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Multi-train simulator for regulation purposes

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Abstract

This paper presents a multi-train simulator for railway networks. The main use of this traffic flow simulator is to serve as a test bench for traffic control strategies. The most interesting features of this particular simulator are twofold: modularity and generality. The traffic flow simulator is build up with three independent components: (1) a signalling and interlocking simulator, (2) a train movement (running and dwell time) module and (3) an automatic route-setting module. This structure of modules does not depend on the particular characteristics of each railway system.

1 Introduction

The work presented in this paper is a result of a long time co-operation between Dimetronic Signals and Instituto de Investigación Tecnológica (IIT) in simulation, analysis and regulation of railway traffic: Cuadra et al[1] describes a train movement simulation model, used for design and analysis of signalling systems and interval calculations; Fernández et al[2] shows how a prototype of a regulation system is tested against a metro line simulator, including passenger flow scenarios and protection system; Fernández et al[3] presents the results of the implementation of an optimal control system for closed metro lines in an integrated control centre. In this paper, these works are extended to complex railway networks.

First of all, this paper describes the breakdown of the simulator in three functional and independent modules:

- Signalling, interlocking and driver simulator.
- Running time and dwell time module.
- Automatic route-setting.

Later, the most important characteristics of each module are described in detail and, finally, some results of the developed simulator are presented. These results are part of a regulation-strategies study for Line #9 of Metro de Madrid after its extension to Arganda del Rey. The prototype has been implemented in the ANSI-C programming language on a UNIX workstation. The algorithms used to develop and integrate every module are based in event-driven simulation. Arrival and departure times of the trains into track circuits and state changes of the interlocking are accurately estimated by the simulator.

2 Modular design

This traffic flow simulator consists of two functional and independent modules, as shown in figure 1: a movement simulator and an automatic route-setting.

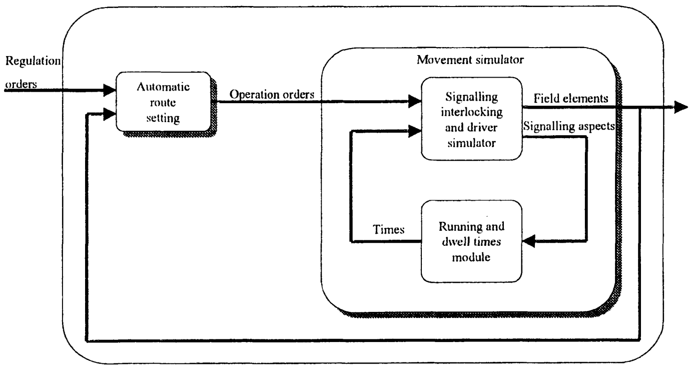

Figure 1. Traffic flow simulator. Modules diagram

The route-setting module defines the local path of every train along the railway network, according to the established service. In response to the occupation (and liberation) events of track circuits, the route-setting module assigns routes and regulates signals, given that certain conditions of field elements (track circuits, junctions and signals) and traffic (timetable) are met.
The automatic route-setting can also receive regulation commands from an external regulator. The service can be thus adapted through new right-of-way priorities assigned to each train at junctions.
The movement simulator takes charge of the train circulation through the railway network, according to the operation orders provided by the automatic route-setting. The movement simulator is made of two independent modules: a signalling, interlocking and driver simulator module, and a running and dwell time generation module.
The signalling, interlocking and driver module undertakes to maintain, first of all, the field elements state updated. This is done by processing the occupation-liberation of track circuits events of every train and the route setting and signals regulation orders. It also calculates the signalling aspect (basically speed restrictions) of every track circuit, which is needed by the running and dwell

time generation module. The driver knowledge is included to model stops at stations and changes of way in the network points established (these are independent on the state of any field element, but are imposed by the actual service knowledge).
The running and dwell time module calculates, for every train, the time associated to the events of occupation-liberation of track circuits. It uses estimations of running time in the track circuit, and the dwell time at stations according to the proposed stop model. These times are generated according to the signalling aspect of related track circuits.

3 Signalling, interlocking and driver module

This module simulates any signalling and interlocking system with a high level of detail. As it is shown in figure 2, the railway network topology is modeled with a graph in which the nodes are the unions between track circuits and the junction points.

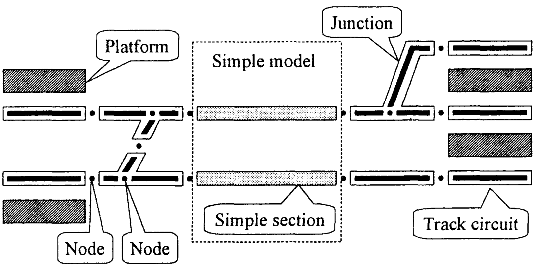

Figure 2. Track model

The signalling, interlocking and driver model performs three fundamental tasks:

- Update the state of field elements: track circuits, junctions and signals.
- Calculate signalling aspects of every track circuit.
- Modify signalling aspects due to driver knowledge.

The state of the field elements is updated from trains movement (occupation and liberation of track circuits) and operation orders (routes setting and signal regulation) when the logical conditions associated to related field elements allow it. The logical conditions are modeled with masks. Each mask contains the states of track circuits, junctions and signals needed to update the new field state. These masks are easily tailored for any particular railway network.
Signalling aspects are calculated from the current field elements state by a similar procedure. Signalling aspects indicate speed restrictions in every track circuit of the railway network. These aspects are needed by the running and dwell time module in order to estimate movement events.
For applications in which the detail level circuit by circuit is excessive, a simplification is proposed. As it is shown in figure 2, several consecutive track circuits without intermediate junctions can be assembled into a "simple section".

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In this case, both the signalling and the movement models are simplified. The simulator only knows when the train enters in the simple section but does not know in which particular track circuit it is. The simulation just considers a minimum interval of train admission at the entrance, a minimum interval of arrival at the end and a maximum train capacity in the simple section. Therefore, the protection systems in a simple section guarantee that trains respect a minimum interval.
Finally, the driver knowledge is included in the model. Stops at stations and changes-of-way decisions are not included in the interlocking model; because this information is only known by the driver. In these cases, a special signalling aspect is calculated as a new effective speed restriction.

4 Running and dwell time module

This module calculates the times associated to the events of next occupation and liberation of track circuits. The future times will be generated from the calculation of the running time of a train through the track circuits and the dwell times at stations.
A look-up table is defined for every track circuit. Every look-up table contains the running times for all possible signalling aspects. Different signalling aspects imply different speed restrictions on trains due to the signalling and interlocking state. A second look-up table contains the times required to clear previous track circuit under all possible signalling situations. This operation is similar to the simulator described in Ho [4].
Running times contained on every look-up table are the following:

- Time to stop: from entering the track circuit to train stop.
- Time from stop: from train start to reaching the end of track circuit.
- Non-stop times: different times (according to signalling aspects) from entering the track circuit to reaching the end of track circuit

If a change of signalling aspect happens while the train is travelling along a track circuit, the running time is re-calculated by a weighted average of the times associated to both signalling aspects.
When the simple section model is locally used, the running time calculation is simplified. A train is allowed to enter the section after a time interval with respect to the last entrance, but only if the capacity of the section is not exceeded. A train is allowed to reach the exit after a given time interval with respect to the last exit.
The platform stop model handles two kinds of behaviour. For long-distance trains, dwell time can be considered a constant. However, for suburban or metro trains, in which it is necessary to take into account the passage accumulation effect, dwell time is calculated according to the model represented in figure 3.
Given the passenger flow to every station, the linear estimation of the passage at station is calculated based on the interval with respect to the last train that stopped at the station. Then, and from that value, dwell time is calculated according to the saturated model of the graph above. The model is mainly linear, but considers minimum and maximum stop times.

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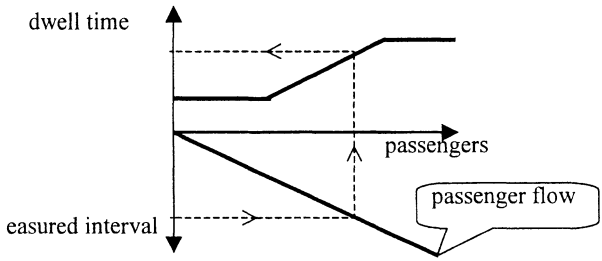

Figure 3. Stop at station model

5 Automatic route-setting

The objective of the automatic route-setting is to guide every train through the network topology keeping the established service assigned to each train. The automatic route-setting is responsible of the routes setting and signals regulation to achieve the programmed right-of-way of trains at junctions.
As it is shown in figure 4, in the control model, the system behavior is determined by a list of actions or operation commands, routes setting and signals regulation. These commands are applied by the automatic route-setting according to entrance events, occupation or liberation of track circuits, if certain conditions or programmed rules are fulfilled. The field elements state (track circuits, junctions and signals) and the predefined timetable are some of the conditions to be checked.

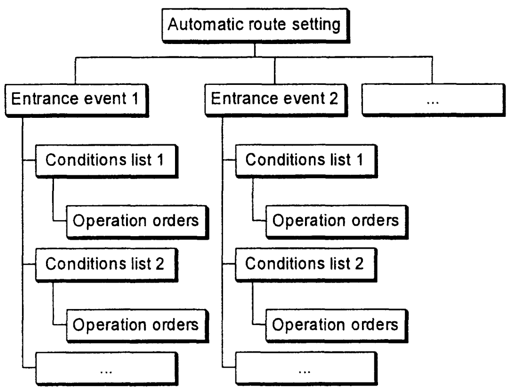

Figure 4. Operation orders diagram

In the other hand, the module receives the possible commands from an external regulator to modify the right-of-way priorities of trains at junctions, initially established by the service. Therefore a disturbed service can be dynamically improved by the external controller or regulator, according to the ideal service and the current state.

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6 Results

The simulator has been used to study regulation alternatives for Line #9 of Metro de Madrid after its extension to Arganda del Rey.
As it is shown in figure 5, Line #9 Herrera Oria–Arganda del Rey is not a simple closed-loop metro line, since two services coexist:

- Urban service: Herrera Oria(HO)–Puerta de Arganda(PA)
- Suburban service: Herrera Oria(HO)–Arganda del Rey (AR)

According to the predefined planning, two suburban trains will always meet in PA, one (S2) to AR and the other one (S1) to HO.

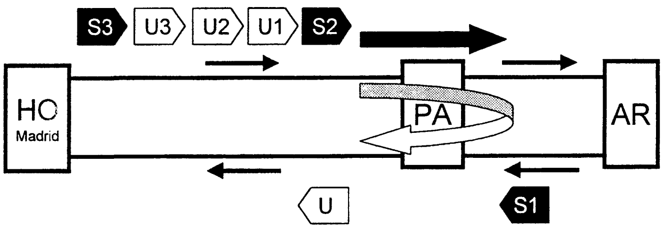

Figure 5. Line #9 HO-PA-AR

But if the suburban train coming from AR (S1) is delayed, the suburban train coming from HO (S2) will continue to AR, and the rest of trains coming to HO (U1, U2, U3, S3, ...) will be delayed because the urban train U1 has not right-of-way in PA. The urban train U1 only will turn to HO when suburban train (S1) leaves from PA.
The regulation decisions correspond to the different alternatives of right-of-way for the trains in PA. In the previous case, a solution could be to give the right-of-way to U1 in PA. This solution would mean that the urban train U1 turned into a suburban train and the suburban train S1 turned into an urban train. In that case, when the train U1 had turned to HO, the new regulation decision could be give the right-of-way to the next urban train (U2) or the train coming from AR (S1). If the urban train turned to HO, the process would be repeated for the rest of trains coming from HO. In any case, the external regulator would have to decide the most suitable alternative.
The general methodology applied to the developed optimization module is direct search. The tree of options is explored by a depth-first strategy. In this simple case, the possible train sequences in PA are [S1-U1-U2-U3], [U1-S1-U2-U3], [U1-U2-S1-U3] and [U1-U2-U3-S1].
The objective function of the optimization algorithm is the total delay in PA. That delay is the sum of the delays of every train affected by the incidence.
On table 1, simulated total delays in view of different train sequences in PA are shown. The last possible alternative [U1,U2, U3, S1] is not shown because the necessary high delay to choose that one is too unusual.

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Table 1. Train sequences in Puerta de Arganda

	S1, U1, U2, U3	U1, S1, U2, U3	U1, U2, S1, U3
Null delay	0	8' 14"	15' 10"
7 minutes delay	8' 41"	8' 14"	15' 10"
18 minutes delay	40' 43"	24' 13"	17' 50"

If there is no delay, any alternative to the programmed service would be obviously worse. However, when a 7 minutes delay occurs, the regulator would modify the right-of-way in PA. The first train by PA would be the urban train U1. In this case, the global delay in PA is reduced from 8' 41" to 8' 14". In the 18 minutes delay case shown in the table, the total delay in PA would be reduced from 40' 43" to 17' 50" if the first and second trains by PA were the urban trains U1 and U2.

Nowadays, this algorithm is used in off-line planning studies but it is proposed as an on-line regulator. Figure 6 shows a CTC-like graphic display of the tool.

In the developed prototype, the two signalling and movement models coexist, track circuits and simple sections. Track circuits model change-of –way stations (HO, PA and AR) and simple sections model the rest of the railway line.

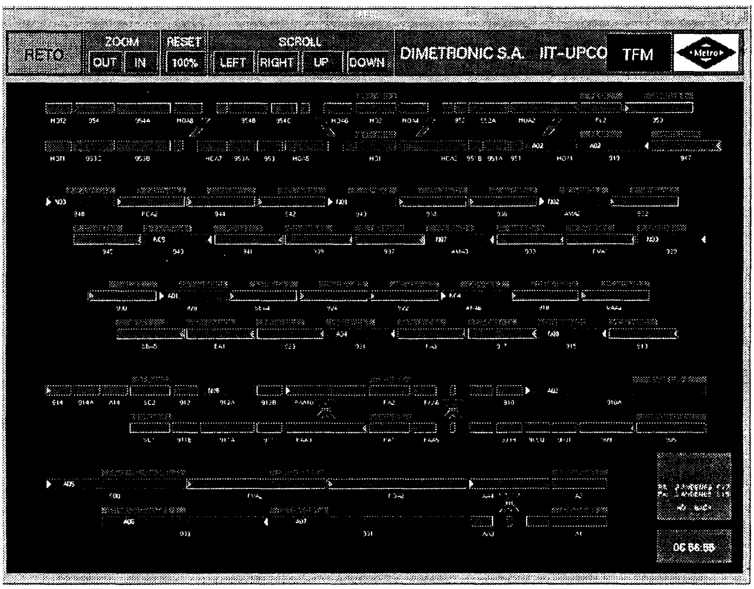

Figure 6. Graphical representation of line state

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7 Conclusions

There are two relevant qualities of the presented simulation model and simulation tool. The first one is the generality of the signalling, interlocking and driver, and automatic route-setting models. They do not depend on the particular characteristics of any railway system. This is possible because every piece of relevant information is configurable for a particular system by logical rules and look-up tables that can be externally edited by the user.

The second relevant quality of the simulator architecture is modularity. Each of the modules can be designed and enhanced separately, according to the desired level of detail and level of accuracy. Therefore, the simulator can be adapted to different applications: long-term investment studies, mid-term planning, short-term service planning, and on-line regulation systems.

Finally, it is worth mentioning that the simulation models and the efficiency of the code implementation have been tested against railway networks -and simulation cases- considerably more complex than the case example described in this paper.

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