USE OF PETRI NET FOR MODELLING OF TRAFFIC IN RAILWAY STATIONS

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1. INTRODUCTION

The main goal of this paper is to give an overall view on use of Petri Nets, a universal modelling formalism, for modelling of railway stations. This topic combines two views together: the area of modelling of systems with concurrency and the area of railway technology. This is reflected also in the structure of this paper.

In the section 2, we will have a brief look at basics of Petri Nets necessary to understand further parts of this paper. In the section 3, we will outline a rough process model of a railway station. The section 4, as the main part of the paper, discusses different approaches to modelling of railway technology using Petri Nets.

The paper focuses mainly on a review of the state of the art with an outline of potential further research in this area. The paper includes also links to other papers, where you can learn more details on specific topics.

2. INTRODUCTION INTO MODELLING WITH PETRI NETS

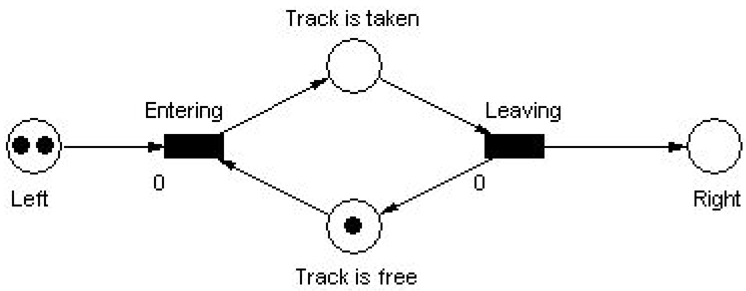
Petri Nets Basics

Petri Net is a formalism used for modelling and analysis of systems with concurrent processes and their behaviour. As the authors in [4] mention, Petri Net can be considered as a model of a system with concurrency that has graphical notation, precise mathematical language and analysis methods for specifying of the system behaviour.

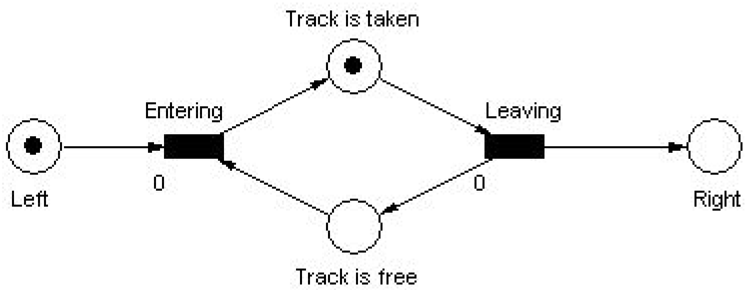
In the most basic form, it consists of places, transitions, arcs and tokens that are placed into a graph. Places and transitions are two types of nodes of the graph. Oriented arcs connect places with transitions and vice versa, while no pair of nodes of the same type can be connected. Tokens are in the places.

Adding and removing of tokens to and from places represents the dynamic behaviour of the net. It happens when a transition, to which the places are connected, fires, i.e. removes and adds appropriate tokens based on the conditions set by oriented arcs.

For instance, the sequence of figures No. 1 a-c could depict a model of a railway line section being used by trains moving from left (the Left place) through the section border (the Entering transition) to the line section, and further through the other section border (the Leaving transition) to right side (the Right place). The line section is modelled by the two places showing, whether it is free (the Track is free place) or taken (the Track is taken place). On the first picture, there are 2 trains waiting on the left side before entering. On the second picture, one of the trains entered the line section. On the last picture, the section has been made free from the train that moved to the next section modelled by the Right place.



a)



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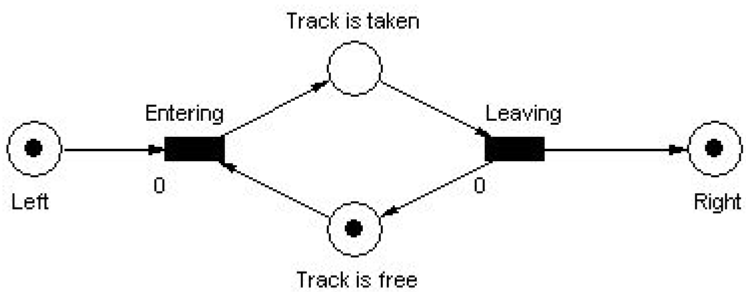

c)

Figure 1: Petri Net model of a line section with a train moving from left to right.

The Petri Net from the example belongs to the basic type called place/transition nets. This concept has been further modified to many different, usually more complicated types. For instance, by adding the dimension of time we can get timed Petri Nets and by adding probabilities of events, we arrive to stochastic Petri Nets. When tokens in a Petri Net receive further specification, they are distinguished by their values (they are not the same any more), the Petri Net gets to higher level. One type of Petri Net on this level is coloured Petri Net.

Further details on Petri Nets and their classification can be found in [21].

Principal Aspect in Modelling with Petri Nets

As mentioned above, Petri Net models (the P/T Petri Nets) contain 4 types of basic elements that can be assigned to real elements depending on the expected goals.

For instance, in a model of car traffic in a road transportation system, one vehicle can be represented as a token that moves in the net between different places and transitions symbolising network of routes. In another model, describing different speed levels of an automobile, the same vehicle can be represented as a set of places, where one place means a certain speed level of the vehicle. In this model, token moving between places through transitions would mean different current speed of the vehicle.

It can be seen that after developing the first model, we can hardly use anything from it in developing the other one. So the other model has to be started from the beginning. If we wish to combine both approaches in one model, we'll probably have to choose another modelling paradigm.

This example shows, how much it is important to decide on the goals of the model and the subsystem to be modelled from the real system (i.e. which elements and which relations among them should be represented in the model) before creation of any Petri Net model.

Major goals to be achieved by creation of Petri Net models are usually:

- Description of the real system,
- Simulation of behaviour of the real system with modelling of different situations of the system, that are sometimes even difficult to achieve in real system,
- Analysis of the system behaviour to find a deadlock or
- Statistical results about the system behaviour.

3. PROCESS MODEL OF RAILWAY STATION

For the purpose of this paper, we chose a model of processes in a railway station as depicted on the Fig. 2.

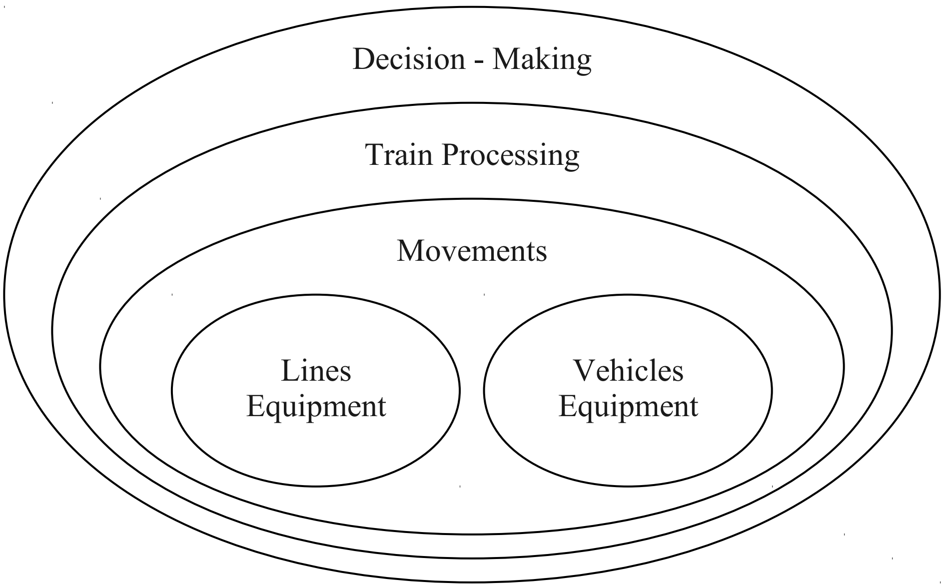

Figure 2: Process model of railway station.

The basic elements of the model represent technical equipment. There are also corresponding processes, which cover route building, safety, signals (lines tracks or infrastructure equipment) and processes connected with locomotives, cars and other moving equipment (rolling stock).

Next higher level comprises movements, where we do not take into account technical details of processes and we focus on movements of vehicles using given routes on the infrastructure.

Train Processing includes processes of sorting of a train set, building a new train set, technical inspection, cleaning operations and any other processes that are done with a train in a railway station.

The top level of the model is decision-making that uses the processes on lower levels and takes decisions about assigning locomotives and staff to technological processes.

4. USE OF PETRI NETS

In this section, we will take the four levels of railway station process model outlined in the previous section and look on the use of Petri Nets for modelling on each of them. We will try to (where possible):

- Mention examples of Petri Net models and applications made so far,

- Evaluate current benefits and problems of modelling by Petri Nets and
- Outline potential ways of further research to solve the problems and enlarge the benefit of Petri Net models.

Technical Equipment Level

On this level, technical issues in modelling the European Train Control System (ETCS) were outlined in [7]. The authors developed two coloured Petri Net models, for both the on-board system and the trackside system. They have been working further on two more models of the interlocking and the regulation.

The aim of their formal model was

- To check completeness of the specification of the ETCS,
- To use it for a systematic derivation of test cases and
- To evaluate, at an early stage, the specification of the standardized interfaces of the ETCS according to the German national railway environment.

This is an example of use of Petri Net for specification of real system and its different cases of behaviour.

Another example based on Extended Deterministic and Stochastic Petri Nets (EDSPN) is presented in [14]. Formal modelling using the EDSPN has been applied for quantitative evaluation of parameters in the risk and system hazard analysis of a simplified level crossing control system. The model served as an example to explanation of safety analysis of railway operation control system in the context of CENELEC standards application.

Movements

When modelling railway stations on the level of movements of trains or vehicles, the usual paradigm is similar to the one outlined earlier: places represent tracks, transitions are borders between tracks, and tokens stand for moving elements. On the abstract level, the network of tracks in a station and network of lines of a railway network can share the same model [2]. Thus when talking about movements in a railway station, we can take also models of railway networks into consideration.

On this level, analysis of possible situations leading to a deadlock in a network is a usual goal. Different situations at the station are represented by states of the Petri Net. The tool allows us to construct states space diagrams (also referred to as reachability or occurrence graphs) that help in analysis of liveness property necessary to find the deadlock. However, an explosion of state space for even small models and its time and resource consuming analysis makes it almost useless method for models of a real station operation [1].

A promising approach in this area has been presented in [17]. The author used interval-timed coloured Petri Net (ITCPN), timed coloured Petri Net where delays are represented in the form of interval, and the Modified Transition System Reduction Technique (MTSRT) to model and analyse a railway station. In the ITCPN model, time is associated with tokens and transitions determine a delay specified by an interval. This also allows to model uncertainty without the necessity to know the delay distribution.

The MTSRT method has been used to analyse throughput and waiting times of trains in railway stations. It constructs a reduced reachability graph that can be used to prove certain properties or to calculate accurate bounds of all kinds of performance measures (e.g. throughput times, waiting times, occupation rates) and also to detect potential deadlocks of trains.

Another view on modelling of train movement with hybrid Petri Nets has been presented in [3]. The original Petri Net formalism has been enlarged here with continuous transitions that allow modelling of not only discrete events, but also continuous processes. This can help in more precise modelling and analysis of traffic processes at railway stations.

It was further used for performance analysis of moving and fixed block train protection [13]. The analysis was carried out with help of reachability graph and showed large potentials of moving block signalling for increasing of the track performance. As the authors state, the modular modelling approach using Petri Nets allows the configuration of large railway systems with different kinds of operation control.

The reachability graph for the model of one line track does not tackle the problem of states explosion that is experienced when modelling network. The reason is that the scale of concurrent processes running on a single line is smaller than in a network.

Train Processing

Villon is a simulation tool for modelling of infrastructure and processes in railway stations [10, 11, 12]. It is build using agent-based approach in the architecture. For definition of reactive agents' behaviour, a modified version of Petri Net has been used [8, 9]. It helps to clearly define flows of messages between agents and their processing by them. Places in this model are divided into certain types based on their position in the net. Transitions are also divided based on certain behaviour that was modelled.

The Petri Net has been then implemented in the simulation tool. It serves for adjusting and adding new features in behaviour of agents in the further development of the tool, as new elements and operations get developed in the model. Till nowadays, there was no need for any analysis of the Petri Net in this case.

This definition allows then construction of technology flowcharts for description of technological processing of trains in the railway station simulation model. The technology flowchart is a marked graph, which is a special type of Petri Net. It is a simplified formalism compared to Petri Net that does not require deeper knowledge of its modelling abilities and it is more widespread among practitioners in the railway industry. Thus new users can get acquainted with the modelling of technological processes faster and easier.

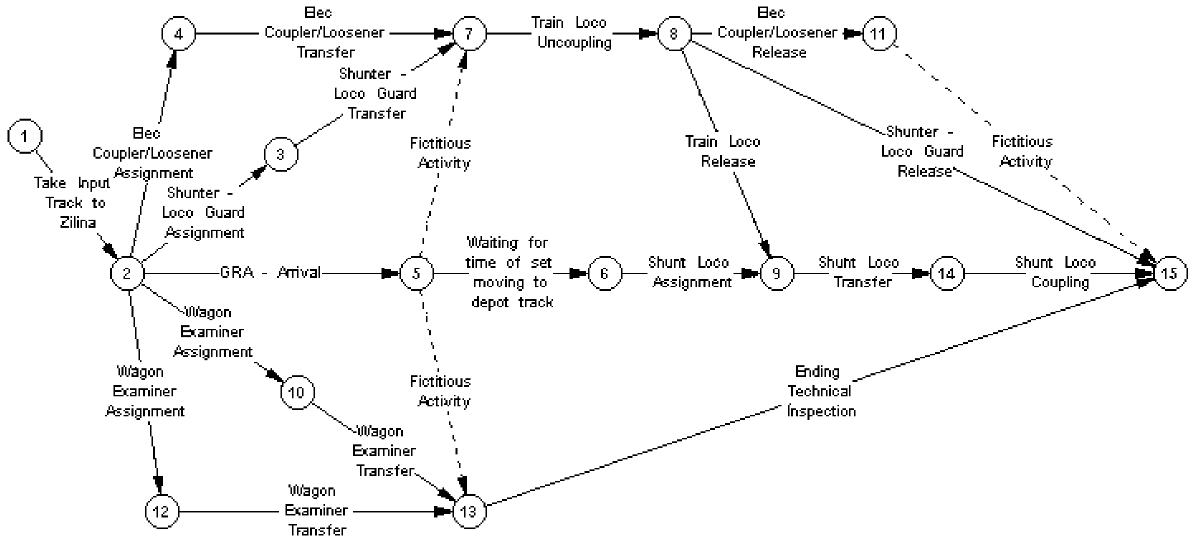

Figure 3: Example of a technology flowchart in Villon.

However, the modelling power of marked graph is not as large as of Petri Net, thus its utilization has certain limits. One of the major obstacles in modelling of the technological processes in a railway station with help of Villon has been modelling of conditional technological processes. More precisely, during the course of operations with a train in a station, there may be some operations carried out only, if a condition is fulfilled – e.g. moving specific passenger cars in and out of a passenger train set or depositing of faulty cars from a train set. Handling of these operations could be modelled through conditional parts of the technological flowchart.

It seems, that the outlined problem is similar to problems in analogic processes in workflow management [15, 20]. In that area, Petri Nets have been applied in modelling of workflows in organisations. They became a base for definition of WF-nets that give further tools for modelling of workflow patterns as described for instance in [18, 19].

The different workflow patterns have been identified and the process still goes on. Their number has been recently about 20. It would be very interesting to compare the identified workflow patterns with the technological operations carried out in railway stations. This will be a topic of our further research.

To summarize this section, the utilization of Petri Nets or of concepts based on Petri Nets in the area of modelling of train processing has been focused more on formal description of real processes and their definition for computer based modelling. Another topic for further research is finding possible ways, how analysis of the models based on Petri Nets representing technological processes can contribute to detection of deadlocks and of effectivity improvement in railway station operation.

Decision-Making

In the section on train processing, we already touched the topic of decision-making in a railway station. The condition-based technological processing contains making of such decisions, which are prescribed ahead and are taken depending on current situation. However, at the stations, there are also decision-making situations that are difficult, if not impossible, to expect in advance. In addition to that, the decision alternatives may appear only at the time the situation is being solved.

One idea is to use similar approach as in the workflow management for recognizing and modelling of such situations. The models could serve as a description tool of the possible decision-making alternatives to the current situation and also evaluation of alternatives giving the base for making the decision.

One possible implementation is through fuzzy Petri Nets, another special branch of Petri Nets that models evaluation of rules taking into account uncertainty (as known in expert systems). Example in this is made in [5], where the author defined methodology for reasoning using this formalism. His view takes into account stages from recognizing and classification of problems or conflicts, through selecting of possible actions in given conditions, simulation of different alternatives until their evaluation and selection for use. Fuzzy Petri Net brings there the graphical description abilities that help in building large knowledge databases, where the rules interconnection may create a complex system.

Combining the Levels

Another look on use of Petri Nets for modelling of traffic in railway station combines more or all levels mentioned so far in one model. This could lead to creation of complex Petri Net models with the goal of understanding of different levels of processes at the station and relations among them.

Some modifications of Petri Nets, namely object and hierarchical ones, create a base for start of exploration of this idea. So far, we have not seen any Petri Net applications of this complexity that could serve as a reference point. It can be seen more as a goal of further research.

5. CONCLUSION

Application of Petri Nets in modelling of railway station can be wide. In the article, we mentioned some utilization possibilities. The possibilities may be wider. They depend on:

- Problems to be solved,
- View used in problems solving,
- Creative approach to problems solving.

Main benefit of Petri Nets using in modelling of a railway station has been so far in description of the investigated system and in simulation of its behaviour. The simulation may lead to different situations what helps to understand the real system better and to predict various situations, including the unusual ones, and to prepare possible solutions to outlined problems.

The analysis of models as the second goal showed up to be hard to use in many cases, since majority of models is complicated. The complexity of models and Petri Nets used for their representation lead to a time-demanding analysis, what is not acceptable in most cases. This makes the utilization of Petri Nets in the domain of transport systems more difficult.

However, there are ways for improvement and we hope to tackle some of the problems in our further research work.

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7. ABSTRACT

The article aims at giving an overall view on using of Petri Nets, a universal modelling formalism, in modelling of railway stations. After a brief introduction into the area of Petri Nets, the author defines 4 levels of elements in a process model of a railway station: technical equipment, movements, train processing and decision-making. In the main part of the paper,

the author describes existing Petri Net models, benefits and shortcomings of them and possible ways of further research.