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SIMULATING TRAIN TRAFFIC ON A DOUBLE TRACK RAILWAY LINE BY PETRI NETS[1]

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Abstract

Simulation modelling is the efficient approach to analyse train traffic on a selected line or on a complex railway node. Simulation model uses an interaction between rail vehicles and infrastructure according to predefined procedures and timetable to compute parameters of train movement, track occupation, and capacity utilization. We propose a High-Level Petri Nets model that incorporates all interlocking and operating rules, infrastructure data, timetable and train delays data. In a Petri net environment, trains are tokens, track sections are places, and transitions are discrete events of train moving according to interlocking principles. Model has a hierarchy structure where each specific section is defined as a subsystem. Results from the simulation model are used to create reports on sections occupancy, train movement, for drawing of train's time-distance graphs, and for animation of train movement. Model is tested on the selected railway line for analyses of the denivelation of the junction in the Belgrade railway node.

Keywords - railway traffic; Petri Nets; simulation modelling

INTRODUCTION

Simulation models are representations of railway systems and an efficient approach to modelling railway processes where different trains interact with each other and with the infrastructure [1]. They require very detailed data

[1] Original scientific paper

about the infrastructure, the performance of the trains and, most importantly, about the timetable. The modelling of train movement is based on modular and hierarchical approach that can simulate the process with all conditions imposed by infrastructure, signalling and control systems.

Petri Nets are tools for graphical and mathematical modelling of various systems [2]. High-Level Petri Nets (HLPN; timed, coloured, stochastic and hierarchical) are tools that can model complex systems and provide good graphical presentation of the model [3]. Simulation models for analysing railway systems can be found in the literature over the past 20 years. Basten, Roland and Voorhoeve [4] created a simulation model for the analysis of interlocking specification using coloured Petri Nets in the Expect software. Van der Aalst and Odijk [5] proposed the interval timed coloured Petri Nets (ITCPN) for modelling and analysis of railway stations, where train delay is specified by an upper and lower bound, i.e., an interval. Daamen, Goverde, and Hansen [6] developed a CPN tool for route conflict identification and estimation of knock-on delay.

This paper is structured as follows. First section defines a High-level Petri Net (HLPN) model for the railway system. Next Section demonstrates a case study and the application of the HLPN model to analyse effects of the partial denivelation of the Junction "G" located in the Belgrade railway node. Finally, conclusions are given in the final section.

PETRI NETS

Petri nets are mathematical tools for modelling used for analysis and simulation of concurrent systems [2]. A Petri net is one of several mathematical descriptions of discrete distributed systems. The theory of Petri nets is based on the mathematical theory of bipartite graphs. The system is modelled as a bipartite-directed graph with two sets of nodes: the set of places that represent a state or system objects and a set of events or transitions that determine the dynamics of the system.

Petri Net formalism and software are selected based on the requirements and criteria that enables efficient and simple simulation model of a railway system [7].

PETRI NET MODEL FOR SIMULATION OF COMPLEX RAILWAY SYSTEMS

In a proposed High Level Petri net (HLPN) model for railway simulation [8], *places* represent sections, *transitions* represent conditions for train movement, and *tokens* represent trains. Model hierarchy enables insulated sections to be defined as subsystems or modules. An insulated section can be a block section, switch section and station track section, but a more detailed description is needed (regarding the position of a section relative to signals, stations and the junction). A module is defined for each distinctive section type. The model is created by positioning and connecting modules according to the railway line and/or station section plan. Although this approach requires more time for initial programming, it allows the use of defined modules for modelling systems with similar processes, such as modelling of traffic processes in the station or on an open railway line. The system model is created in ExSpect v6.41, where the High-Level Petri nets have the following dialects: hierarchical, timed, stochastic, and coloured.

Mostly used module is block section module.It represents block section on an open line (Figure 1). The module contains *places*, *transitions*, and nodes to store parameters and objects for connecting with other modules. Transitions in the module enable or prevent entering and leaving the section based on the storage data. Storage nodes contain information about the state of the connected sections, the signals and the simulation clock.

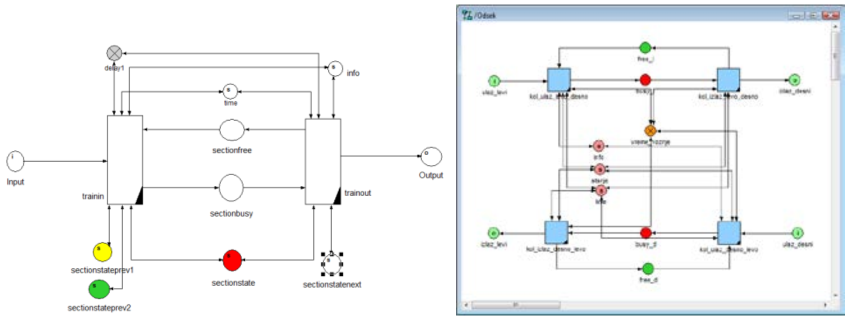

Fig. 1. Module of block section and station track

Station Track Section Module (Figure 2)is used to process entering and leaving of trains in the station tracks. Moduleis connected to a large number of storage nodes. Some of them storage data that manages logistic conditions and calculate section occupation time (train travel time on section). There are also modules similar to those already described that differ by implementation of the train traffic rules dependent on the location of the section in the system.

After defining the modules, creating the simulation model requires connecting modules according to the sections layout. The modules shouldthen be connected to the storage node.

The parameter values kept in storage vary dynamically with train movement.

Train input data are imported to the model before simulation. *Places* in the generator module are marked with coloured tokens that contain information from the train timetable. Trains in the model are defined by the train number, train type, train route and departure time. Train data are defined in the timetable database and can be easily changed to enable experimentation with different train timetables that are deterministic or stochastic. Each storage node of type *info* must be marked with initial values: section name, section length, maximum speed and its type. The simulation program provides data on the movement of each train through the model as well as data on the state of each section (total and physical occupancy of each section). The database is customized for creating quick reports based on queries and for filtering data by train, section, signals or train delay time in the model. Data can be presented in tables or graphs and can be easily validated.

EXAMPLE OF RAILWAY SYSTEM PETRI NET MODEL

Part of the Belgrade railway node encompassing Junction G in the Belgrade railway node is chosen as an example for the Petri Net simulation model. The boundaries of the model are the Belgrade Center, Topcider, Rakovica and Karadjordjev Park stations (Figure 2).

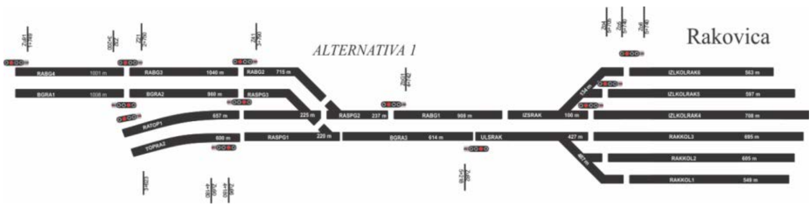

Fig. 2. Block section plan of part of the Belgrade node - junction G system

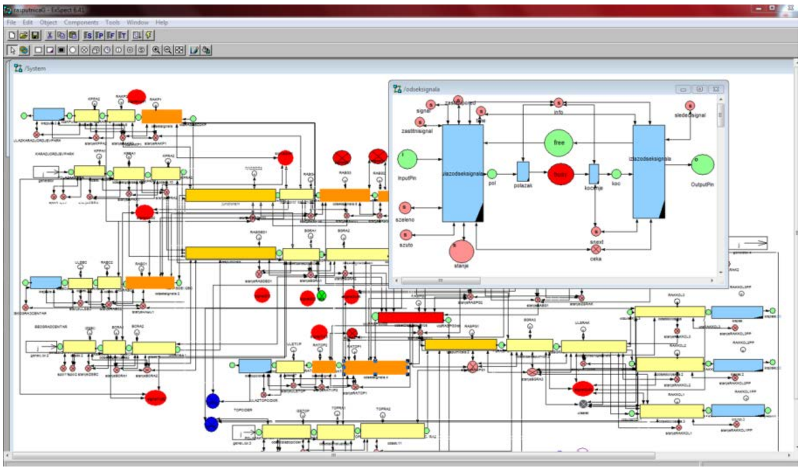

Fig. 3. HLPN model of the part of the Belgrade railway node

In the HLPN model of a part of the Belgrade railway node (Figure 3), a section occupation time is calculated based on equations of train movement and maximum speed for the section (and speed limits). The section occupation time depends on section length and train speed.

When creating a model, one must take into account all of the rules and operating conditions of a railway system [9]. The algorithm must include following steps: data sorting and analyzing; creating and defining modules; creating a Petri net graph by connecting the modules; defining and connecting storage nodes; defining the input database; defining the database that stores data from the simulation program; creating the animation window for the section state according to the section plan.

The simulation can be observed by viewing the token movement through the Petri Net Graph, the storage state indicators and the animation window that shows the state of each section in the model (Figure 4).

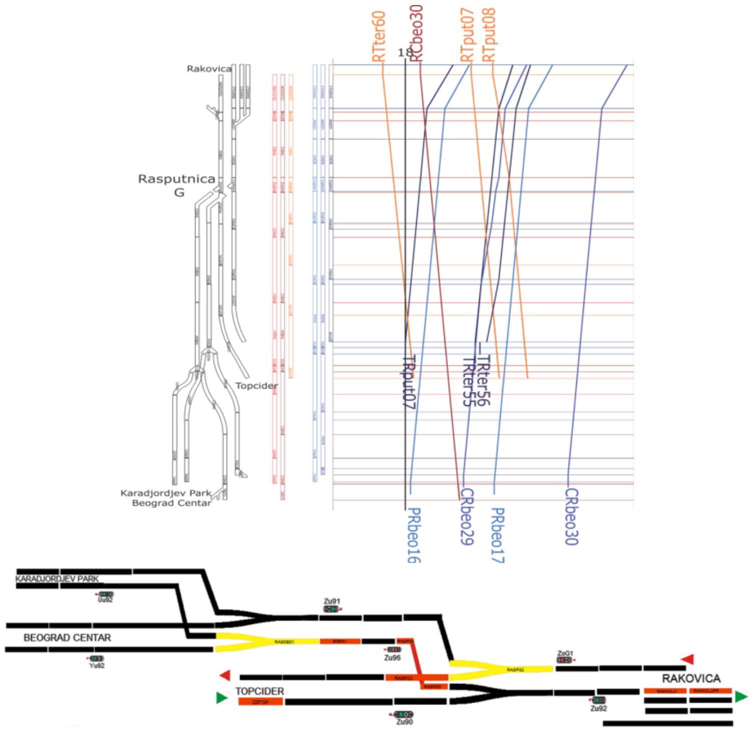

Fig. 4. Results of the model presented by animation and train time-distance graph

<u>Verification and validation of the HLPN model</u>

The Petri Net simulation model can be validated and verified by the following: monitoring if token movement is in accordance to operating rules; inspecting storage indicators; animation window that shows the state of each section in the model (Figure 4); and data analysis of the simulation results that are stored in a database from which reports can be generated. Additionally, the database generates a time – distance diagram (Figure 4). Any irregularities in the model can be easily identified on the train diagram.

In order to verify the HLPN model, simulation results are tested and compared with the results obtained from the OpenTrack simulation software for the part of the Belgrade railway node.

RESULTS OF THE HLPN MODEL OF JUNCTION G

Junction is located on an open track and is a point where train routes are conflicted. If there are a lot of trains there is a high possibility that junctions can transfer of train delays and thus affect the total delay of trains and reduce stability of the timetable. The effects caused by junctions can be reduced by organizational and technological actions, but with the high number of trains it is necessary to consider the partial grade separation of the tracks – denivelation. We have prepared two simulation models of the junction: the existing tracks, signals, and section layout, and in Alternative II (Figure 5), the new layout partially denivelated, with tracks that are separately set and directed to station Rakovica. In Alternative II, tracks from Beograd Centar and Topcider are separated and led to Rakovica, while tracks from Rakovica still have junction in the facing direction of train movements towards Beograd Centar and Topcider.

Fig. 5. Plan of sections for Alternative II – partial denivelation of Junction G

Table 1. Occupation of tracks in the model for a 10 day simulation (hours)

		Rakovica - Beograd Centar	Rakovica-Topcider	Rakovica – Karadj. Park	Topcider - Rakovica	Beograd Centar - Rakovica	Karadj. Park - Rakovica	TOTAL	
Alterna-tive I	Suburban	32.9	10.7	21.3	16.3	50.2	35.2	167	258
	Freight	0.0	31.3	0.0	26.2	0.0	0.0	58	
	Passenger	6.5	7.0	0.0	9.2	10.6	0.0	33	
Alterna-tive II	Suburban	32.7	9.1	21.1	14.9	46.7	32.6	157	239
	Freight	0.0	26.6	0.0	24.0	0.0	0.0	51	
	Passenger	6.6	6.0	0.0	8.5	9.9	0.0	31	

Results from the HLPN simulation models are presented in Table 1. Total occupation times of the sections are calculated in a simulation run for a period of 10 days. Results indicate that there is a difference in results although the initial timetables are the same for both simulation models. This is attributed to the additional delays that occurred in Alternative I of the model. Further, we have run a scenario with variating planned timetables by analyzing the pessimistic, realistic and optimistic number of trains in a future. Results presented in Figure 6 also shows that Alternative II has significantly less delays in the system.

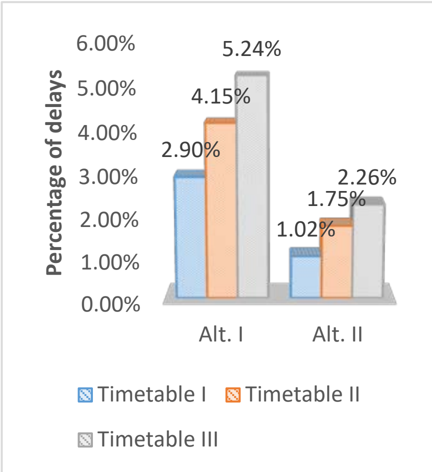

Fig. 6. Percentage of delays compared by alternatives and timetables

CONCLUSION

The Petri Net HLPN model for the complex railway system is based on a hierarchical structure with connected distinctive modules. Simulation by HLPN model can be usedinmanyanalysis of the railway systems (decision making in investment projects,testing infrastructure or technological designs, analyzing timetables and line capacity, train delays, etc.).

Future development of the model will be focused on testing ofHLPN model and improving the application by implementing the model in the software environment that is easier to adopt, apply and connect to other applications.

ACKNOWLEDGEMENT

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