Analysis of timetable stability and delays resulting of track maintenance works by means of simulation

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Abstract

In order to compete with other transport modes, European railways must improve their efficiency, which imposes an optimal use of the infrastructure and therefore its availability, and service quality, of which important features are trains punctuality and operation reliability.

The infrastructure reliability and availability can only be achieved by means of track maintenance and renewal works, which induce perturbations and local capacity restrains, whilst complete operation should be ensured.

The analysis of the timetable operation is therefore very important, not only under normal conditions (without perturbations to ensure its feasibility, and with random minor perturbations to verify its stability), but also in presence of tracks works, to study the effects of the resulting perturbations on train punctuality and timetable stability.

The research focuses on the development of a tool in order to analyse the stability of timetable on an interconnected network, at a national level. This tool is a simulation model that can deal with all trains on a day and takes into account not only infrastructure limitations (number of tracks and headway on the lines, number of tracks in station), but also commercial constraints (connexions, turnaround at terminus), fixed or random travelling times and stopping times. Extra effort has been devoted in modelling perturbations induced by track maintenance and renewal works.

Further developments can aim at the development of an improved traffic control module, extension to other transport modes (metro, tramways), and the introduction of economic indicators in relation with delays.

Keywords

railways – network simulation – timetable stability – track maintenance – long term planning

1. Introduction

In order to compete with other transport modes, European railways must improve their efficiency, which imposes an optimal use of the infrastructure and therefore its availability, and service quality, of which important features are trains punctuality and operation reliability. The problem is even more complex on highly interconnected networks where the number of connexions in numerous stations induces a large number of dependencies between trains, which results in extensive delays propagation from train to train.

The analysis of the timetable operation is therefore very important, whether without perturbations to ensure its feasibility, or under normal conditions (with random minor perturbations) to verify the timetable stability.

Moreover, the infrastructure reliability and availability can only be achieved by means of track maintenance and renewal works, which induce disturbances and local capacity restrains, whilst complete operation should be ensured. In this context, the timetable stability must also be assessed in presence of tracks works, to study the effects of the resulting disturbances on the punctuality and the stability.

The LITEP laboratory has developed the CAPRES model for the evaluation of a railway network capacity [Hachemane]. This model allows the user to develop a timetable, on a given network, corresponding to a desired transport supply and, on the basis of this timetable, to saturate the network following various possible strategies in adding extra trains. The resulting timetable is thus feasible, but the study of its robustness can only be achieved by means of timetable stability analysis.

2. Timetable stability

Timetable stability may be defined as the ability of a timetable to recover normal planned operations within a given time after an incident (involving small disturbances).

Even if a timetable is designed with much care, many factors may influence the running of trains and the interactions between them.

Considering a single train on a line, the running time can be affected by factors like meteorological conditions, driver reactions, drop of voltage on the power supply (e.g. catenary, third rail), or also the time needed by passengers to get on or off the train in stations. Buffer times can be added to travel or stopping time to deal with these problems, but the effect is an increase of the global travel times and a reduction of both the network capacity and the service quality. In the same way, buffer times are added between trains on the line, to avoid that a late train slows down the following train on the track, but once more, it is at the cost of capacity.

On highly interconnected networks, one way to have links between all points in the network is to introduce a great number of connections. If the connections are maintained even in case a train is late, the delay can be transmitted to a large number of other trains and, through a snowball effect, can extend to a large part of the network. Buffer times should therefore be added in overlapping times in station to avoid this delay propagation. The cost in this case is a loss of capacity, particularly in stations, and again increased travel times. The same problem occurs at terminal stations, when a train composition reverses.

Timetable stability analyses are therefore essential to reach a compromise between buffer time introduction, network capacity use and timetable robustness.

Simulation is one of the most efficient means to analyse stability. Simulation consists in reproducing a system evolution during the time, with the aim to study its behaviour under normal conditions or in response to modification of internal or external constraints. Simulation can be continuous, in which case the state of the system can be determined at regular time intervals, or it can be discrete when one considers that the state of the system only changes at special moments, when particular events occur.

3. Concept

The FASTA simulation model [Noordeen, 1996], was developed with the aim to ascertain the necessary buffer times to ensure the Rail 2000 timetable stability. The model was designed to simulate long distance train traffic on main lines, the effect of all other trains only taken into account by means of stochastic travel times, representative for delays incurred by regional and freight trains.

Discrete event simulation produced very interesting results, but the limitations of FASTA revealed to be too restrictive, particularly when dealing with perturbations occurred by maintenance track works. It proved to be necessary not only to introduce all the trains, including regional and freight trains, but also to have a more detailed description of the network, in order to model the real state of the tracks during works (speed restrictions, track suppressions).

FASTA II has been developed on the bases of FASTA algorithms, with enlarged possibilities. It is a discrete event simulation model, where the state of the system is being considered to change when trains arrive in (or depart from) "nodes", i.e. any particular point of the network such as stations or junctions.

In order also to take into account disturbances in normal operation, the simulation can be carried out in two operating modes:

- Deterministic, in which case the travel time of trains are fixed, determined by the timetable, the margins and the train delay, or
- Stochastic, in which case travel time can vary according to pre-defined delay curves.

In deterministic mode, while trains are on time, they use the travel time defined in the timetable. If they are late, they can use the margin to recover the delay, if possible, or at least to reduce it.

Stochastic simulation allows taking into account small disturbances during simulation, such as those found in daily operation. In stochastic mode, two delay curves are introduced, one or trains which run according to schedule, and another one, more optimistic, for delayed trains, assuming that delayed trains will run faster than trains which are on time, in order to recover the delay. In stochastic mode, the margin as stated in the previous paragraph is used as a weight in the estimation of the travel time on the basis of delay curves.

In both modes, it is possible to introduce local disturbances, in order to model track works or other disruptions that can appear during operation. These disturbances can be introduced in nodes as well as on sections.

At the moment, the model consists of two modules, one module to introduce/modify data and control simulations, and another one to visualise results. Basic data are stored in a Visual Access database, used by both modules. The simulation creates a file in text format, from which a small utility program creates a Visual Access results database. The results module uses these two databases to produce numerical and graphical outputs.

4. Modelling and functionalities

4.1 Hypotheses

In order to limit computing time, some simplifications are made in the model. The most important ones are: traffic control, node capacity and travel times.

Traffic control

Traffic control is still rudimentary. A list of connections is automatically provided by the model, on the basis of train directions and arrival and departure time in the nodes. This list can be modified by the user and is used during simulation by making trains wait for their connections. If the arriving train is late, its delay is transmitted to the waiting train, unless the incurred delay becomes greater than a defined maximum connection waiting time δt, in which case the connection between the two trains is broken. The maximum connection waiting time δt is defined for each station and depends on the train categories.

In the same way, it is possible to define a turn-round plan at line ends, assuming that a given train-set will be used for a subsequent service. The model ensures that trains can start only if the train-set according to the turn-round plan is available. A threshold ensures that if the turn-round plan is broken (i.e. the incurred delay is too large), a new train-set is introduced to take over the service, but it is supposed there are enough train-sets and drivers in the station to ensure the service.

Rush hours

Some parameters such as minimal stopping times or minimal transfer times for connections can vary according to passenger rush.

Node capacity

The station capacity is supposed sufficient for the timetable. Only the number of platform tracks in the station is taken into account. Delays due to lack of available routes to enter or leave the station are not modelled and are considered to be included in the running-time of trains.

4.2 Modelling

4.2.1 Network

The network is represented by nodes and sections. Nodes not only model stations or stopping points, but must also be introduced to model any special points in the network, such as forks or modifications of the number of tracks.

Sections model the tracks between two points.

4.2.2 Nodes

FASTA II knows four types of nodes: stopping nodes, connection nodes, junctions and virtual nodes.

Stopping nodes

Stopping nodes are the basic nodes in FASTA II. They can model any station or network point where trains can stop and have their terminus, but where there are no connections.

Connection nodes

In addition to the previous nodes, connection constraints are dealt with into these nodes. According to connection parameters, the model automatically creates a list of connecting trains. This list can be manually modified.

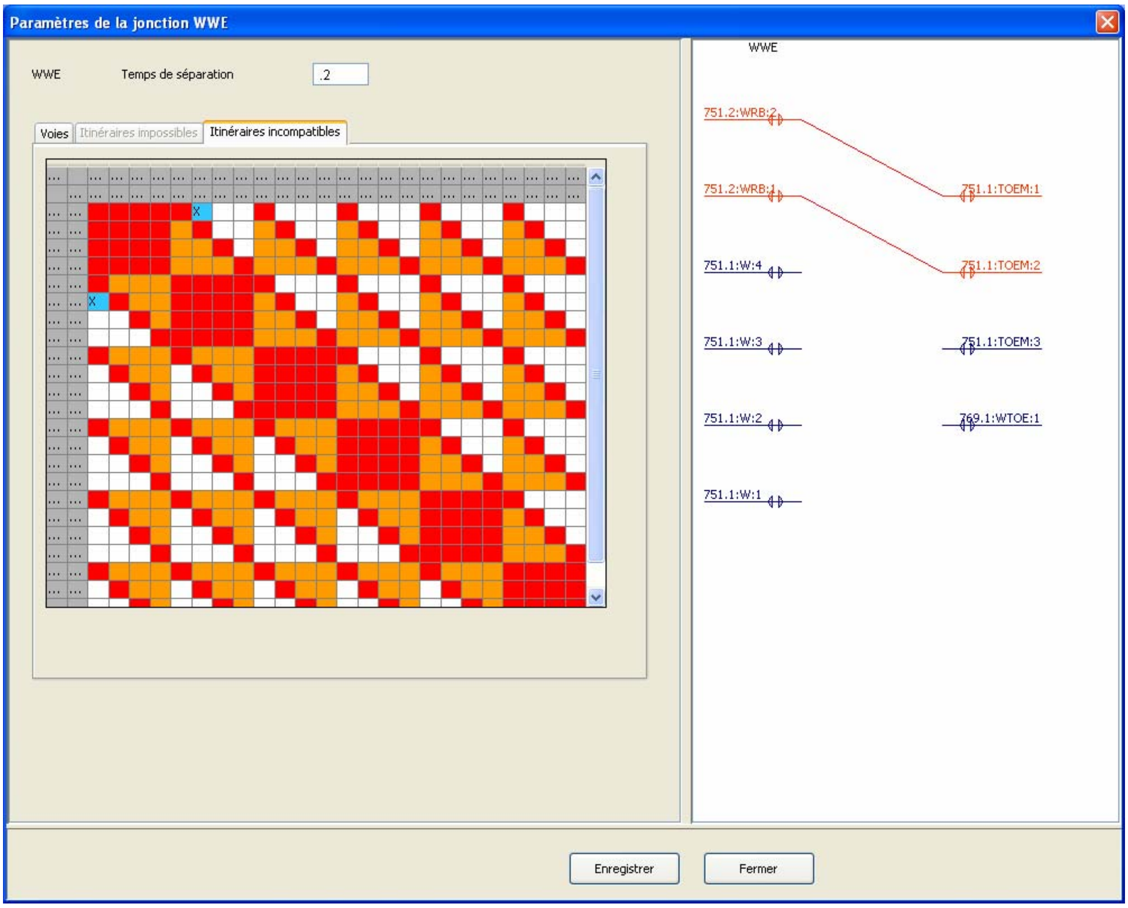
Junctions

Junctions model bifurcations on the line, where trains cannot stop according to the timetable. According to the adjacent nodes, the model automatically detects crossing routes, but the user can add supplementary incompatible routes. A separation time between incompatible routes is attached to these nodes.

Virtual nodes

Virtual nodes are used to describe other particular points in the network, such as points where the number of track changes. The trains cannot normally stop in these nodes and the only constraint that is verified is the number of tracks in the node.

Figure 1 Incompatible routes definition in junction nodes



FASTA II interface

4.2.3 Sections

Sections model the line between two adjacent nodes. They have one to eight tracks; each one can be unidirectional (in one direction or the other) or contra-flow (bidirectional). Two headways are associated to the section, one in each running direction.

In the model the headway is not verified all along one section, but it is sufficient to ensure that it is respected at departure and at arrival times. A basic headway is associated with a section and a running direction. It can be modulated according to the two successive train categories. Since the headway is only verified at the departure and arrival node, the risk occurs that, if the destination node is occupied, trains can heap on a section. To avoid this problem, a capacity C is automatically associated to a section, corresponding to the maximum number of trains possible on the track.

$$C = \max\left(\frac{Traveltime}{Headway}, 1\right)$$

A train cannot leave a node on a track if the number of trains on the track line is equal to the track capacity or if a train runs on the same track in the opposite direction.

The model dynamically assigns a track to the train; it first chooses a unidirectional track, before opting for a bidirectional track. There are in fact three possibilities. The track can be part of the train definition and the model always assigns the given track; the model automatically assigns a track, but the predefined track has priority; or the model is free to assign any track. As for now, there is no verification of possibility of routings in a node (cf. chapter 5).

4.2.4 Travel times

There is no travel time calculation in the model. Travel times are first introduced when adding a timetable. Two parameters are defined for each train and each section of its route: the timetable travel time, which is the actual running time of a train between the arrival in a node and the departure from the preceding node in the timetable, and a margin, which the train can use to recover its delay when it is late.

4.2.5 Timetable

Trains are grouped in families. A train family contains all the trains that carry out the same service; i.e. all trains that have the same itinerary, stop in the same stations and have the same arrival and departure minutes in the nodes of their itinerary, all along the day. Each family has a category which specifies the type of service (IC, Direct trains, regional trains, freight trains, etc.). Some parameters, such as minimal stopping time and parameters defining connections are attached to the train category. Headways on sections can also be modulated according to the category of the following trains.

4.2.6 Disturbances

Disturbances can be introduced in nodes and on sections. A disturbance can be applied on one or several successive periods of time, one period being defined as 15 minutes.

Node disturbances

Perturbations in nodes can be introduced as delays or as capacity restrain.

Table 1 Artificial disturbances in nodes

Type	Parameter	Sections	Family 1	Family 2	Start	End
Delay at arrival	Delay	One or more section	One or more train families		Beginning period	Ending period
Delay at departure	Delay	One or more section	One or more train families		Beginning period	Ending period
Stopping time	Stopping time	One or more section	One or more train families		Beginning period	Ending period
Connection	Passenger transfer time	One or more section	One or more train families	One or more train families	Beginning period	Ending period
Track number	Track number				Beginning period	Ending period

Section disturbances

As in nodes, disturbances on sections can be introduced as incurred delays or as track restrictions.

Table 2 Artificial disturbances on sections

Type	Parameter	Track	Direction	Family	Start	End
Travel time	Delay	One or more tracks	One or two direction	One or more families	Beginning period	Ending period
Headways	Increased headways	One or more tracks	One or two direction	One or more families	Beginning period	Ending period
Track type modification	New track type (N = normal, I = inverse B = bidirectional, F = closed)				Beginning period	Ending period

Disturbances scenarios

The effect of a single track work on the infrastructure may be complex. It can for example result in the modification of the track types of sections coupled together with the speed restriction on the sections and the reduction of the available track number in nodes. In order to model track works or other network perturbations, it is generally therefore necessary to define several punctual disturbances, in nodes and on sections. FASTA II allows to group several disturbances into a scenario, which represent the real state of the network for one particular day, with all track works and other network disruptions, and to simulate the exploitation with this disturbances scenario.

4.3 Causes of delays

4.3.1 Nodes

Track number

Two general parameters are verified in the nodes: the number of tracks and the minimal stopping times. If all the tracks are used when the train arrives in a node, the train will have to wait for a free track and the model gives a delay at arrival in the node, due to insufficient number of track.

Stopping time

If a train stops in a node, according to the timetable, it cannot leave the node before the planned departure time, but it must also respect the minimal stopping time. If the minimal stopping time is greater than the timetable stopping time, the train departs late and the model generates a delay at departure in the node, due to stopping time.

Overtaking

An overtaking algorithm allows for a low priority train to wait for a higher priority train in a node, depending on the delays and the travel time on the following section.

In the same way, when two or more trains are ready for departure from a node at exactly the same time and must use the same track, a priority algorithm can change the order of the trains, taking into account the train categories and delays.

In both cases, the model generates an overtaking delay at departure from the node.

Junctions

In certain points in the network there are potential conflicts between trains as their routes cross each other. In these particular nodes, successive trains on antagonistic routes cannot follow each other with a time interval smaller than a separation time. The model generates a junction delay at arrival or departure, depending the routes and timetable.

Connections

In nodes where connections have been defined for pairs of trains, the minimum connection time must be respected. If, however, the connecting train has to wait for a delayed incoming train more than a predefined threshold, there will be a connection break. This threshold depends on the node and the train category. The model generates a connection delay at departure.

Train turn-round

In nodes where train turn-rounds have been defined, a minimum turn-round time must be respected, unless the delay is too important. Then there will follow a roster break. The model generates a turn-round delay at departure.

4.3.2 Sections

Headway

In railways, two trains cannot follow each other at less then a certain time, i.e. the headway. If the headway is not respected at departure, the following train must wait in the station and the model generates a headway delay at departure. If the constraint is not respected at arrival, the train waits on the section, before entering the station, and the model generates a headway delay at arrival in the station.

Stochastic

In stochastic mode, the resulting travel time on a section can be longer or shorter than the timetable travel time. In this case, the model generates a stochastic delay at arrival at the destination node of the section.

Table 3 Causes of delays

Cause	Train (causing delay)	Event (in node k)	Parameter	Simulation parameter
Track number	Unknown	Arrival	Number of tracks	Number of trains in the node
Stopping time	None	Departure	Timetable stopping and minimum stopping time	max (timetable departure time, simulated arrival time + minimal stopping time)
Overtaking	j	Departure	Train categories, threshold	Train delays, simulated departure time from the node
Junction	j	Arrival or departure	Antagonistic routes, separation time	Train routes and simulated timetable in the node
Connection	j	Departure	Minimal transfer time	Timetable departure (i) – Timetable arrival(j)
Rotation	j	Departure	Minimal rotation time	Timetable departure (i) – Timetable arrival(j)
Headway	j	Departure or arrival	Headway	Train categories, simulated arrival or departure times
Track capacity	Unknown	Arrival	Section capacity	Number of trains on the track
Stochastic	None	Arrival	Travel time	Delay curve
Artificial	None	Arrival or departure	Perturbation	
Transmitted	None	Departure or arrival	Delay at previous arrival or departure	Running time, buffer times

4.3.3 Nodes and sections

Artificial

It is possible to introduce perturbations in nodes and on sections in the form of a decrease of velocity or enlarged travel or stopping times. When the model encounters one of these perturbations, it generates an artificial delay, at arrival or departure depending on the perturbation.

Transmitted

Eventually, when a train is already late when arriving in a node and then leaves late because of its delay on arrival, the model generates a transmitted delay at departure. Similarly, when a train is leaving a node late and then arrives late at the next node because of this delay, the model provides a transmitted delay at arrival.

4.4 Data input and Display of the Results

The major model functionalities are:

- data introduction and modification
- simulation
- presentation of results

4.4.1 Data introduction and modification

All data and parameters can be introduced manually via dialog boxes or imported from text files (and XML files in the future). The same graphic interface allows to complete and to modify them at any moment.

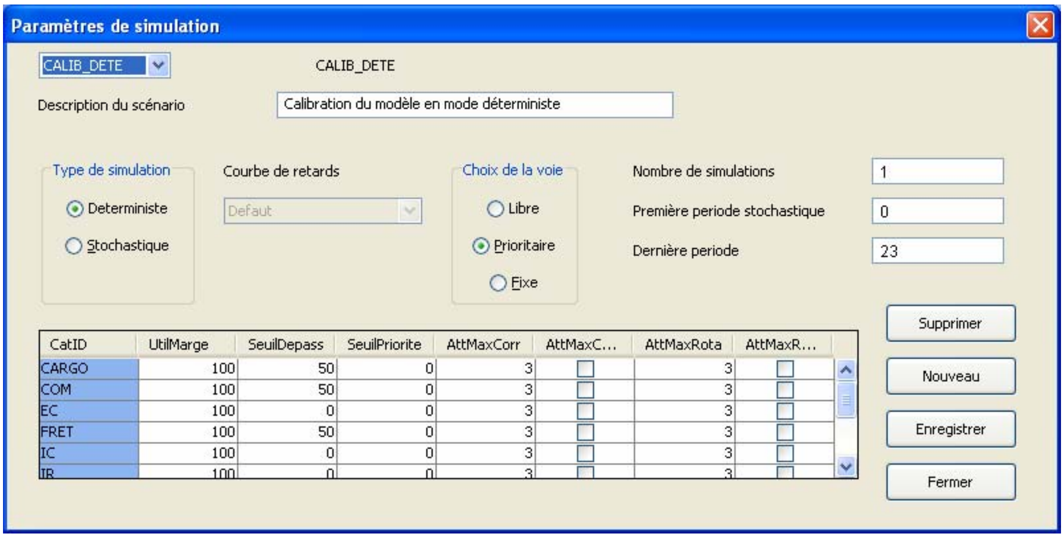
4.4.2 Simulation

In order to carry out a simulation, it is necessary to choose the simulation parameters, such as the simulation mode, the use of margins, etc. The set of these parameters define a parameter scenario that is stored in the database and can be selected at the beginning of a simulation.

A database can contain more than one timetable variant or timetables for different days in the week. In that case, it is necessary to select which train families will be included in the simulation. In the same way, it is possible to define different family scenarios, the default one being a scenario containing all the families.

Finally, as mentioned before, the database can contain different perturbation scenarios, but at least one, i.e. the "without perturbation" scenario.

Figure 2 Simulation parameters

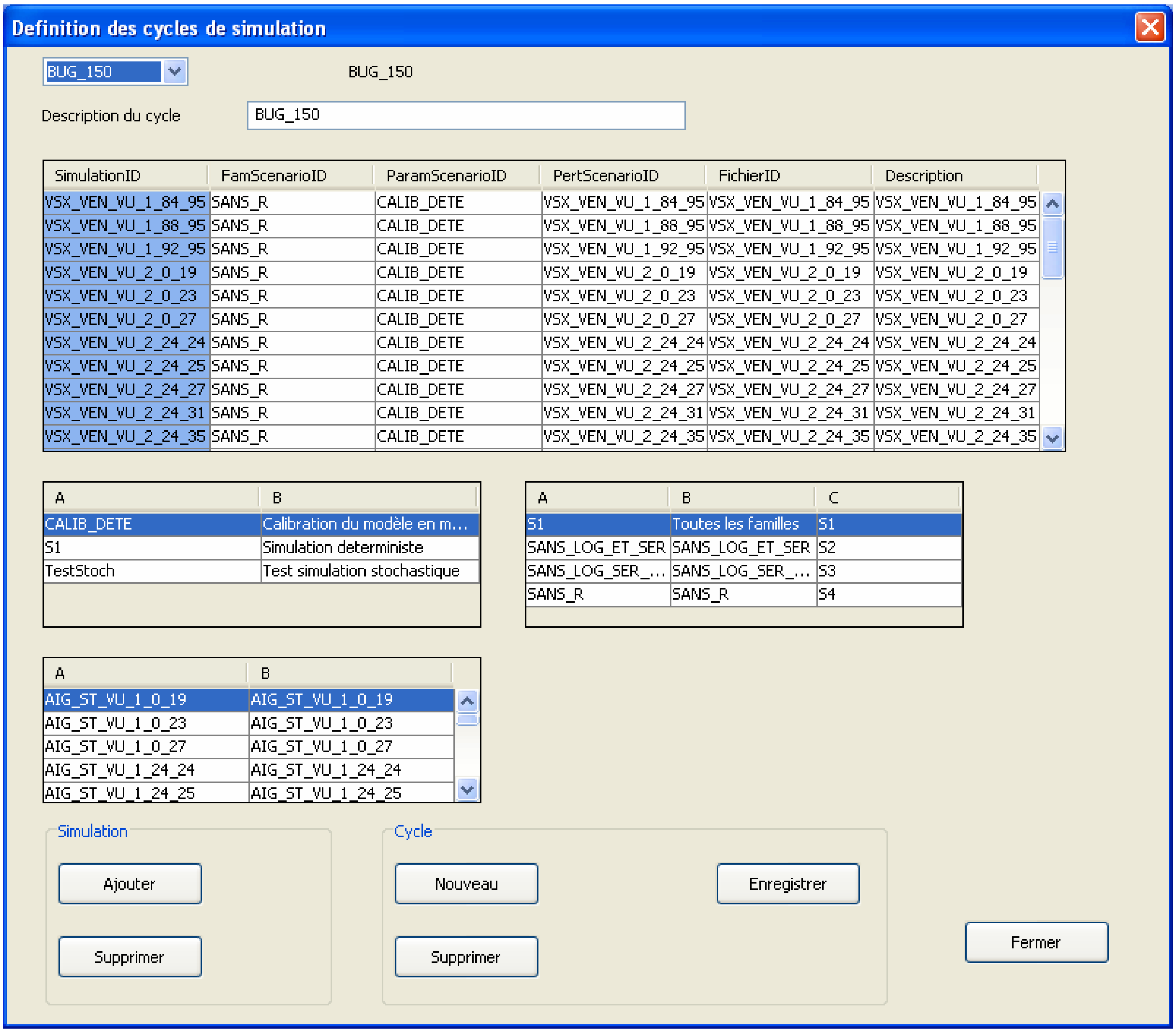


FASTA II interface

4.4.3 Simulation cycle

When a large number of simulations must be completed, for example to analyse the effects of different track works on the timetable stability, it is possible to process all these simulations, grouped in a simulation cycle, automatically.

Figure 3 Simulation cycle definition



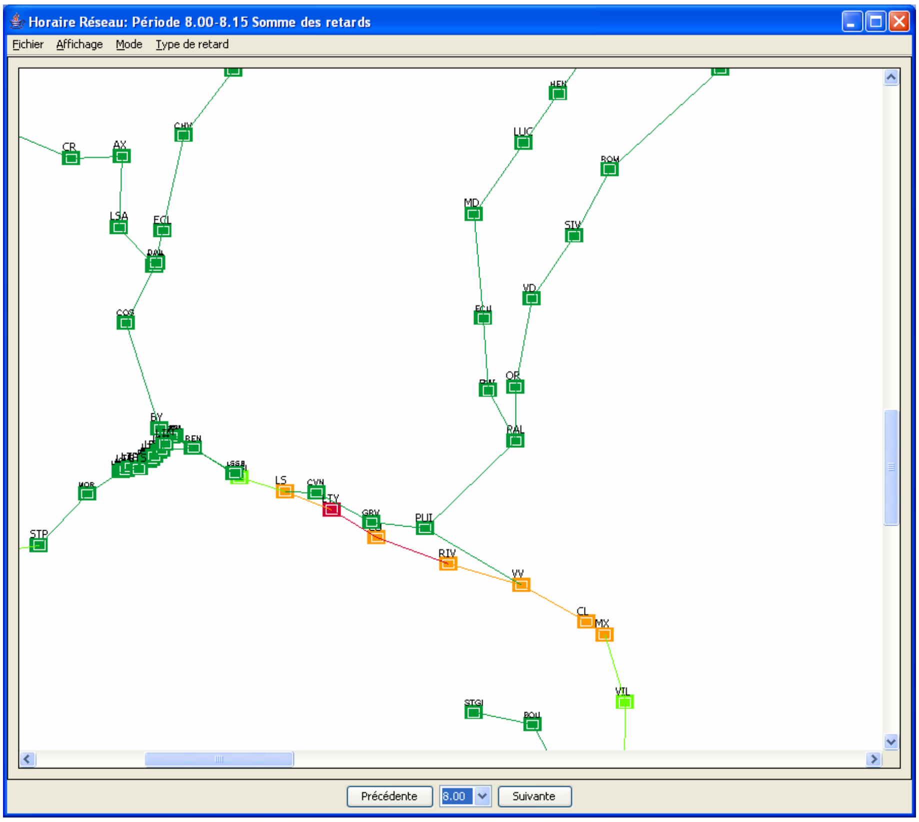
FASTA II interface

4.4.4 Presentation of results

Graphical results

A network representation of delays during a time period (15 minutes) gives very rapidly an idea of delay development during the simulation. The colour indicates the importance of delays in each node during the period; the internal rectangle represents the delay at arrival and the external rectangle the delay at departure.

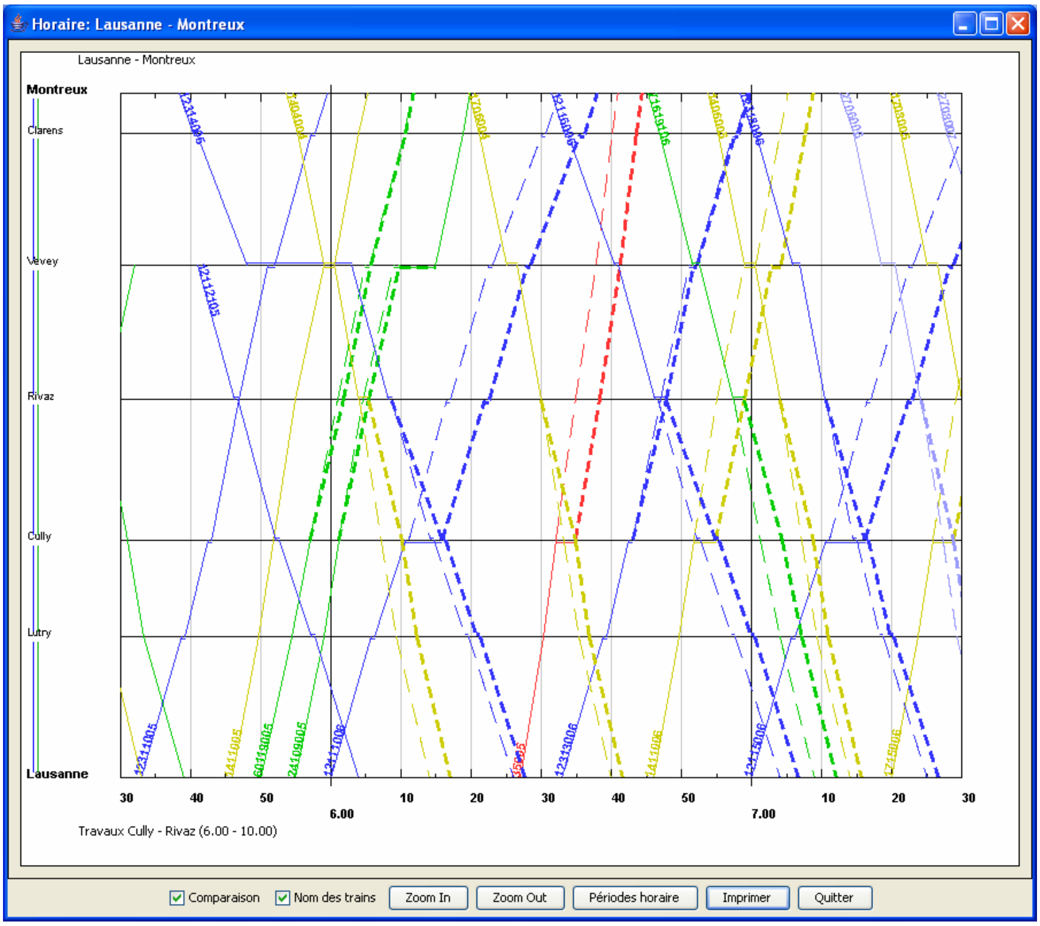
Figure 4 Delay propagation in the network



FASTA II Results display

It is also possible to display a graphical timetable, either a comparison of simulated and planned timetable, or only simulated results. The colour can indicate the train category or the track. The line type (continuous or dotted) distinguishes planned and simulated times.

Figure 5 Graphical timetable: comparison of simulated and planned timetable

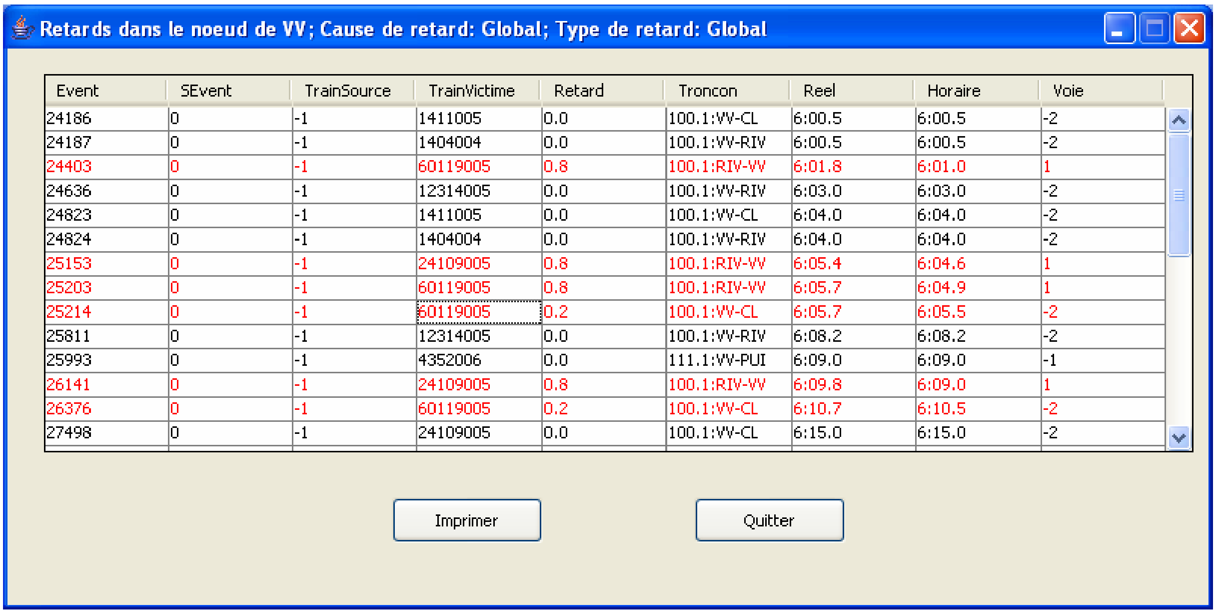


FASTA II Results display

Numerical results

Detailed numerical results can also be obtained in nodes, on sections or for a train. It is also possible to display the reason of the delay and, when it is appropriate, the train that initiates the delay. Other important information is connection or rotation breaks.

Figure 6 Timetable in a node: comparison of simulated and planned timetable



Event	SEvent	TrainSource	TrainVictime	Retard	Troncon	Reel	Horaire	Voie
24186	0	-1	1411005	0.0	100.1:VV-CL	6:00.5	6:00.5	-2
24187	0	-1	1404004	0.0	100.1:VV-RIV	6:00.5	6:00.5	-2
24403	0	-1	60119005	0.8	100.1:RIV-VV	6:01.8	6:01.0	1
24636	0	-1	12314005	0.0	100.1:VV-RIV	6:03.0	6:03.0	-2
24823	0	-1	1411005	0.0	100.1:VV-CL	6:04.0	6:04.0	-2
24824	0	-1	1404004	0.0	100.1:VV-RIV	6:04.0	6:04.0	-2
25153	0	-1	24109005	0.8	100.1:RIV-VV	6:05.4	6:04.6	1
25203	0	-1	60119005	0.8	100.1:RIV-VV	6:05.7	6:04.9	1
25214	0	-1	60119005	0.2	100.1:VV-CL	6:05.7	6:05.5	-2
25811	0	-1	12314005	0.0	100.1:VV-RIV	6:08.2	6:08.2	-2
25993	0	-1	4352006	0.0	111.1:VV-PUI	6:09.0	6:09.0	-1
26141	0	-1	24109005	0.8	100.1:RIV-VV	6:09.8	6:09.0	1
26376	0	-1	60119005	0.2	100.1:VV-CL	6:10.7	6:10.5	-2
27498	0	-1	24109005	0.0	100.1:VV-CL	6:15.0	6:15.0	-2

FASTA II Results display

5. Future developments and improvements

Some simplifications and limitations in the model are quite restrictive and should be alleviated in the future.

5.1 Choice of the track on sections

The assumption that all track configurations are possible is rather rough and overvalues the network capacity and the timetable stability. A more realistic description of the track configuration will be introduced, in which the real possible changes of tracks in stations and the impossible routes will be introduced. As this possibility increases the risk of deadlock in the process of simulation, a better anti-deadlock algorithm will be developed.

5.2 Complex nodes

At the moment, incompatible routes are only taken into account in junction nodes. This possibility will be taken into account in large stations, with numerous entering and leaving routes. The incompatible routes description will be quite similar to that in junctions, which implies to better ascertain the platform track for each train in the station (at the moment, only the number of trains in stations is taken into account to verify the node capacity). This development requires either to fix the platform track (or a group of platform tracks) for each train in the large nodes, or to have a platform track allocation algorithm in the model.

5.3 Travel times

When a train must slow down or stop because of operational problems such as interaction with other trains, the model only considers the delay due to the waiting time. In fact, when a train, specially a long and heavy freight train, must stop, it also looses time because of its deceleration and subsequent acceleration. A travel time increase will be introduced when a train must stop somewhere else than in its planned stopping places, in order to deal with these supplementary delays and to avoid a timetable stability overvaluation.

5.4 Traffic control

Traffic control is very basic in the model and is limited to breaks in train connection and rolling stock roster.

In practice, when a passenger train is very late (in a cyclic timetable), the service may be interrupted before the train reaches its terminus, and the train-set is then turned round to ensure on time the planned service in the opposite. Sometimes, a substitute train runs on time from some point on the train route. One improvement in the model traffic control module will be to implement such trains cancellations or early turn-rounds.

Another possible traffic control improvement will be the possibility to define alternative routes for some trains, so that if delays become too big on the "normal" route, the model can reroute them on these optional routes.

5.5 Economical indicators

Delays are always related to waste of money, either because passengers are late (sometimes railway companies must pay compensation for the delay) or because freight is not available for the client.

Some basic economical indicators will be introduced in the model, related with train delays and load factor (number of passengers, freight value and tonnage).

6. Conclusion

FASTA II is a software tool developed to support the assessment of timetable structures on a highly interconnected network. It is a simulation program for long term planning that allows not only to analyse the timetable robustness under normal and disturbed conditions, but also to assess the effects of track works on the punctuality and the stability.

FASTA II does not aim to produce detailed results. At this stage of study, planners need a tool able to run fast and to carry out a large number of simulations to understand the behaviour of the timetable on a given network and under multiple assumptions.

The main question, in developing such a tool, is to set the right balance between modelling simplicity (unavoidable due to uncertainties about the exact infrastructure layout in a far future, and also due to the broad definition of timetable elements) and accuracy of the results. The trade-off problem between simplicity and accuracy bears no single solution.

The current version of the model already gave very interesting results on the Swiss railway network and allowed to assess the effects of track works on the current timetable. New developments will enhance its accuracy and improve its ability in traffic control.

7. References

Hachemane, P. (1997) Evaluation de la capacité de réseaux ferroviaires, *Thèse N° 1632*, Institut des Transports et de Planification, EPFL, Lausanne.

Noordeen, M. (1996) Stability analysis of cyclic timetables for a highly interconnected rail network, *Thèse N° 1435*, Institut des Transports et de Planification, EPFL, Lausanne.

Putallaz, Y. (2007) Gestion stratégique de la maintenance et de la capacité d'un réseau ferré, *Thèse N° 3852*, Laboratoire d'Intermodalité des Transports et de Planification, EPFL, Lausanne (à paraître).