K<W, and the exact values obtained for the researched path section are given in appendixes.

The adjustment methodic and algorithm of traffic schedules are analyzed in the third section ("Streams adjustment methodic and algorithm").

In the common case *m* train traffic railway line going through *n* stations and with no branches, the schedule is used to be optimal, if the minimum of such criterion is secured. More detailed form must be given for this criterion:

$$C = \min_{t_{1j}, v_{ij}} \left(\sum_{i=1}^{n} \sum_{j=1}^{m} \left[W_{Eji} W_q + W_{Tji} + W_{Sji} \left(t_{1j} \mid_{j=\overline{1,m}}, v_{ij} \mid_{i=\overline{1,n},\, j=\overline{1,m}} \right) W_q \right] \right) \tag{17}$$

where:

W_{Eji} is the input of the energy (in fuel or energy units) for the jth train crossing (going) the ith line block connecting ith and (i + l)th stations;

W_{Tji} is the input (in terms of money) related to the spend time of jth train in the ith line block (including (i+1)th station); equipment lease, salary to the staff, etc.;

W_{Sji} is the input (in fuel or energy units), related with the braking of the jth train (racing further) in the (i+1)th station;

W_q is the price of the fuel or energy unit.

The further mentioned formula is used for the W_{Eji} calculating:

$$W_{Eji} = k_{ri} k_{ti} \left(S_j + \left(R_j + \frac{T_j}{Q_j} \right) \right) w_{ji} \frac{Q_j l_i}{3440} \tag{18}$$

Where:

S_j, R_j and T_j are the parameters of jth train locomotive, given in its documentation;

Q_j is the weight of jth train, t;

L_i is the length of Ith line block, km;

$$W_{Tji} = w_L \left(t^i_{j(i+1)} - t^i_i \right) \tag{19}$$

$$W^0_{Tji} = w_L \left(t^i_{ji} - t^i_{11} \right) \tag{20}$$

In the case of electric powering

$$W_{Sji}=\begin{cases}1{,}17\times10^{-7}v_{ji}^2Q_j\left[1029\left(1+\gamma_j\right)-\dfrac{w_{ji}}{a_{jT}}\right] & \text{If the } j^{th} \text{ train is stopped in the } (i+1)^{th} \text{ station}\\ 0 & \text{In the opposite case}\end{cases} \quad (21a)$$

In the case of thermal powering

$$W_{Sji}=\begin{cases}0{,}51`5\times10^{-7}v_{ji}^2Q_j\left[1029\left(1+\gamma_j\right)-\dfrac{w_{ji}}{a_{jT}}\right] & \text{If the } j^{th} \text{ train is stopped in the } (i+1)^{th} \text{ station}\\ 0 & \text{In the opposite case}\end{cases}$$

$t_{11}>0$; (22)

$t_{1j}>t_{1(j-1)}v_{(j-1)1}l_1$; (23)

$v_{jimin}\geq v_{ji}\geq v_{jimax}$ (24)

The problem (17) – (24) is nonlinear (because of (21)) and can be solved in the methods of stochastic extremum search or the method of the version reselection.

The solution of the problem using the algorithm of version reselection can take a lot of time even using modern calculation means. E.g, if the number of stations is n = 10 and the number of trains is m = 30, the time is discretized by 10s steps and the speed by 0,1 km/h step, the number of versions reaches N = 2,16 x 10^7, what means very many, having in mind that braking or not braking in the stations can be set only by the method of imitational modeling.

The simplified formulation of the problem (17) – (24) is proposed in this work. It is grounded by the preposition that the effect is obtained decreasing the speed and it is bigger than the loss conditioned by the greater use of the equipment and staff occupation in time.

$$C=\min_{v_{ij}}\sum_{i=1}^{n}\sum_{j=1}^{m}\left[W_{Sji}\left(v_{ij}\,|_{t_{1j}\to fix}\right)W_q\right] \quad (25)$$

W_{Sji} is expressed by (21)

The problem (25) is proposed to solve using the following algorithm:

1. The traffic schedule is composed, where (∇j, ∇i)

   $v_{ji}=v_{ji\max}$,

   $t_{11}=0$,

   $t_{1j}=t_{1(j-1)}+\dfrac{v_{1j\max}}{l_1}, \quad j>1;$

2. The train standing time in all transitional stations is obtained by the method of imitational modeling.

$$\Delta t_{ji} = t_{ji}^{i} - t_{ji}^{a} \big|_{(i \neq 1, i \neq n)}.$$

3. The train speed is reduced according the formula

$$v_{ji} = v_{ji\max} - \frac{l_i}{\Delta t_{ji}}$$

The unscheduled stop search algorithm is researched in the fourth section ("The algorithm of unscheduled stop search and adjustment").

The search of unscheduled stops and they are removed decreasing the train speed, i.e., the traffic schedules will be made without unscheduled is the algorithm of unscheduled stop search.

Every critical place consists of three critical points and those points make the triad. The coordinates of those three points are characterized by the six variables:

X1, Y1; X2, Y2; X3, Y3;

Where:

X is the time;

Y is the distance.

The presentation of critical places is given below:

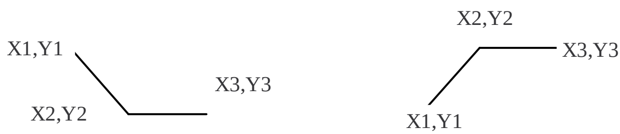

Fig. 8. The presentation of critical places

The conflict origin can be set just when it occurs during the imitational modeling, but the time for train standing can be set only after obtaining the results when the train begins to move again. As this process is going in time, so the model can not influenced in backward time, and the other ways of solution must be searched.

The way of modeling when all the information during imitational modeling is put into appropriate data basis is proposed. Then the full obtained analysis can be made determining all possible and impossible situations and during the second modeling automatically or manually the traffic schedule adjustment can be made.

The solution of such a problem was not found, so for setting such situation and forecasting the recommended speed to avoid the unscheduled stop the following algorithm of program fragment is proposed.

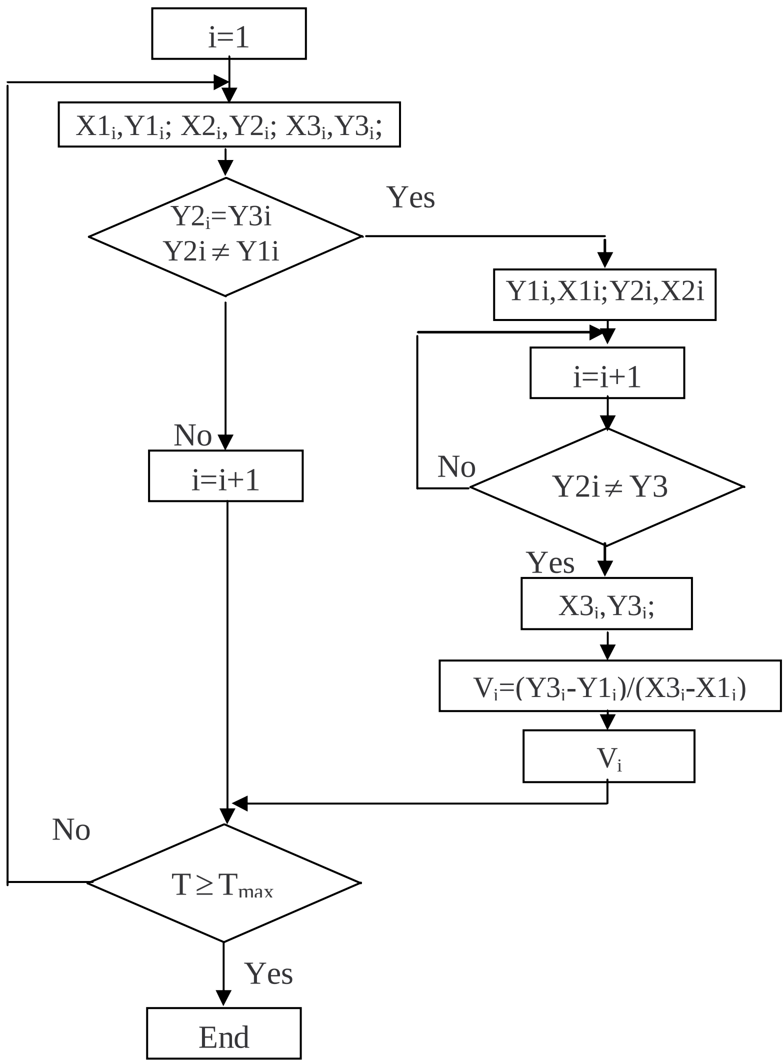

Fig. 9. The algorithm of unscheduled train stop search and traffic schedule adjustment

From the given algorithm (Fig. 9) can be seen that the variables X1i, Y1i; X2i, Y2i; X3i, Y3i are written at first, then it is checked if the variable Y2i = Y3i and Y2i ≠ Y1i. The first condition checks if there was a stop of the train,

and with the second condition it is checked if the train was moving before the stop. The second condition is checked for the purpose to set if the train had any move at all before the stop. If all those conditions are completed, then
the variables X1i, Y1i; X2i, Y2i are memorized and recorded, then it is going to the next variables X1i, Y1i; X2i, Y2i; X3i, Y3i. With the help of the step i = i + 1 step the condition Y2i ≠ Y3i is checked. If this condition (during this check it is set, when the train has moved) is:

- completed, then the variable X3i, Y3i is memorized and recorded and the proposed train speed is calculated according formula V=((y3-y1)/(x3-x1)), where X is the time and Y is the distance. Having calculated the recommended train speed, having memorized and recorded it, the history file time is checked;
- uncompleted, it is going to the other variables X1i, Y1i; Xx2i, Y2i; X3i, Y3i by the help of the step i = i + 1;

If the conditions are uncompleted:

It is going to the other variables X1i, Y1i; Xx2i, Y2i; X3i, Y3i by the help of the step i = i + 1;

After that the condition $T \geq T_{max}$ is checked (if the history file has not finished):

uncompleted:

All the checks are made once more;

completed:

The end of the process.

The train traffic schedule modeling possibilities using colored Petri nets are researched <u>in the fifth section</u> ("Train stream schedule modeling using colored Petri nets").

The program packet *Centaurus C* created by the scientific group "Hybrid system modeling" at Kaunas University of Technology was applied in order to establish the train traffic schedule using colored Petri nets.

The following description was chosen for creating the railroad traffic model using the program package *Centaurus C*:

1.Declarations;
2. Time;
3. Token;
4. Place;
5. Transition;
6. Branch.

Declarations

The declarations in the *Centaurus C* packet differs from standard Petri nets declaration because the data needed for schedule structure (distance between the stations) are described for depiction of train traffic schedules. The train going directions (odd, even), train sorts (freight and passenger) are distinguished in the declarations. The special program sub-system for the depiction of traffic schedule and the solution of the problems of this work was created.

Time

The time in *Centaurus C* packet is global, differently from the other program means working on the basis of Petri nets. The variable *$Time* describes it. The time in the created model is calculated when the delay is processing, in the other case it is stopped, because the tokens instantly are going through the branches into the transitions or places.

Token

The train with all features urgent for the modeling is described by the token. The train-token expression is:

1'(n, v, t1, l2, t3, d, r, sp, st, gp, gv);

where:

n is the number of the train;

v is the speed of the train in the line blocks;

t1 is the entry time of coming into the station, this time is recorded when the train from the branch comes into the station and is used for the drawing of train traffic schedules;

l2 is the driven distance by the train; it is recorded every time when the train leaves the line block;

t3 is the time of leaving the line block; this time is recorded when the train leaves the station and is used for the drawing of the train traffic schedules;

d is the going direction (odd, even) that is used for setting the direction of the train;

r is the sort of the train and is committed for the determination of the type of the train (passenger, freight) and the designed speed in the line block;

sp is the list of the stations where the train will stop for the intended stop;

st is the list of the time, how long will the train stand in *sp* list named station;

gp is the list in what line blocks (transitions) the train must go in recommendable speed;

gv is the list by what recommendable speed the train will go in the certain line block.

The remained attributes of three types (positions, transitions, and branches) can successfully model the situations of railways and stations.

Place

Place corresponds the station.

All the trains are put in the phenomenon of the initial position initiation, i.e., the tokens that must pass the created model.

Transition

The transition corresponds the line block.

The transition is created from two functions, i.e., control and delay functions.

Newly created function *IsMin* is used in the transition. It is designed for several trains that come into one station and according the description of Petri nets nothing disturbs them to come together to the line block; so all the trains that wish to come into the line block are controlled by the control phenomenon (function *IsMin*). The control phenomenon establishes that the first to leave the station train is that (function *IsMin*), which came into the station the first, i.e., that has t1 (time of coming into the station) is less. The *IsMin* phenomenon greatly simplifies the structure of the net, because there is no need to install additionally the control phenomenon for the train leaving the station (above mentioned situation).

The train going in delay phenomenon is simulated; i.e. subjected to the sort (freight or passenger) in the delay phenomenon the different delay will be set (if the train is passenger, it can go more quickly in the line block and the delay time will be smaller, if the train is freight – its speed is less and the delay will be bigger). The train leaves the line block after the delay and then the line block becomes empty.

Branch

The branches are of two types:

a) b)

Fig. 10. The types of the branches

The example of the branch when the traffic goes from the station to the line block (from the place to the transition) is given (Fig. 10 a). Then branch phenomenon is a constructor, i.e., the phenomenon is created only from the variables; so those variables obtain the values of attribute of the train (token) in the station (place).

The example of the branch when the traffic goes from the line block to the station and in this branch the direction d of the train going is checked, and only after the coincidence of the proper direction, the train can come into the station; the train data renews, i.e. the existing time is recorded to the train t1 variable (the time of coming into the station), and the variable l2 (driven distance) is added to the distance that the train had passed in the former transition (this is necessary for the drawing of the diagram).

The model of dual gauge line block

The structure between two stations, when there is dual gauge line block model between those stations is composed and shown in Fig. 11.

Places 1 and 6 correspond A station, and positions 2 and 5 correspond B station; the color is depicted by the title *TRAIN*.

The train movement goes in one direction between the stations 1 and 2 in the line block A-B in the even road, and between the stations 5 and 6 in the other direction by the line block A-B of the odd road.

The transitions 3 and 8 depict A-B line block, transition 3 corresponds the even road, and the transition 8 corresponds the odd road.
The line block title, the delay and control phenomena are recorded there.

At the beginning of the phenomenon, with the help of delay

```
if exists($nmb,gp) then
   AB/nth(gv,isnth($nmb,gp))
else
   if r = kel then
      if v > 1.67 then
         AB/1.67
      else
         AB/v
   else
      if v > 1.33 then
         AB/1.33
      else
                  AB/v
```

it is checked if there is no speed adjustment in this line block; if it is, then the speed adjustment is made and the train going is simulated contrarily for the biggest allowed speed in this line block and at the same time it is checked if the train according to its sort can go by this speed, if no, the speed is slowed to the maximal allowed speed for this sort. The numbers 1.67 and 1.33 in this phenomenon are the speed of the train in km/h; in the first case it is for the passenger trains, and in the second case – for the freight trains. The train leaves the line block after the delay.

The phenomenon *IsMin* performs the check of the variables t1 in the line block control phenomenon *IsMin t1 andalso (e1 <=$Time)*, i.e., which of them is the smallest; so having inscribed this phenomenon it controls when several trains come into one station and according to the description of Petri nets, nothing disturbs them to go together into the line block, what is forbidden according to the rules of the railway. So, when both or several trains come into one station, the first to come into the line block is that train that came into the station first.

Positions 4 and 7 are described by the color *BUSY* that are connected by the departure indicators and the entrance indicators with the line blocks 3 and 8 are used for the control of the line block non-occupation, i.e., to control that the train could not enter the occupied line block.

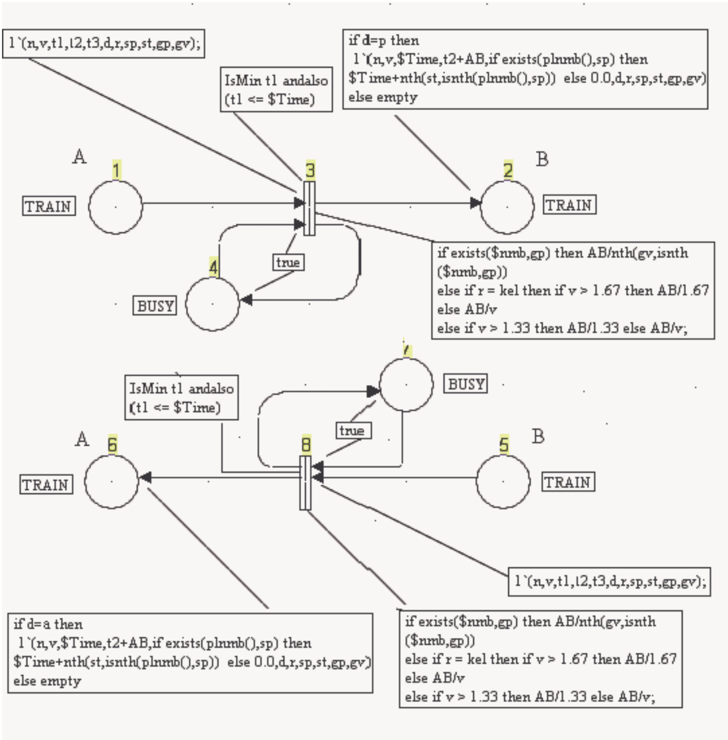

Fig. 11. The model of dual gauge railway line block

The branch from the station to the line block is described by the names of train variables *l'(n, v, t1, l2, t3, d, r, sp, st, gp, gv)*; so the train "re-carries" its data from the departure station. The phenomenon

if d=p then
1`(n,v,$Time,l2+AB,
if exists(plnmb(),sp,gp,gv) then
$Time+nth(st,isnth(plnmb(),sp,gp,gv))
else
0.0,d,r,sp,st)
else
empty

depicts the situation, when the train goes from the line block to the station, where the train going direction (variable d) is checked, and when the proper direction coincides, the train can enter the station and the train data resume, i.e., the existing time is recorded to the train variable t1 that records the time of entering the station, and the variable l2 recording the passed distance is added to the distance AB that the train had passed in the previous line block (this is required for the drawing of the schedule). The scheduled stops of the train are checked by the phenomenon

```
if exists(plnmb(),sp) then
   $Time+nth(st,isnth(plnmb(),sp,gp,gv))
else
   0.0
```

i.e., it is checked if there is the scheduled stop in this station (list *sp*); if there is scheduled stop, the train standing in this station is performed for the intended time (list *st*), otherwise the train passes the station if the conditions of the model allows.

The phenomenon *TRUE* is written in the branches with the controlled line block non-occupation. It means that the token from the position controlling the line block non-occupation will pass to the other transition only when the train from the other place will occur in it and the token will "come back" to the place of the controlled line block position when the train will vacate the line block.

The train (token) going from the station A (place 1) to the line block AB (transition 3) will come only then when the branches that are between the station A (place 1) and line block AB (transition 3) will coincide with the parameters of the train direction. The token must be in the place N 4 for the train coming that controls the non-occupation of the line block AB (transition 3). The line block AB (transition 3) is occupied when the train comes there and the token from the place 4 will come to the transition 3. When the train will pass the line block AB after the line block AB (transition 3) delay, the train from the line block AB (transition 3) will leave for the station B (place 2) and so the line block AB (transition 3) will be vacated and the line block AB (transition 3) non-occupied controlling token will come back to the place 4. The train moving in the even direction is depicted there; in the odd direction everything will be analogically, only to the opposite direction.

Earlier described train movement from one station to the other when the line block is dual gauge. Everything is more complicated when there is the single line roadway line block.

The model of the single line roadway line block.

The net structure between two stations is created when the single line roadway is between those stations (Fig. 12).

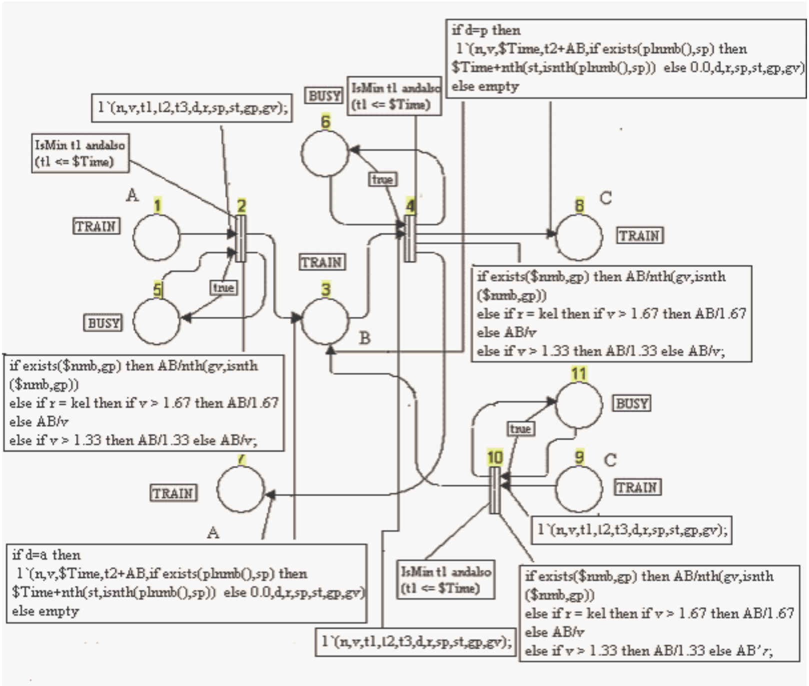

Fig. 12. The model of the single line roadway line block

The elements, such as: transition, place and branches are given in the structure of this net (Fig. 12) and they perform the identical actions as in the above mentioned net structure between two stations (Fig. 8) when dual gauge railway is between them. Every road had its transition element with the non-occupation control place (Fig. 12).

Transition 4 and places 6 and 3 are common for the single line roadway in the net structure (Fig. 12), i.e., transition 4 will correspond the delay for the train going as in the even as in the odd directions, also the place 6 will control the line block non-occupation in both directions and if the even train will come to the line block the first (transition 4), so the odd train can not enter the line block (transition 4) till the even train will vacate the line block (transition 4). The same will be if the odd train will come to the line block the first (transition 4), so the even train can not enter the line block (transition 4) till the odd train will vacate the line block (transition 4). So, the modeling of single line roadway is made in transition 4. Two outgoing branches (apart one branch that takes part in the control of one line block non-occupation with the phenomenon *true*) are in the transition 4 (Fig. 12). One branch leads to the station C (place 8) with the phenomenon

```
if d=p then
    1`(n,v,$Time,l2+12,3,
        if exists(plnmb(),sp,gp,gv) then
            $Time+nth(st,isnth(plnmb(),sp,gp,gv))
        else
            0.0,d,r,sp,st, gp, gv)
else
                empty
```

and the other branch leads to the station A (place 7) with the phenomenon

```
if d=a then
    1`(n,v,$Time,l2+12,3,
        if exists(plnmb(),sp,gp,gv) then
            $Time+nth(st,isnth(plnmb(),sp,gp,gv))
        else
            0.0,d,r,sp,st, gp,gv)
else
                empty
```

As it can be seen from those phenomena, they differ by the directional elements *d*, because in one case the direction is *a*, and in the other direction it is *p*. So, the train (token) going with attributes where the direction *d* will be *p* transition 4 and it will point the train to the station C, when the direction *d* in the train attributes will be *a*, so the transition 4 will point this train to the station A.

The train (token) going from the station A to the station C, leaves the station A (place 1) and comes into the line block AB (transition 2), if the line block is empty, i.e., if the token that has passed the line block AB (after the delay in transition 2) is in the place 5, the train comes into the station B (place 3). After that the train comes into the line block BC (transition 4), if the line block is empty, i.e., if the token is in the position 6, the train comes into the station C (place 8) having passed the line block BC (after the delay in transition 4). In the opposite direction the train (token) goes identically only from the station C to the station A through the station B (transition 4).

Chapter 4 ("The practical application of train streams adjusting methodic and algorithm").

The path section of Lithuanian railway Kaišiadorys – Radviliškis is taken for the verification of obtained solutions and methodic with many single line roadway line blocks arising problems for the intensification of traffic. This section is chosen for its complexity because it has five single line roadway line blocks and the most problems arise there when the trains pass.

According to the composed jet models for single-line and dual gauge line blocks. Having solved the creation of structural net scheme for single line and dual gauge line blocks, the structural net scheme for the many problems arising Kaišiadorys – Radviliškis section is created.

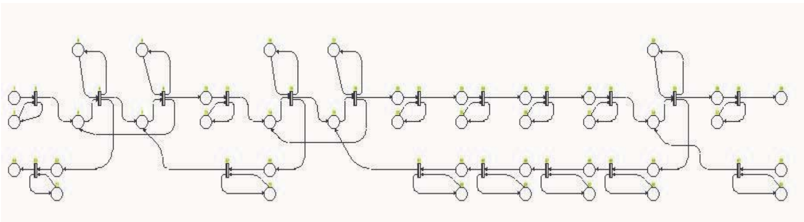

Fig. 13. Structural net scheme for Kaišiadorys – Radviliškis section

The Kaišiadorys – Radviliškis road net model is seen in Fig. 13. On the left upper place is Kaišiadorys station even direction, and in the lower right place is the odd direction of Radviliškis station.

The following situation is chosen for the created Kaišiadorys – Radviliškis road model:

The train traffic was stopped by force for a long time after the accident or natural disaster. The problem to pass the collected equipment (in our case there are 10 trains in Radviliškis station 10 trains in Kaišiadorys station, four of them are passenger: two in Radviliškis station and two in Kaišiadorys station) and go to the normal traffic schedule in minimal time and with minimal input arises. So, every 20 min one train leaves the researched section terminal stations, i.e., Kaišiadorys and Radviliškis (Fig. 13). This train release from the terminal station every 20 min. is obtained according the methodic described in the chapter 1.3, i.e., the train passage from the initial station to the next station is calculated 11 min., and the delay time is 9 min. because the semiautomatic blockage is added.

The time is described in the horizontal axis and is calculated in minutes; the distance (in kilometers) with the names of the stations is described in vertical axis of the Kaišiadorys – Radviliškis section train traffic schedule.

The trains going from Radviliškis to Kaišiadorys are going from the above down, and the trains going from Kaišiadorys to Radviliškis are going from the bottom upwards.

The following train traffic schedule is obtained after the modeling (Fig. 13.):

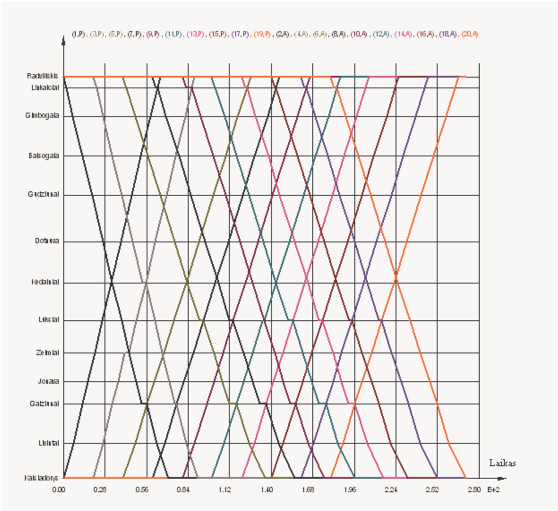

Fig. 14. Train traffic schedule

As it can be seen from the full train traffic schedule (Fig. 14), there are 22 unscheduled stops for the researched case.

The train traffic in order to avoid those unscheduled fuel input must be organized so that all the trains could pass in the station or would like to come to the line block when it is empty.

The critical places can be found (the places in train traffic schedule where the train had to stop for passing or when it came when the line block was occupied before it and he had to wait for empty line block) when the model of Kaišiadorys – Radviliškis section with 10 even and 10 odd trains was designed.

Those critical places are found according to the previously described method.

Having designed the section Kaišiadorys – Radviliškis, the program packet *Centaurus C* has found critical places and has calculated the corrected speeds of those trains.

Having inserted those speeds and designed once more we obtain that the trains have passed the section Kaišiadorys – Radviliškis without unscheduled stops.

The train traffic schedule, when the trains are going by the packet recommended speed in the critical places, without forced stops is obtained (Fig. 15) and so the unnecessary fuel input is avoided.

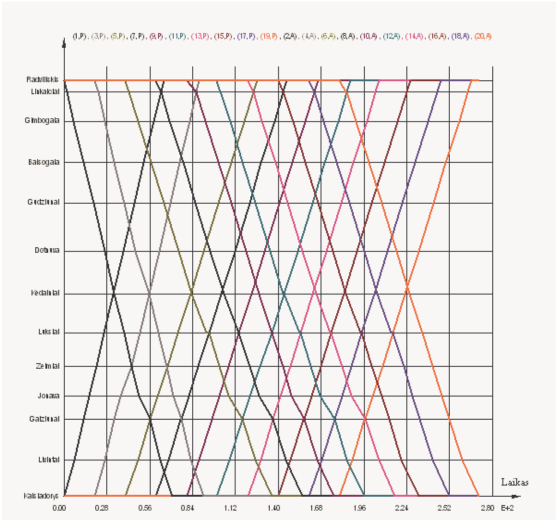

Fig. 15. Train traffic schedule after the speed correcting

Having analyzed the critical places (the places where the trains must stop unscheduled) of trains-tokens by the program package *Centaurus C* , and having given the adjusted speed in what the trains must go avoiding the unscheduled stops, it must be proved that those train speed adjustments will have the economic profit for the train fuel input.

Having calculated the fuel input of the trains going in the adjusted and non-adjusted speed according the methods, the obtained schedule is shown in Fig. 16. From the schedule it can be seen that the trains going in adjusted speed uses about 22 % of fuel less than the trains going in non-adjusted speed.

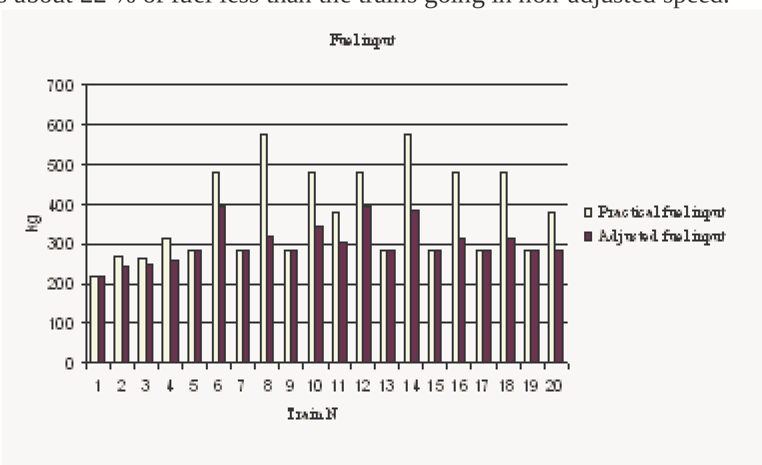

Fig. 16. Train fuel input

Conclusions

1. The main nowadays transport stream managing tasks, such as: to plan close to optimal and easily adjusting transport traffic schedules, to compose the technical program systems enabling to enlarge the transport traffic realization exactness, and, if there is need, to adjust optimally train traffic schedules, were distinguished.
2. Streams adjustment for the avoiding forced stops adjusting the transport coming time into the point of forecasted conflict allows getting fuel saving, because the fuel input for the transport racing after the forced stop is unnecessary.
3. Forced train stops greatly enlarges the fuel input overcoming the distance, so it must be achieved that there must be no forced stops, and for this purpose the realized formula evaluating fuel input changing transport speed is also used during optimization as the target function.
4. Theoretical apparatus of simple (black and white) Petri nets is insufficient for solving streams problems, because the model allows to vary the speed, i.e., there are no transport going at different speed in the same model, there are possibilities to show graphically traffic schedules.
5. Composed and programmely realized the proposed streams adjustment algorithm in the imitational model packet Centaurus C, enabling to forecast possible forced stops during the imitational model and to accomplish the adjustment of transport speed according to proposed algorithm for the absent forced transport stops in the composed traffic schedule that challenge the extra expenses.
6. Typical dual gauge and single line roadway line block models were created on the basis of colored Petri nets working in the imitational model program; they allow to solve all the problems of traffic schedule realization problems raised in the work; train path section imitational model was realized on their basis.
7. After the modeling and experiments with the model made with colored Petri nets, it was set that the created algorithms are functional optimizing according to the chosen criterion varying the speed in the line blocks for the avoidance of the unscheduled train stops.
8. After the research and experiments it was set that adjusting unscheduled traffic schedules when the jams must be excluded as soon as possible, the forced stops minimization criterion was made (changing train speed in separate line blocks) showed the functionality because this does not prolong train riding time and give additionally fuel economy.

9. The proposed methodic for the set of effectiveness eliminating the forced stops for the chosen path section Kaisiadorys - Radviliskis showed their effectiveness and additionally gave fuel economy.

The list of publications

ARTICLES

in periodical publication from the list approved by Lithuanian Ministry of Education and Science

1. **V. Taurienė, O. Švėgžda, M. Juraška**. Traukinių eismo grafiko optimizavimas pagal kompleksinį kriterijų. // *Elektronika ir elektrotechnika* 2001 m. Nr. 6 (35). ISSN 1392-1215. Kaunas, Technologija, 2001. 68-72 p.

2. **M. Juraška, K. Šarkauskas, R. Stadalius**. Eismo grafiko optimalaus papildymo ir koregavimo uždavinių formulavimas. *Elektronika ir elektrotechnika* 2003 m. Nr. 1 (43). ISSN 1392-1215. Kaunas, Technologija, 2003. 69-73 p.

3. **M. Juraška**. **T. Magyla**. Investigation of thermal traction train fuel consumption for non-scheduled. *Transport*. 2004 m. XIX, Nr. 5. ISSN 1648-4142. Vilnius, Technika, 2004 m. 230-235 p.

4. **S. Bartkevičius, V. Bagdonas, M. Juraška, K. Šarkauskas.** Train trafic simulation with coloured Petri nets and schedule optimisation. // *Elektronika ir elektrotechnika* 2005 m. Nr. 3 (59) . ISSN 1392-1215. Kaunas, Technologija, 2005. p. 18-23.

ARTICLES

in the material of the papers of scientific conferences (in Lithuania)

1. **M. Juraška**. Traukinių automatinio intervalinio valdymo sistemos padidintų greičių sąlygoms. *Automatika ir valdymo technologijos – 2000*. Konferencijos pranešimų medžiaga. Kaunas, Technologija, 2000. 99-101 p.

2. **M. Juraška**. Traukinių eismo dinamiško grafiko matematinis modeliavimas. *Automatika ir valdymo technologijos – 2001*. Konferencijos pranešimų medžiaga. Kaunas, Technologija, 2001. 124-127 p.

3. **M. Juraška**. Eismo grafiko optimalus papildymas neapibrėžtumo sąlygomis. *Automatika ir valdymo technologijos – 2002.* Konferencijos pranešimų medžiaga. Kaunas, Technologija, 2002. 102-104 p.

4. **M. Juraška**. Geležinkelio eismo modeliavimas Petri tinklu. *Automatika ir valdymo technologijos – 2003.* Konferencijos pranešimų medžiaga. Kaunas, Technologija, 2003. 93-97 p.

Short description about the author

Mindaugas JURAŠKA was born in 1975, in Kaunas. He has graduated Kaunas college in 1993. He has obtained the degree of bachelor of electrical engineering at Kaunas university of technology, faculty of electrical engineering and control systems in 1998. Also he has obtained the qualification degree of Master of electric engineer in 2000. Since 2000 he studies at Kaunas University of Technology, as doctoral student at electrical and electronics engineering sciences.

e-mail: minjura@centras.lt

Reziumė

Šiuo metu geležinkeliai jaučia labai stiprią kelių transporto konkurenciją: mažėja geležinkeliais pervežamų tiek krovinių, tiek keleivių dalis. Ši tendencija būdinga visai Europai. Kita vertus, kelių transporto eismo intensyvumo didėjimas kelia ekologinių problemų, didėja avaringumas. Europos Sąjungoje imamasi priemonių geležinkelio sektoriaus efektyvumui didinti. Tai orientacija į vartotoją, nekompromisinė rinka, žymus aptarnavimo kokybės gerinimas, didinant sistemos lankstumą ir keliant geležinkelių techninį lygį, platus informacinių technologijų panaudojimas; tikslingi rinkos tyrimai; energetinių sąnaudų ir neigiamo geležinkelių poveikio aplinkai mažinimas.

Dabartiniu metu traukinių eismas negali būti laikomas pakankamai sklandžiu, nes yra:

- dažni priverstiniai (tik eismo sąlygoti) ar neplaniniai stabdymai;
- ilgos prekinių traukinių prastovos tarpinėse stotyse;
- didelės eismo grafiko vykdymo paklaidos (traukinių vėlavimai).

Ilgesniam laikui priverstinai sustabdžius eismą, pradinis tvarkaraštis smarkiai sutrikdomas. Iškyla uždavinys: per trumpiausią laiką ir galimai mažesnėmis sąnaudomis praleisti susikaupusius riedmenis ir pereiti į normalų eismo režimą.Yra žinoma, kad norint sustabdyti vidutinio svorio prekinį traukinį ir jį įgreitinti, sunaudojama 50-60 l. degalų. Vidutiniškai dėl priverstinių stabdymų kuro sąnaudos padidėja apie 15% (degalų, elektros energijos).

Tarpinėse stotyse (Lietuvoje) prekiniai traukiniai prastovi apie 30% viso kelyje sugaišto laiko.

Iš šių duomenų matyti, kad esant dabartiniam geležinkelio apkrautumui (kai neišnaudojama nė pusės pralaidumo) dabar esanti eismo valdymo sistema yra neefektyvi, nes nepanaudotos naujų technologijų teikiamos galimybės. Iš dalies dėl tų pačių priežasčių atsiranda eismo grafiko vykdymo paklaidų. Tyrimai rodo, kad tarpinėse stotyse apie 30% keleivinių traukinių vėluoja daugiau kaip 5 min.Toks vėlavimas dažniausiai yra dėl blogos maršruto kontrolės (ilgesni vėlavimai dažniausiai atsiranda dėl rimtų techninių ir organizacinių nesklandumų ir jie būdingi tarptautiniams maršrutams).

Šiuo metu traukiniu eismo organizavimo pagrindu yra eismo grafikas. Eismo grafikai matyt išliks ir ateityje: stichinių traukinių srautų (kaip kelių transporte), tikriausiai, nebebus, "kamščiai" geležinkelyje būtų labai nuostolingi. Tačiau šiuo metu traukinių eismo grafikai yra gan nelankstūs vien jau dėl to, kad jais pagrįsta sistema (visu rūšių stočių darbas, infrastruktūros priežiūros organizavimas) yra inertiška.

Sudarius galimybę operatyviai koreguoti ar papildyti traukinių eismo grafikus, pavyktų iš esmės sumažinti nuostolius dėl techninių ar organizacinių

eismo trikdymų, atsirandančių dėl infrastruktūros ar riedmenų gedimų, sutrukdymų pasienio stotyse ir pan.

Be minėtų priežasčių, eismo grafikų optimalaus koregavimo (papildymo) uždavinio svarba labai padidėjo pradėjus įgyvendinti laisvos prieigos prie Europos Sąjungos geležinkelių infrastruktūros koncepciją. Šioje koncepcijoje akcentuojama „paskutinės minutės“ (*ad hoc*) prašymų aptarnavimo svarba. „Paskutinės minutės“ prašymai paprastai esti susiję su vienkartinių (turistinių, komercinių ir pan.) reisų įterpimu į jau sudarytą tvarkaraštį (tvarkaraštis sudaromas metams). Visa tai turi būti atliekama nesutrikdant planinių reisų. Numatytas „Paskutinės minutės“ prašymų aptarnavimo 5 parų terminas pareiškėjams dažnai gali pasirodyti per ilgas. Norint jį sutrumpinti būtina automatizuoti procedūras su ES šalių geležinkelių infrastruktūros valdytojų duomenų bazėmis (traukinių eismo grafikai, stočių apkrautumo grafikai, infrastruktūros mokesčiai ir kt.), suteikiant galimybę šias bazes papildyti (nepažeidžiant tam tikrų nustatytų apribojimų). Iš čia kyla eismo grafikų optimalaus papildymo uždavinių svarba: be specialių algoritmų eismo grafikų koregavimas ES mastu yra neįmanomas.

Darbo tikslas

Sukurti eismo optimalaus koregavimo metodus ir algoritmus, patikrinant jų funkcionalumą Petri tinklų teorija.

Ištirti sukurtų algoritmų funkcionalumą.

Darbo uždaviniai

Sukurti efektyvią sustojimų skaičiaus minimizavimo metodiką.

Naudojantis Petri tinklų modeliavimo priemonėmis sukurti kelio ruožų imitacinį modelį, įgalinantį pagal pasiūlytą metodiką išspręsti neplaninių sustojimų problemas.

Darbo aktualumas

Pagal transportui keliamus reikalavimus, reikia:

didinti pervežimų ekonominį efektyvumą; sukuriant ir įdiegiant metodus ir algoritmus įgalinančius, kad būtų išvengta priverstinių, bei neplaninių sustojimų, sukeliančių papildomas energijos sąnaudas.

Darbe pateikiama ir ginama

1. Srautų optimalaus (pagal neplaninių sustojimų eliminavimo kriterijų) koregavimo metodika ir algoritmas, kuriuos naudojant atsiranda galimybė optimaliu režimu praleisti susikaupusius riedmenis bei pereiti į normalų eismo režimą.
2. Srautų modeliavimo metodas, pagrįstas spalvotų Petri tinklų teorija.
3. Sąnaudų minimizavimui skirtas eismo koregavimo algoritmas, pagristas spalvotų Petri tinklų teorija, sukurtas eismo modeliavimo metodu.

Darbo naujumas

1. Spalvotų Petri tinklų bazėje sukurtas srautų imitacinis modelis, įgalinantis prognozuoti konfliktines situacijas, kurias išsprendus minimizuojamos sąnaudos.
2. Analogiškų metodų ir algoritmų, pagrįstų spalvotų Petri tinklų teorijos taikymų, literatūros šaltiniuose neaptikta.

Darbo aprobacijos

Pateikiamojo darbo tema skaityti pranešimai 4-iose mokslinėse konferencijose.

Pateikiamojo darbo tema paskelbtos publikacijos Lietuvos švietimo ir mokslo ministerijos patvirtinto sąrašo periodiniuose mokslo 4-juose leidiniuose.

Disertaciją sudaro: įvadas, keturi skyriai, išvados, literatūros sąrašas ir autoriaus publikacijų sąrašas.

Įvade: apibūdinta tiriamoji problema, nurodytas jos aktualumas, suformuluoti darbo tikslai ir uždaviniai.

Pirmasis skyrius: (“Srauto organizavimas ir eismo grafikų optimizavimas ir koregavimas”) susideda iš septynių skyrių. Juose glaustai pateikiama eismo grafikų samprata, apžvelgiami keleivinių ir prekinių traukinių eismo grafikų optimizavimo metodai jų analizė. Išnagrinėjamos traukinių kuro sąnaudų priklausomybės. Išnagrinėtas spalvotais Petri tinklais geležinkelio stočių modeliavimo metodai.

Antrasis skyrius: (“Transporto greičių teorija”) susideda iš trijų skyrių. Šiame skyriuje pateikiama traukinių energijos sąnaudų skaičiavimo metodika, atliekama šių energijos sąnaudų skaičiuotė, o taip pat nagrinėjamas traukinių prasilenkimas stotyse ir traukinių eismo grafikų sudarymas naudojantis nespalvotais Petri tinklais.

Trečiasis skyrius: (“Transporto srautų optimizavimo metodika ir algoritmas”) yra šio darbo pagrindinis skyrius. Jis susideda iš šešių skyrių. Šiame skyriuje yra nagrinėjami eismo grafikų kokybiniai kriterijai, eismo grafikų modeliavimo metodika ir algoritmas. Taip pat atliekamas geležinkelio eismo grafikų modeliavimas spalvotais Petri tinklais. Sudaromas kritinių vietų paieškos algoritmas kurio pagalba yra nustatomos traukinių kritinės vietos ir juos šalinamos mažinant traukinių važiavimo greičius.

Ketvirtasis skyrius: (“Traukinių srautų koregavimo metodikos ir algoritmo praktinis pritaikymas”) Šiame skyriuje yra atliekamas realaus Kaišiadorys – Radviliškis ruožo modeliavimas. Randamos šiame ruože važiuojančių traukinių kritinės vietos, juos šalinamos mažinant traukinių važiavimo greičius ir pateiktos energijos skaičiuotės važiuojant nekoreguotais ir koreguotais greičiais.

Trumpos žinios apie autorių:

Mindaugas Juraška gimė 1975 m., Kaune. 1993 m. baigė Kauno technologijos technikumą. 1998 m. Kauno technologijos universitete, elektrotechnikos ir automatikos fakultete įgijo elektros inžinerijos mokslo bakalauro kvalifikacinį laipsnį. 2000 m. ten pat įgijo elektros inžinerijos mokslo magistro kvalifikacinį laipsnį. Nuo 2000 m. studijuoja Kauno technologijos universitete elektros ir elektronikos inžinerijos mokslo krypties doktorantūroje.
Elektroninis paštas: minjura@centras.lt.

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Išleido leidykla “Technologija”, K.Donelaičio g. 73, LT-44029 Kaunas
Spausdino leidyklos “Technologija” spaustuvė, Studentų g. 54, 51424 Kaunas