A new approach to model signalling systems on railway networks

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Abstract

SCIRONET, an integrated simulation environment for the analysis of the railway network operation, has been developed in order to evaluate the mutual interaction between the signalling system and the network capacity. It provides the train circulation simulation on a set of interconnected railway lines taking into account signalling system, different supervision modes and track-to-train interfaces. The major development effort has been devoted to the full modular structure of the integrated simulation environment, which is the result of the application of Object Oriented Analysis and Design techniques. The full modular structure enables to add or modify functions and features easily, in order to extend the application to new signalling systems. Through the parametric description of each system component the user can better tailor the different simulator module to the needs of all the life cycle phases, especially during the design and the traffic operation planning.
1. Introduction

Planning modern railways networks is a difficult and complex task, because it has to take into account many different factors and at the same time to comply with the basic safety and availability requirements.

The modern railway networks complexity is increasing due to the introduction of new signalling systems which operate with the existing ones. Furthermore the trains are equipped with different control and command systems from the new cab signalling and ATP equipment to the old standard equipment.

These issues, along with regulation practices and tighter project timescale constraints, have given as a result a considerable pressure upon the responsible for railway network infrastructure planning, operations and timetabling.

A lot of subsystems play a fundamental role in the operation of a railway network. Many analytical and statistical methods have been proposed in order to assess line capacity and to plan the train timetable, but they lack in accuracy whenever the problem complexity increase.

The only suitable method to evaluate the mutual interaction of network layout topology, signalling systems, stations resource allocation, train movement and rule book, is to utilise computer-based simulation tools. The computer based simulation tools allow detailed modelling of the network topology and of the signalling system defining the exact location of each equipment, and the train movement simulation, taking into account the rule book and the mutual interaction with the signalling system. The train movement implies the track section occupancy and consequently the updating of the signalling information, related to track circuits, light signals, balises, loops, radio block centre database and so on.

The railway simulation tool should be able to calculate the train timetable in each branch of the network, to evaluate the train speed diagram, taking into account all the imposed constraints.

The current simulation tools have often been designed in order to solve the problems related to a particular national signalling system; consequently they embed the peculiarities of a unique railway systems. The enhancement of the implemented models could be very complex and time-consuming because it would require full revision of the software structure.

Further implementation problems may be related to the development of the user graphic interface, to the data entry procedure and to the standardisation of the data management.
The proposed integrated software environment tries to solve the above mentioned issues.

2. Tool description

The SCIRONET software tool has been developed using C++, the current standard in large scale project development. The result of the object oriented programming paradigm application is a software modular structure, easy to maintain, update and customise.

The software has been developed using a classes library, called SimBuilder of Sciro Electra, which provides a large set of standard functions, such as graphic user interface management, graphic output display, scheduler and simulation events management, databases interface, etc. SCIRONET takes advantage of this rich software layer; it only adds specific modules related to the modelling of the railway system, being deeply founded on SimBuilder.

The SCIRONET simulation platform consists basically of the following modules, whose data structure will be described hereinafter:

- network lay-out;
- train;
- station and traffic manager;
- rule book;
- signalling;
- traffic regulation;
- timetable;

The Network lay-out module allows to define the topology of the network to be simulated. The network description is carried out by an oriented graph, consisting of nodes and links, whereas the nodes represent the main stations or junctions and the links represent the connecting lines. For each line it is possible to define gradients, speed limit values, stations and stops position, traffic regulation, track section position and length.

The train module allows to define the features of the train circulating on the line. Train circulation is simulated in time domain, integrating motion differential equations. The acceleration value at each time step is calculated according to the available traction effort, to the motion resistance (as train speed, gradient and curves function) and to the max. allowed acceleration. The train is assumed to follow a parabolic braking curve, which is characterised by the standard deceleration value.
The software tool allows definition of templates to be used during the data entry phase:

- train templates simplifies the specification of the type and number of train engines, train category, mass, length, max. allowed acceleration, standard deceleration, max. allowed speed, rank and coefficient to calculate the motion resistance (constant, linear and quadratic term with the speed); for each train it is furthermore possible to define the on board signalling equipment;
- an engine database, in which it is possible to specify the drive traction diagram (kN vs. km/h) and the rotating masses inertia ratio.

The existing stations in the plant are modelled taking into account macroscopic constraints: in particular, the software takes into account the available track number for each direction and the relevant allowed speed value.

As described for trains and engines it is possible to define a set of templates for the standard stations, characterised by the number of tracks for each direction and their length. It is furthermore necessary to specify the straight track in both directions and the different allowed speed in other tracks.

The traffic manager module is responsible for the following tasks:
- station resources allocation (straight or other track),
- solving train overtaking conflicts,
- solving train departures conflict.

The Traffic Manager’s rules can be tailored according to the user needs.

The rule book module implements the train driver’s rules to be followed according to the timetable, the minimum station dwell time, the different signal aspects and the track to train available information.

Each layout line can be equipped with different kind of signalling equipment, such as light signals, track circuits, balises, loops.

The signalling system module allows to define the type or the types of signalling equipment of each line so that different trains can receive information in different ways.

The traffic regulation module defines the circulation types on each line, in particular: manual electric block, axle-counting block, coded current automatic block, different ERTMS levels.

The timetable module defines the route and the scheduled timetable of each train. In particular the train number and type (reference to train
templates) and the list of stations and stops with relevant departure and dwell times have to be specified.

The simulator provides, as a result, the graphic and tabular timetable of each line and of each train. It also provides statistical data about the exploitation of system resources and, on demand, the event history data recording concerning each particular system or equipment. For each train the simulator provides, as a result, position, speed and wheel mechanical power vs. time data. According to these data a graphic as well as a tabular timetable of each line and for each train will be given. It is also possible to obtain a graph with the speed of each train and the wheel mechanical power.

3. Advanced features

The full modular structure of the proposed integrated simulation environment could be easier obtained through the application of Object Oriented Analysis and Design techniques. The full modular structure enables to add or modify functions and features easily, in order to extend the application according to user new needs, such as:

- ATP/ATO technical features;
- introduction of new equipment (balise, loop, ...);
- new signalling system (Radio Block Centre);
- interoperability related problems (trains running on track equipped with different signalling systems).

A considerable development effort has been devoted to the parametric description of each system component in order to modify the
characteristics of their model and consequently their behaviour, without modifying the software structure. Through this parametric description of each system component the user can tailor the different simulator module to the needs of all the life cycle phases, especially during the design and the traffic operation planning.

As an example, the light signal parametric description is reported in order to show how the user could customise the information related to each signal aspect in the context of the different national signalling system.

Each signal aspect is characterised by the following set of parameters, as reported in figure 1:
1. aspect name,
2. allowed speed at the signal,
3. next speed limit,
4. allowed speed at next signal
5. minimum distance to the next signal,

The above mentioned parameters are a subset of the ones defined in SCIRONET. In order to define the signal aspect characteristics the user is not requested to specify all parameters: some of them are mandatory whereas others are optional or mutually exclusive.

Figure 2: example of normal sequence related to the train stop in Italian railway system.

Figure 2 shows an example of the above mentioned parameters table related to a train stop signal aspect sequence in the Italian railway system. Only few parameters are used to characterise each signal aspect.
Figure 3 shows an example of the above mentioned parameters table related to a train speed restriction to approach a secondary route of a station.

<table>
<thead>
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<th></th>
<th>Green</th>
<th>Yellow/Green</th>
<th>Red/Yellow</th>
</tr>
</thead>
<tbody>
<tr>
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<td>30</td>
</tr>
<tr>
<td>2</td>
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<tr>
<td>3</td>
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</tr>
<tr>
<td>4</td>
<td>30</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
</tr>
</tbody>
</table>

Figure 3: example of normal sequence related to the approach of a speed restriction.

As far as the technical issues, like user graphic interface and the data management, are concerned the tool complies with the Windows Graphic User Interface standard and support a wide range of database format by means of the Object Data-Base Connectivity (ODBC). ODBC is the database portion of the Microsoft Windows Open Services Architecture, an interface which allows Windows-based desktop applications to connect to multiple computing environments without rewriting the application for each platform.

5. **Conclusions**

In this paper the authors have proposed a object oriented model to simulate signalling system on complex railway networks. This approach enables to add or modify functions and features easily, in order to extend the application to new signalling systems. The Object Oriented Analysis and Design techniques have allowed to build a parametric description of each system component, giving the user the ability to customise the behaviour of the simulator.

The authors have also described an integrated simulation environment, SCIRONET, for the analysis of the operation of a complex railway network.
Potential users of this tool are the operators responsible for the design and the operation planning of railway systems.

The main tasks, which underline the SCIRONET capabilities, are following listed:

- new infrastructure planning and optimisation,
- impact evaluation of modifications to signalling system;
- timetable development and check,
- signalling and Automatic Train Protection studies,
- capability analysis,
- traction performance requirements evaluation,
- impact studies of perturbations from track maintenance and line disruption on capability and performance.

The modular structure enables the SCIRONET expandability towards the modelling and simulation of new signalling system, such as the Radio Block Centre.

6. References