Railway traffic simulation by means of a Petri Net model

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Abstract

The paper explains the main results of an ongoing research concerning the development of a network model, including lines and stations, capable to simulate the traffic operations on the basis of the actions performed by the signalling components; this approach allows a high flexibility and capability to manage the traffic command and control operation. The model feasibility has been demonstrated and a global network model has been built up. It includes: i) a generalised station model to be applied to any lay-out and interlocking system; ii) a generalised line model to be applied for any signalling system.

The represented network may be analysed with the simulation of different timetables without traffic density constraints. The main outputs of the model application are: i) the global rate of occupation for line and station components (track circuits, points, etc.); ii) the traffic development representation with the underlying of the critical situation (conflicts among trains).

The model has been successfully tested on a network including a line section equipped with a codified currents automatic block signalling system and two stations.

1 Introduction and objectives

From the increasing attention towards the railway interoperability and safety arise the need of models capable to support the decision processes concerning the system upgrade, particularly for the performances of the signalling in terms of carrying capacity and safety.
The successful work carried out in the past on the application of the Petri Net formal method for the simulation of the station interlocking systems (Malavasi [1], Malavasi [2]) suggested to investigate the possibility to apply the same method to the more general problem of traffic simulation.

2 Methodological approach

The development of a global network model includes the integration of:

- a generalised station model to be applied to any lay-out and interlocking system;
- a generalised line model to be applied for any signalling system;
- a timetable model capable to reproduce the traffic perturbations.

The modularity performance of the Petri Net modelling tool (Peterson [3]) allows the easy integration of the models with a simple chaining of their elementary modules (e.g. track circuits, block sections and related signals); the resulting network model allows the simulation of different timetables without traffic density constraints.

3 Station model

The Petri net station model includes typically sets of nodes corresponding to various objects categories: track circuits, switches, signals, etc. linked by transitions on which the token run at defined conditions; on this basis the train movement simulation including route selection, occupation and release results strongly simplified.

In Figure 1 a flow-chart of check, recording and interlocking procedures within the station model is shown.

Figure 1: Sequentially performed check, recording and interlocking procedures

In Figure 2 the Petri net dedicated to reproduce the track circuit recording check procedure is shown as a sample.
The model may be structured in two functional parts:

- a common module to be applied to any station (common set of nodes and transitions);
- a specific module including two sub-modules respectively corresponding to the station lay-out and the timetable.

In Table 1 an overview of the dimensions of common and specific modules for a set of modelled stations characterised by increasing complexity (Figure 3) is reported.

<table>
<thead>
<tr>
<th>Station Model</th>
<th>Common Module</th>
<th>Specific module</th>
<th>Global station model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transitions</td>
<td>Nodes</td>
<td>Transitions</td>
</tr>
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<td></td>
</tr>
<tr>
<td>Ciampino (estimated)</td>
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<td>Casilina</td>
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<td>2000</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>2438</td>
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</tbody>
</table>

Table 1: Amount of transitions and nodes in 3 station models

The high level of modularity of the model allowed by the Petri net tool is self-evident, particularly considering the amount of nodes of the specific module: no more than 39% for the largest station.

The Petri net adopted for the modelling of the timetable is shown in figure 4.
Figure 3: Modelled stations lay-outs

Figure 4: Timetable module and its connections with lay-out and common modules
In the timetable module the actual train arrival time is determined by the temporisation of the transitions (A1 and A2) calculated on stochastic basis. Starting from this time the following procedures included in the station lay-out and the common modules are activated: i) route set up; ii) train access; iii) track circuit occupation.

4 Line model

Obviously the Petri net line model includes sets of nodes corresponding to objects categories only partially different from station: block sections, signals, etc. linked each other.

For the automatic block systems, both at fixed (D.C.) or codified (A.C.) current, the core process is the modification of block system code depending upon occupation and release of the block sections.

It may be simply modelled as showed in figure 5.

![Diagram](image)

**Figure 5**: Flow-chart of block system code modification process

In Figure 6 the Petri net dedicated to reproduce the transmission of code 75 within the line block system (with codified current) is shown as a sample.
Figure 6: Petri net reproducing the transmission of code 75 for the codified current automatic block system (BACC)

5 Integrated model output

The integrated model including both line and station modules is capable to simulate the train operation and to produce the following main outputs:
global rate of occupation for components (track circuits, points, etc.);
traffic representation with underlying of the critical situations (conflicts among trains).

6 Model application

The model has been successfully tested on a network including a line section equipped with a codified currents automatic block system and the two extreme stations (Figure 7); the simulated timetable is represented in the same figure.
The results of the application are reported in the time occupation diagram (Giuliani [4]) of the line sections (Figure 8) and one of the two stations tracks (Figure 9).

![Figure 7: Schematic lay-out of simulated network and timetable](image)

7 Conclusions

The Petri net tool is particularly suitable for the simulation of railway traffic operation due to the capability to take into account the system states changing caused by train movement by means of the progressive transitions activation.
The station model requires a high codification effort for the common framework but the modular structure allows a simple extension to various station lay-outs; this approach is also fully consistent with logic safety checking criteria of electronic interlocking systems (Gottschalk [5], Ricci [6]).
The modularity is still higher for the line model and it may be easily adapted for mid-continuous and discontinuous block systems based on codified or fixed currents, axle-counters, balises (e.g. ERTMS Level 1 to 2), etc.
References