LIPARI: train management solutions for very dense traffic flows

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Abstract

The LIPARI project consists of defining and simulating control-command and traffic management solutions to handle extremely dense traffic flows with a satisfactory degree of regularity. It is based on the ERTMS2 control-command system and describes the target architecture of a future traffic management system essentially combining semi-automatic traffic control and traffic flow modules; the regularity standards achieved with this system will be evaluated by means of simulation, in relation to a so-called reference system.

Keywords: punctuality, high-density, ERTMS 2, automatic driving, dispatching, smoothly flowing traffic, route control, optimisation software, simulation.

1 Introduction

To cater to the prospect of a sharp upsurge in traffic on the French railway network, research in hand in the SNCF’s Research and Technology Division has to focus, in particular, on finding ways of ensuring the regularity of train movements, which is one of the tasks of the infrastructure manager.

The LIPARI project is part of the resulting programme of action to optimise the use of infrastructure, with the main goals of: a) establishing whether a “standard” train control-command and traffic management system, called the “reference” system, can handle extremely heavy traffic flows with the requisite degree of regularity; b) defining the target architecture for a new system of operational traffic control based on the use of sophisticated control-command and traffic monitoring techniques; c) measuring by means of simulation the potential benefits in terms of regularity to be obtained with the various parts of the target system and with this system as a whole.

The reference system consists of the BAL KVBP automatic colour light block signalling system, manual train driving and conventional traffic control rules.
The target system is made up essentially of the ERTMS 2 control-command system, automatic train driving and semi-automatic traffic regulation and flow control modules.

The performance of the target system and its technological components, and of the reference system, are measured in the same way, by simulating the same set of incidents and analysing their repercussions on train punctuality.

The case under study and test is a complex plan to interconnect the East and West outer loop lines around Paris, which are scheduled to be used by a mixture of heavy suburban, main line and TGV traffic (32 trains per hour in each direction on the interconnecting part of the line are expected).

The LIPARI project is a research project under the auspices of the SNCF Research & Technology and Civil Engineering Departments.

2 Methodology

The project consists of 3 main phases: a) simulation of the reference system and assessment of its performance, b) study, design and development of the Traffic control layer of the target system, and c) simulation of the target system, assessment of its performance, and identification of expected benefits.

![Diagram](https://via.placeholder.com/150)

**Figure 1:** Methodology.

2.1 Reference and target system modelling and simulation

Models of the rail network infrastructure, the control-command system, trains, theoretical timetable and the type of driver control (automatic/manual) of the
reference and target systems are produced and simulations carried out using the
SNCF’s SISYFE rail system simulator (cf. Fontaine and Gauyacq [1]).

This software simulates train running patterns in detail and, for each
characteristic event, produces information that shows how the system evolves for
the working assumptions tested. On the basis of the information displayed by the
lineside or cab signals, the movement of each train is calculated up to the next
landmark. This operation is carried out by means of an algorithm that takes
account of the dynamic performance of the moving vehicle, the distance to be
covered, track layout, all of which are weighted to factor in driver behaviour.

The Traffic control layers of the reference and target systems are developed in
the LIPARI project using linear programming techniques, mathematical
optimisation and heuristic algorithms. These layers communicate with SISYFE
on a real-time simulation basis in order to be supplied with data on current train
movements and to send instructions for train sequencing, routing and train flow
control.

2.2 Performance assessment

To date, the robustness of a rail system configuration used to be evaluated by
simulating a small number of incidents selected by experts in the particular field
and analysing the repercussions of these incidents on train punctuality.

A new complementary approach supported by an SNCF doctorate thesis and
with the working name of SARDAIGNE consists of including a stochastic
dimension into this process and adopting a systematic approach to the different
circumstances that may occur (cf. Chandesris and Labouisse [2]).

This approach enables to generate simulation scenarios automatically from
experience planning techniques and to analyse statistically cumulative results of
simulation findings.

NB: these assessments of system robustness are based on simulation of the
most common minor incidents and not on major incidents, since the purpose is to
ascertain the intrinsic strength of the configuration and thereby its ability to
absorb the little everyday “blips” of normal operation.

2.3 Comparison of configurations

The following configurations are being analysed and compared in terms of
performance:

The reference system: BAL KVBP signalling and manual drive and
“normal” traffic control. The target system: ERTMS2 and (manual or automatic
drive) and (“normal” or optimised traffic control). Optimised traffic control
comes in a number of alternatives depending on whether or not the following
functions are in operation: traffic flow control, train sequencing, re-routing.
3 The reference system

3.1 KVBP BAL signalling system

The reference system is based on the BAL signalling system combined with the KVBP speed control system.

BAL is a lineside automatic colour-light block system, which is in use on most French conventional medium-to-heavily trafficked railway lines, suburban lines in particular.

KVBP is a transponder-based speed control system in which coded currents are transmitted continuously through stretches of rail lying over track circuits; the status of the signal(s) further down the line can be communicated to the moving vehicle in real-time so that the driver does not have to wait until he proceeds a previously restrictive signal which is reset to clear before recovering speed.

This speed control system is not yet in widespread use on conventional railway lines in France. The most common system on such lines is the transponder-based KVB technique with intermittent transmission, with which the driver cannot recover speed before it proceeds the previously restrictive signal, even if this signal has been reset to clear in the meantime.

KVBP has, however, been taken for the reference system in the LIPARI project because it is scheduled to be extended and in general use in the next 10 to 15 years.

3.2 Manual drive

In the reference system, train driver behaviour is assumed to be “cautious”, in other words the train is driven in line with the actual instructions given to drivers. In the SISYFE traffic simulation model this factor is taken into account in relation to a number of parameters such as: anticipating braking at a restrictive signal, the speed selected by the driver during the braking process, and his behaviour when the signal is reset to clear.

3.3 Traffic control rule

The traffic control rule applied in the reference system is that of “compliance with the scheduled train sequence”. It is assumed, in fact, that the train sequence will not be altered in the event of minor disruptions.

4 The target system

The sophisticated control-command and traffic control techniques used in the target system are:

- A more efficient train control-command system: ERTMS level 2.
- Automatic train drive, to eliminate the “blips” resulting from manual drive.
Use of traffic flow control techniques to minimise potential train path conflicts and the unscheduled train stoppages which may result.

Semi-automatic traffic control that may involve changes in train sequencing and in routing in stations and at junctions.

4.1 ERTMS 2 control-command system

The main advantages of ERTMS 2 for our target system are that: a) ERTMS 2 improves the available network capacity as it takes the actual braking performances of trains into account; b) it enables traffic to be kept flowing smoothly by transmitting speed control instructions integrated with the security ones to the cab; and c) it provides a safety speed control system, which can lead to automatic drive.

4.2 Traffic control architecture in the target system

The LIPARI target traffic control system has three different levels of supervision and control: a supervision and diagnostics module, an optimisation module, and a module for implementing the decisions of the optimisation module. They are simulated in interaction with the real traffic, itself simulated with our SISYFE train system simulator.

From information received from the SISYFE simulator and the operator about train movements and incidents, the supervision and diagnostics module calculates any differences in relation to the most recent schedule of movements (original schedule or schedule produced by the optimisation module); it also determines the new operating conditions (changes in trip times and minimum headway as a result of incidents, etc.).

The optimisation module is responsible for adapting and optimising the train running diagram in real time to unexpected events. For this, the module has a number of possibilities at its disposal, the parameters of which can be adjusted and combined: train timings at junctions on the network and in stations, train sequences and routes.

This module schedules the timetable graph to avoid conflicts that could occur and, in particular, to comply with minimum headway requirements between trains and between incompatible paths. These values are dynamically updated in relation to the new train times and routings. Each new schedule allows for delays already noted or expected, and exploits the possibilities for trains to make up lost time, and to reduce the amount of standing and turn-round time in stations. Its goal is to minimise the aggregate delay of all trains in operation.

The application module calculates the indications and orders necessary to produce the new train running diagram and transmits this information to the SISYFE simulator: departure times from stations, train speed indications (to enable them to cover the distance between two reference landmarks in the timetable within the scheduled time), routing orders.
4.3 Traffic and flow control

Traffic and/or flow control in the LIPARI target system are achieved through a number of possible actions in the optimisation module, and different types of instruction calculated by the application module.

The traffic/flow control methods possible are: flow control only, sequencing only, sequencing + flow control, sequencing + re-routing, sequencing + re-routing + flow control.

The table 1 gives an example of achievement of traffic and flow control functions through the combination of functions operational in the optimisation module and instructions operational in the application module.

For flow control only, the schedules calculated by the optimisation module (designed to enable trains to follow conflict-free routes) will be produced by applying the speed instructions and the station departure times. Train sequencing and routes will remain those of the theoretical schedule.

For train sequencing only (with no flow control), the train sequence set by the traffic control module will be applied by means of interdependent routing orders. By contrast, since the speed indications are not in operation, it is quite possible that trains will not necessary pass the different staging points at the set time – they may even be on conflicting paths when arriving in stations or at junctions.
Table 1: Example of optimisation and application functions combination.

<table>
<thead>
<tr>
<th>Functions in the optimisation module</th>
<th>Instructions in the application module</th>
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<tbody>
<tr>
<td>Flow control only</td>
<td>Scheduling</td>
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<td></td>
<td>Speed indications</td>
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<td></td>
<td>Station departure indications</td>
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<td>Train sequencing only</td>
<td>Scheduling</td>
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<td>Train sequencing</td>
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<td></td>
<td>Routing</td>
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4.4 The supervision and diagnosis module

This module acts as a traffic supervision tool to alert those in charge of any deviations from the normal schedule. In our simulation of the target system, the resulting output of this module will serve to inform and activate the optimisation module.

The incidents detected by the supervision and diagnosis module are: actual or expected delay in departure from a station; actual or expected delay in a train passing a specific point; unscheduled stoppage of a train. In all cases, the module detects the delay as soon as the theoretical time of departure/passing or arrival of the train has been reached and treats it as an incident if the delay lasts beyond a pre-set threshold, a parameter that can be set by the user and which was one minute in our study.

When the module detects an incident, it transmits the following information to the optimisation module: position, train concerned, and estimated duration of the incident. To provide this last item, the module can interact with the user by asking him to enter the estimated duration of the incident. In automatic mode, the system itself works out the expected duration (data contained in the incident scenario), in particular when automatically launching several successive simulation scenarios.

The module also reports the position and speed of the trains at the time the incident was detected to the optimisation and application modules.

4.5 Optimisation module

The optimisation module in the LIPARI project works at the moment by means of a linear optimisation program in integers operated via the ILOG CPLEX optimiser.

The program contains a model of the railway network devised from the graph theory and involving junctions and line sections. It aims to optimise train movements (minimising delays), by recalculating the time at which trains should pass the different junctions on the network in the event of operating incidents.

The main variables are: train trip times, arrival and departure times of trains at junctions, train sequencing at junctions (if the “sequencing” function is in operation), routing (if the “routing” function is in operation). At a later stage of the project, the optimisation module should also be able to manage changes in service patterns itself (runs curtailed because of incident) and cancellations.
Optimisation is subject to constraints, the main ones of which are:

- Operating constraints:
  - Minimum trip times over sections of line, per section and per train category,
  - Minimum headway to be allowed between trains; this is fixed per train category and per line section and is recalculated dynamically during processing by weighting minimum headway by train trip time.
  - Minimum time to be allowed between two trains on incompatible routes, per pair of routes and per train category.
  - Minimum track occupation time in stations, per track and per train category.
  - Minimum turn-round time in station/terminal per station/terminal and per train category.

- Commercial constraints:
  - Minimum standing times per station and per train category,
  - Connections to be guaranteed per train and per station.

For rescheduling purposes, the optimisation module naturally has access to the data in the theoretical running diagram, in other words a description of the trains scheduled to run (arrival and departure times at the different places passed and served, links between shuttles), and a description of the incident and its repercussions on the operating constraints, as well as the position of the different trains at the time of the incident.

4.6 Application module

The role of this module is to calculate the routing orders and departure instructions that enable implementation of the transport plan established by the optimisation module.

Where the speed indications are concerned, depending on the schedules set by the provisional graph produced by the optimisation module, it is necessary to establish for each train: the points at which each deceleration and speed reduction phase will begin and end; and the target speeds for these phases.

Speed indications are calculated once the running pattern of the train has been established taking into account its physical characteristics (potential acceleration and deceleration), the characteristics of the lines used (maximum speeds and line profile) and the original speed of the train when the incident was detected (speed at which simulation clicked in).

It should be noted that speed indications will always be highly dependent on track allocation, since the speed restrictions for points and crossings on the different lines may very often be highly specific.

For the train sequences recommended by the optimisation module to work in practice, it is also necessary to obey time sequences set in the routing orders for the routes followed by the trains, especially in cases where two successive trains through a junction are on incompatible routes. This explains why the application module should determine the routing order.
4.7 Train driving mode

The different versions of the target system affect not only the traffic and flow control modes but also the train driving technique (manual or automatic).

The differences between the two relate to: a) the values of the advance indication and anticipation periods in ERTMS 2, which are reduced to the time necessary to cut the traction power and apply the brakes with automatic driving; b) the speed of the moving vehicle, which is slightly “doctored” in manual mode to allow for the irregularities typical of manual driving.

5 Description of the case study

The network simulated in the LIPARI project includes all the lines in the Paris East suburbs (as far as Tournan and Meaux), Groups 2 and 5 of Paris Saint-Lazare (as far as Versailles Rive Droite, Saint-Nom La Bretèche and Mantes-la-Jolie) and the proposed underground interconnection between these lines in Paris. It also incorporates the plan for express shuttles between Paris Est station and Roissy – Charles de Gaulle Airport, and the spur to link up to the future LN6 high-speed line.

In the SISFYE simulation tool the network is modelled with some 1,000 km of track, 95 stations and halts and 694 routes. The BAL signalling represents 929 signals.

On this network the optimisation module manages 118 junctions (with 372 tracks), 138 sections of line (with 306 tracks), 648 routes and 868 routing incompatibilities.

The simulation period lasts over 6 hours (from 5 to 11 a.m.) including the morning peaks. The train running diagram consists of 476 trains, including 270 shuttles.

6 Results of performance assessments

At the time of writing this article, the full findings of the performance assessments are not yet available. Development work on the Traffic control layer of the target system is coming to an end, whilst reference system simulations are now running. The latest findings will be presented at COMPRAIL 2004.

7 Prospects

The next stage of work will consist of making the Traffic control layer of the LIPARI target system operational in the short/medium term, in particular by expanding on the role of the operator in a traffic management support system, and on the optimisation of the processing speed of the optimisation and application modules.

In the LIPARI project, we have deliberately decided to ignore the constraints imposed by these two factors, since the goal was to assess the maximum regularity of the different configurations studied by means of simulation.
The aspects to be addressed in future will, in particular, involve examining and suggesting techniques other than linear programming for the optimisation module; in particular, with the French national IT and automatic systems research institute (INRIA) we are currently looking into the possibility of using genetic algorithm technology for traffic management purposes.

References