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Train Traffic Simulation with Coloured Petri Nets and Schedule Optimisation

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Introduction

The basis of train traffic organization is a traffic schedule which should fulfill certain conditions (times of departure and arrival, overall duration of the journey, etc.) and be optimal according to a certain criterion (minimal number of train stopping, minimal time of passengers' waiting in change stations, minimal total economic expenditure , etc.).

Many methods of scheduling and optimising train traffic are known. Most of them are oriented to the passenger train traffic [1], others are oriented towards mixed or only goods train traffic [2].

All train traffic optimisation algorithms are based on some methods of traffic simulation. Quite often mathematical traffic models are used. [1,2]. With regard to the well-developed traffic simulation methodology and the designed corresponding simulation programs, the methodology of train traffic schedule optimisation based on these tools can be offered.

The train traffic schedule algorithm based on traffic simulation

A train traffic schedule can be expressed with two matrixes:

$$\mathbf{G} = (\mathbf{T}^i, \mathbf{T}^a)\,, \qquad (1)$$

$\mathbf{T}^i$ – the matrix of departure from the stations; $\mathbf{T}^a$ – the matrix of arrival to the stations; $\mathbf{T}^i = \left\| t^i_{ji} \right\|$, $i = \overline{1,n}$, $j = \overline{1,k}$; $\mathbf{T}^a = \left\| t^a_{ji} \right\|$, $i = \overline{1,n}$, $j = \overline{1,k}$; j – the index of the train; k – the number of trains in the train schedule; t^a_{ji} and t^i_{ji} - the time of the j^{th} train arrival to the i^{th} station and the time of its departure from that station.

The matrix $\boldsymbol{L}_j$ describes the train path of the j^{th} train:

$$\mathbf{L}_j = \begin{Vmatrix} t^a_{jn} & \left(t^i_{jn}\right) \\ \dots & \dots \\ t^a_{j2} & t^i_{j2} \\ \left(t^a_{j1}\right) & t^i_{j1} \end{Vmatrix}.$$

Some train paths are fixed in the traffic schedule **G** (for example, international passenger trains), others are chosen according to necessary limitations and optimum criterion.

When applying the minimal overall expenditure criterion W, the task of train traffic scheduling is formulated in the following way:

Find the optimal (according to the overall expenditure criterion W) traffic schedule $\mathbf{G}_0$, which has the minimal overall realization expenditure:

$$(\mathbf{G}_0, W_0) \rightarrow \min_{W_z} (\mathbf{G}_z, W_z). \qquad (2)$$

The overall expenditure criterion W, used for optimisation includes:

1) energy expenditure W^E to run the route;

2) expenditure W^L, connected with the time spent in the journey: the rent of rolling stock, personnel's salaries, etc.,

3) a charge for using infrastructure of track side W^{IT};

4) charges for using infrastructure of track side:

W^{IS} – for passing the stations;

$V^{IS}\,t$ – for the time t spent standing in the stations;

5) additional losses W^{SS}, connected to the emergency train stopping (conditioned by traffic only);

$$W = W^E + W^L + W^{IT} + W^{IS} + V^{IS}\,t + W^{SS}. \qquad (3)$$

The methodology of calculating overall expenditure criterion W values is known [3].

The block scheme of traffic schedule optimisation algorithm based on traffic simulation is shown in figure 1.

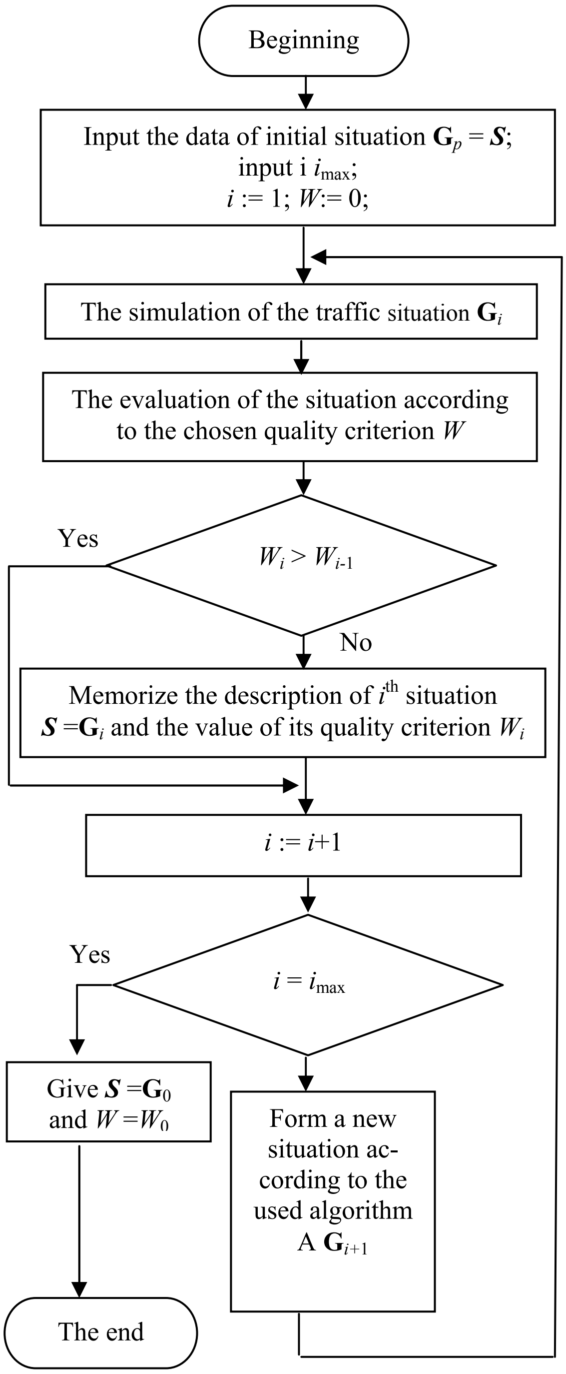

Fig. 1. Traffic schedule optimisation algorithm

According to this algorithm primary traffic is scheduled in the chosen railway polygon $\mathbf{G}_p = (\mathbf{T}^i_p, \mathbf{T}^a_p)$, where fixed train paths are parameters, and planned ones are variables. Every other situation $\boldsymbol{G}_i$ is characterized by the variable vector $\boldsymbol{X}_{i,}$ which consists of particular arrival and departure times of planned train path trains in all stations: $(\mathbf{T}^i{}_{\mathrm{i}}, \mathbf{T}^a{}_i)$.

According to this data, the simulation of the situation $\mathbf{G}i$ is performed and the value $\boldsymbol{W}i$ of the quality criterion W is calculated according. to these results.

The number of cycles i_{max} depends on the algorithm A, according to which the optimisation is done. (variant reselection algorithm, Monte Carlo algorithm, genetic algorithm, etc.).

Train traffic simulation

Various techniques of train traffic simulation are known [4,6,8].

The aim of simulation is to find characteristics of a certain traffic schedule, to detect conflicts.

Coloured Petri nets are well suited for the simulation of conflicting object interaction [9].

According to the authors, it is rational to strive that the structure of the Petri net was as close to the structure of the railway net, in this case the model and the processes are perceived more easily, the results of simulation are clearly linked to the real railway. It is especially important, when the results of simulation must be interpreted rapidly and unambiguously, for example, when solving uncommon situations after traffic blockades in some railway section.

The models presented in this study were created and tried by using a software package CENTAURUS-COLOURED, which was designed in the Kaunas University of Technology. This packet allows hierarchical coloured Petri nets and notations of expressions used are analogous to the described ones [10]. The packet contains the subsystem of graphical simulation result depiction, which allows forming traditional, easily understood by railway men traffic schedules.

The model of a railway section has to be separated into two parts. The first part is the models of stations with track sections, the second one is trains taking the tracks and going past the stations. A station with track sections has to react differently to the parameters of the trains passing by. In every case traffic must be simulated individually. By the way, it is desirable that the model of the railway track structure should correspond to the real situation in order to relate the actions in the simulation to the physically existing situation.

An example of train traffic simulation

The situation of an inconvenient track section is presented in Fig. 2. There are one-way sections where problems for trains going in opposite directions arise.

The fragment of the full model of this section made by the software package CENTAURUS-COLOURED is shown in Fig. 3

In the fragment of the model (Fig. 3) stations and track sections are simulated with subnets, which include other models, which in one case simulate the functioning of the station, in another case they solve conflicts in one-way sections.

A train is simulated by a structural token. The movement of the "train" in a model corresponds to the communication of information to the newly generated tokens. While observing tokens with information characteristic to a particular train (e.g. a train number) it is possible to evaluate the movement of the train. Information can be gathered or transformed.

In order to solve traffic problems it is necessary that the throughput of stations would be sufficient. Supposing the stations cause no problems, a model can be simplified without simulating situations in the stations. A derived model is much simpler (Fig. 4). One-way sections cause most of the problems, because it is required to solve conflict situations. Next picture introduces a detailed model with all hierarchical levels. The basic level simulates the physical situation of tracks and the first hierarchical level solves conflict situations and establishes traffic organization in a one-way track.

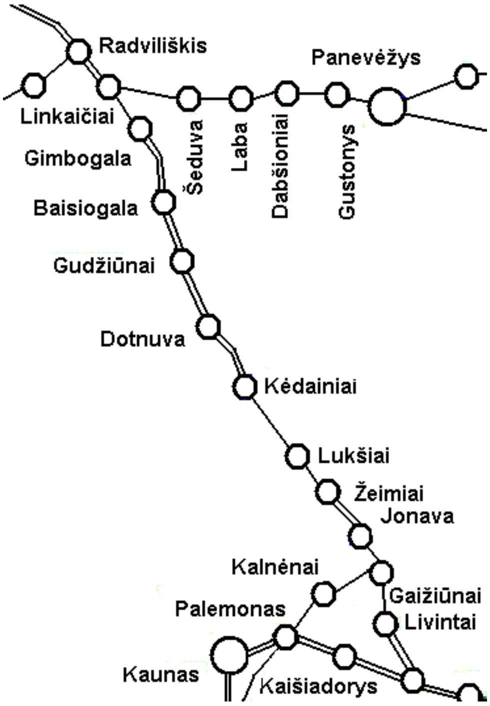

Fig. 2. The fragment of the railway track situation between junctions Radviliskis – Kaisiadorys

The hierarchical model of stations is more complex, because it is necessary to simulate the physical situation of the station in the first hierarchical level, the functioning of control systems and blockage in the second one, and the system of train service in the third level.

The results of simulation are depicted very differently [6].

CENTAURUS-COLOURED graphic subsystem allows collecting information by using only the operational marking of the Petri net, i.e. it is not necessary to have the occurrence graph. Information about trains is attributes of tokens, therefore is enough to know the following four things in order to collect it: how to distinguish different graphs, which tokens to analyze, and what to represent in the ordinate and abscissa of the graph point. In the described subsystem the above-mentioned things are characterized by four expressions: schedule identification tuple, token identification expression which has a result *Boolean*, and expressions of calculating abscissa and ordinate which have results *real*. All afore mentioned expressions such default variables can be used: "_" – current token; "$place" – current number of position; '$tot" – the number of all tokens which are in the position $place; "$time" – current value of time; "$step" – the number of simulation step.

Graph identification tuple defines a tuple, which has to be unique for every schedule. Information of all tokens which attribute values produce the same tuple will be presented in the same graph. This tuple is also the title of the graph.

Token selection expression *(Boolean)* defines which tokens in the positions to analyze. If the result of this expression calculated with the attributes of a token is false that token is ignored.

The expressions of calculating ordinate and abscissa enable to shape graphs in a desirable way. All expressions use the SML syntax. Besides, afore mentioned default variables can be used.

For example, if in the first position of train description is the number of a train, in the 4^{th} position is the way gone, in the 6^{th} a feature defining the direction of movement (f|b), the graph identification tuple can be the following: (# 1_, #6_).

If you want to look through all tokens (trains), the token identification expression can be the following: true, the ordinate is calculated depending on the movement direction: if #6_ = f then #4_ else 125.7 - #4_, and the abscissa is the time $TIME. Thus the graphs are described in Fig. 6, they are in the problematic track section shown in Fig 2.

Presented schedules reflect the traffic situation, when after traffic delay due to faults in the track a number of trains have been delayed in the junctions. After restoring normal traffic conditions delayed trains have to be sent off in an urgently. Firstly one passenger train and then nine more goods trains are allowed to go from both junctions.

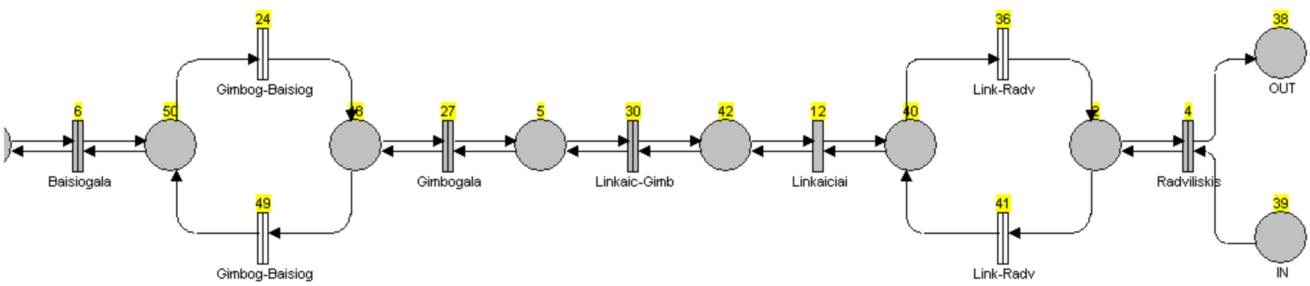

Fig. 3. The fragment of the full model of the railway track section Radviliskis – Kaisiadorys. In the model, stations simulated with transitions have one-word caption (e.g. Gimbogala), tracks, simulated with transitions, have two-word captions (e.g. Gimb – Baisog)

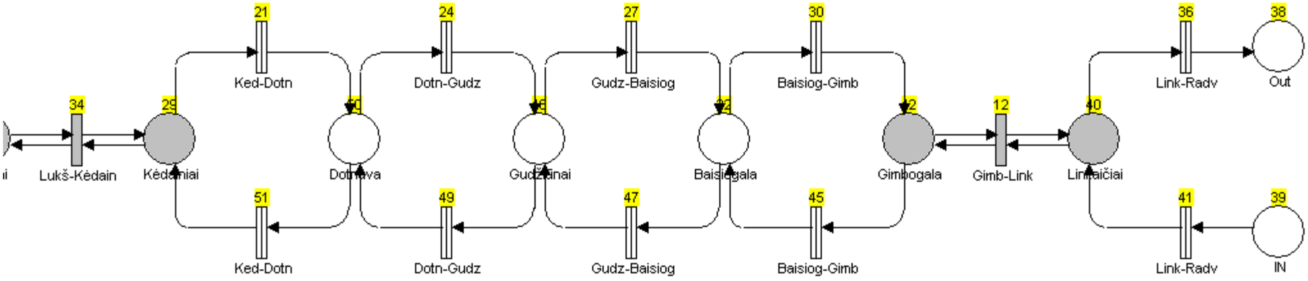

Fig. 4. The fragment of the simplified model of the railway track section Radviliskis – Kaisiadorys. In the model, stations simulated with transitions have one-word caption (e.g. Gimbogala), tracks simulated with transitions have two-word captions (e.g. Gimb – Baisog)

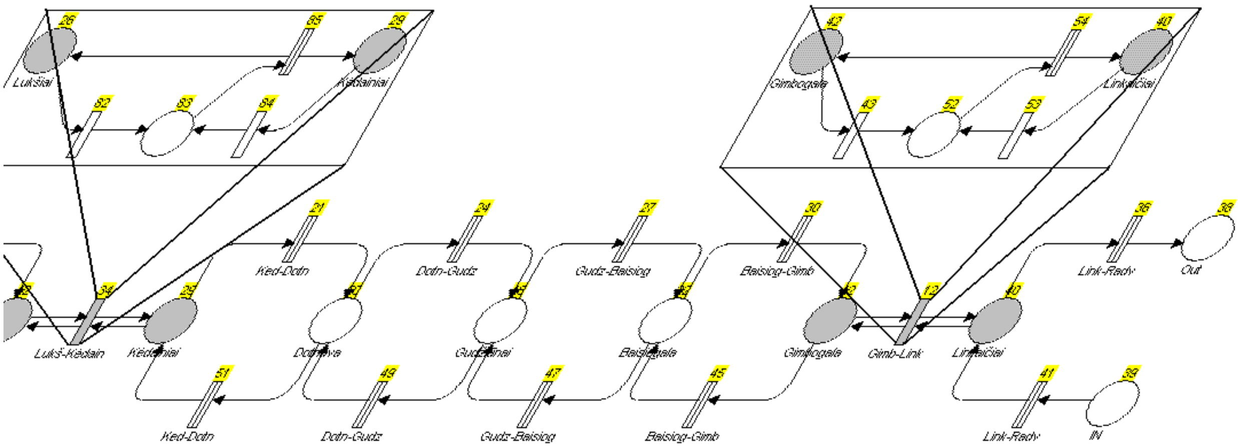

Fig. 5. The detailed fragment of the simplified model of the railway track section Radviliskis – Kaisiadorys. In the model, stations simulated with transitions have one-word caption (e.g. Gimbogala), tracks simulated with transitions have two-word captions (e.g. Gimb – Baisog). One-way tracks are simulated with the models of solving conflict situations in another hierarchical level

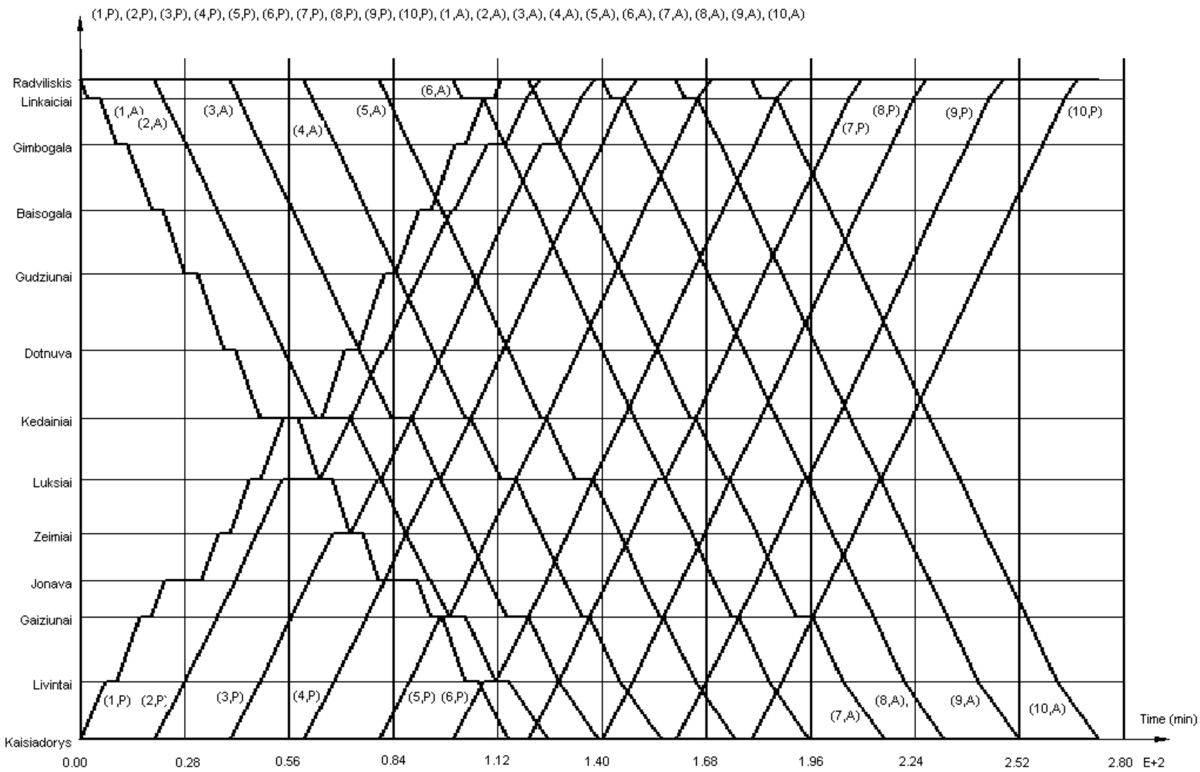

Fig. 6. The traffic schedules/graphs of the railway track section Radviliskis – Kaisiadorys. After emergency train delay 10 trains are allowed to go from junctions in both directions. Horizontal parts of schedules/graphs show which goods trains have to stop and wait for the free track. There are 28 such conflict situations

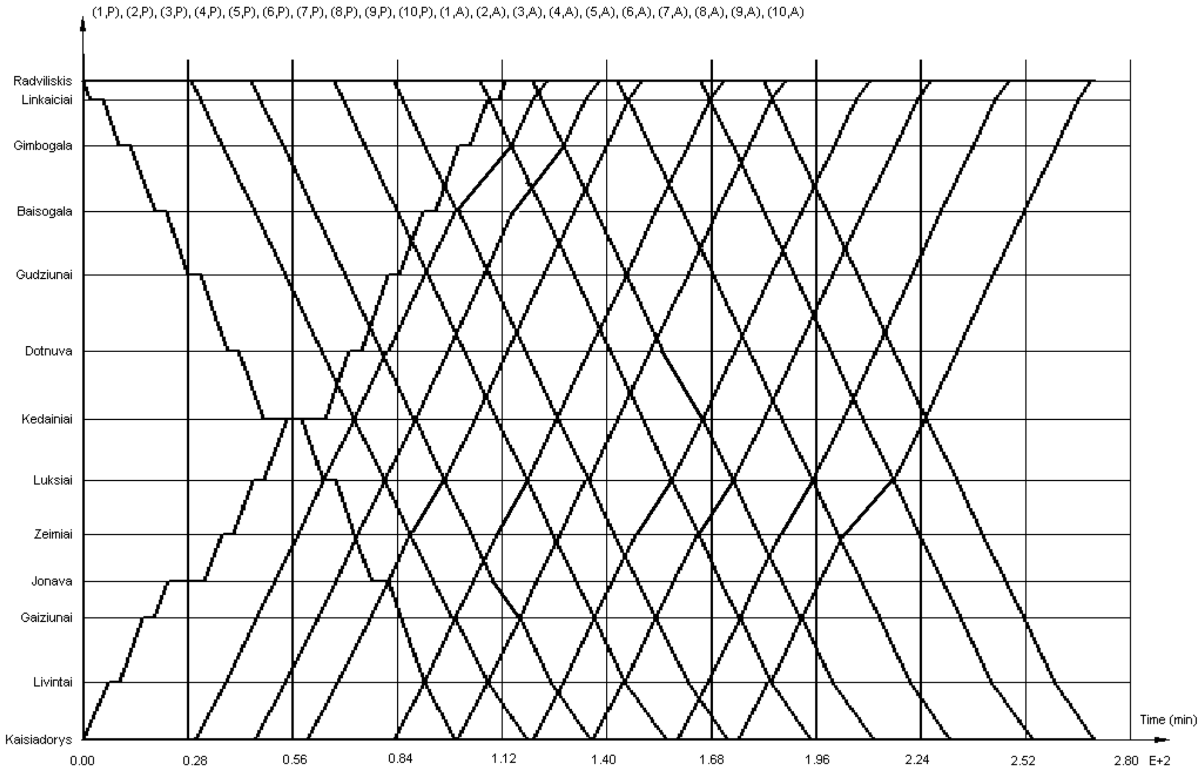

Fig. 7. The traffic schedules/graphs of the railway track section Radviliskis – Kaisiadorys after optimisation

Conclusion

The traffic schedule optimisation criteria of passenger trains, goods trains and mixed type traffic are different. The optimisation of goods train traffic schedules should be based on minimum overall expenditure criterion.

With regard to the well-developed traffic simulation methodology and the designed corresponding simulation programs, the methodology of train traffic schedule optimisation based on these tools can be offered.

A software package CENTAURUS-COLOURED designed in the Kaunas University of Technology is well-suited for train traffic simulation. The basis of models consists of coloured Petri nets, which are used to describe the parameters of tracks and stations as well as the conditions of going. Tokens containing all train parameters necessary for simulation reflect trains.

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S. Bartkevičius, V. Bagdonas, M. Juraška, K. Šarkauskas. Traukinių eismo modeliavimas ir eismo grafiko optimizavimas spalvotais Petri tinklais // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2005. – Nr. 3(59). – P. 18–23.

Didėjant traukinių eismo intensyvumui kelia problemas geležinkelio kelių pralaidumas, dėl ko atsiranda konfliktinės situacijos, dėl ko traukiniai yra priverstinai stabdomi, dėl to didėja išlaidos krovinių transportavimui. Suformuotas optimizavimo kriterijus taip keisti eismo grafikus, kad išlaidos būtų minimizuojamos, tas pasiekiama keičiant traukinių išvažiavimo laikus ir keičiant važiavimo greičius. Traukinių eismas modeliuojamas spalvotais Petri tinklais, realizuotais programų paketu CENTAURUS. Modeliavimo efektyvumas yra tame, kad modelis turi konfigūraciją labai artimą realiai geležinkelio kelių situacijai. Modeliavimo rezultatai parodo, kad likviduojamos visos konfliktinės situacijos, sukeliančios didžiausius nuostolius. Il. 7, bibl. 10 (anglų kalba, santraukos lietuvių, anglų ir rusų k.).

S. Bartkevičius, V. Bagdonas, M. Juraška, K. Šarkauskas. Train Traffic Simulation with Coloured Petri Nets and Schedule Optimisation // Electronics and Electrical Engineering. – Kaunas: Technologija, 2005. – No. 3(59). – P. 18–23.

The article provides the methodology of train traffic schedule optimisation according to minimum overall expenditure criteria. Simulation of traffic processes is used in the algorithm of optimisation. For this reason a software tool theoretically based on coloured Petri nets has been created. The major advantage of the model is the convenience of observation of the situation simulation as its configuration corresponds to the real configuration of the tracks. Ill. 7, bibl. 10 (in English, summaries in Lithuanian, English, Russian).

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С увеличением интенсивности движения поездов проблемы возникают из-за состояния проводимости железнодорожных путей, из-за этого возникают конфликты, поезда принудительно останавливаются, увеличиваются затраты на перевозки. Сформулирован критерий оптимизации для минимизации затрат на перевозки, что достигается изменением время отправки или изменением скорости движения поездов. Движение поездов моделируется цветными Петри сетями, реализированными в программном пакете CENTAURUS. Эффективность моделирования в том, что конфигурация модели максимально соответствует реальной ситуации моделируемых железнодорожных путей. Результаты моделирования показали, что ликвидируются все конфликтные ситуации создающие наибольшие затраты. Ил. 7, библ. 10 (на английском языке; рефераты на литовском, английском и русском яз.).