Integrated timetable design tool
enabling optimization and robustness assessment

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Abstract
This research project integrates in a unified structure various issues regarding the conception of timetables at the SNCF. In this paper we present the architecture and the new concepts brought up in the company, needed to take account of functions essential for the design of timetables and their evaluation. On this basis we will discuss the details of the included functionalities and show examples of the developed framework.

Introduction
Since the separation in France between Railway Undertaking (RU) and Infrastructure Management (IM), the RU had no tool of its own to study its foreseen transport plan (often studied 2 to 5 years in advance, according to the number of modifications). Such a tool is nevertheless essential when we seek to verify that the planned trains are compatible all together, particularly in case of a cadenced grid. Without this tool, the IM will detect the conflicts and do the arbitrage, not necessarily in the same direction as the RU would have wanted it to be.

On the other hand, the main existing tool used by the IM is designed to calculate individual train paths and to graphically arrange them with a macroscopic description of the infrastructures without decision support modules to help the timetable designer. For example, the conflicts are avoided by the timetable designer who applies the headway norms between trains. This method has to be improved in order to take account of indications of the signaling elements and detect conflicts between trains.

Moreover, with the generalization of cadenced trains new timetable design concepts appear: the domestication of the paths of different kinds of trains and symmetry between trains connecting two cities. The existing tool is not adapted to build easily the appropriate timetable and manual work and assessment remain important.

Finally, building a timetable integrating all train path requests is not enough to operate properly. The timetable can be too dense and, when an incident occurs, a snow-ball effect can disturb all the trains and decrease heavily the punctuality. Therefore, the robustness of the timetable must be assessed during the design process and if robustness is too low, it must be improved.

Consequently, building a new timetable design tool has a strategic importance for the RU and the purpose of project EPSILLON (Élaboration Préparatoire des SILLONs) is the realization of an integrated tool to design paths and timetables by an optimized and robust way. It is allocated to the timetable designer of the RU to prepare and study the transport plan in order to define precisely the paths that will be requested from the IM.

The new abstract model including “microscopic” and “macroscopic” views of the railway system is developed. This model is used in every function provided by the tool.
Objective of the tool

The main objective of this project is to define an **integrated tool for timetable design**. The tool will be composed of five main functional modules:

- **Individual train path calculation** – based on the description of the infrastructure and the material. The train running time can be calculated with regularity margins that can be used for minimizing power consumption.

- **Conflict detection** [3] – this module guarantees that the driver sees “green lights” during the whole journey. It automatically detects the conflicts between two trains in nodes, junctions, stations and also line segments. This module is based on a precise infrastructures description, including signaling elements, visibility in curves, etc. The possibility of detecting conflicts with user-defined headways and intervals is provided to the user when detailed description of the infrastructure is not available.

- **Timetable design support and optimization** [4] – this function helps the timetable designer to arrange trains in the timetable so that the timetable is conflict-free and optimized according to user-defined criteria (capacity optimization for example). Optimization techniques from operations research are used for this function.

- **Capacity analysis** [4] – this function allows to evaluate the remaining capacity on a line or a network by producing a compacted timetable (without margins) and consequently determine the number of trains of a certain type that can be added in the timetable.

- **Evaluation of the timetable robustness** [1, 2 and 3] – by introducing incidents based on stochastic approach we measure the effects on the delays and the recovery of the delays. This robustness evaluation is done thanks to a traffic simulator [1] integrated in EPSILLON and also used for the conflict detection.

Modeling and architecture

To start with, this project is also the opportunity to review the parameters used for path design. For example, the dwell times, the different buffers and recovery times, the cinematic parameters of rolling stock are assessed to be more realistic according to the improvement of rolling stock (better acceleration and deceleration) and to take account of the passenger crowd and behavior in stations.

Another aspect highly important in operational use is the application of a reference data with a regularly managed update. The precision of the running time calculation and conflict detection depend on the precision and the actualization of data.

The modeling of railway system is a fundamental aspect of the project. Several levels of precision and description are possible from the macroscopic level (the nodes of the graph are the cities, for instance) to the microscopic one (real description including tracks, signalization, routes, etc.). Notice that when a microscopic definition of infrastructure is available, the macroscopic definition can be computed directly. The macroscopic model is particularly used in the optimization functions. A link between the different models permits a smooth use of the model and complete compatibility of the results. The microscopic model is used for running time calculation, conflicts detection, simulation and robustness evaluation.

To approach this problem, we have developed a new abstract model of the railway system that includes the following items:

- infrastructure,
Thus, this model allows different level of modeling and a mixed representation. It is used in all functions developed in this tool and allows a generic development for the algorithms and a better quality and stability for implementation.

All algorithms are implemented in service oriented architecture based on this model. This architecture is presented in figure 1.

### Description of technical modules

All functional modules are based on these technical modules and are developed in service architecture:

- **Individual train path calculation:**
  
  This service implements an advanced running time algorithm. It calculates the train path with margin and minimizing power consumption. It also permits to determine the utilization of infrastructure. This information is used for conflict detection.

  With the abstract model, the module is based on:
  
  - definition of the infrastructure (speed limits, works, etc.). Abstract model is use and allow a mixed (microscopic and macroscopic) calculation of running time,
  - signalization and behavior of driver (VISA legislation in France),
  - all signaling system in France (BAL, KCB, KVBP, KCVB, KCVP, BAPR, TVM, ERTMS and manual bloc),
  - precise calculation of margin with determination of speed and coasting order,
  - precise parameters of materials,
  - determination of the utilization of infrastructure (track circuit).
- Conflict detection:

Based on information given by the train path calculation, this service determines the conflicts between all pairs of trains. Furthermore, the algorithm of conflict detection is based on the abstract model. Thus, it is possible to determine the conflicts on a mixed representation of infrastructure. With the simulation tool, more precise conflicts detection is possible.

The different types of conflicts are:

- between two circulations at each common signal on the path,
- between circulations and work infrastructure time slot,
- between circulations and constraints of infrastructure (length of platform, max weight supported by the track, etc.).

- Optimisation tool:

This service is based on works in operations research. The algorithm uses the abstract model with a macroscopic level. Microscopic level is available when the perimeter of infrastructure is not too large or with a powerful computer in use. It allows determining a set of train path with an objective to optimize. For example, you can optimize the maximum running time of each train, the allocation of track, the number of trains, etc.

The same algorithm allows:

- the determination of timing at each point for all train,
- the determination of track affectation,
- a conflict resolution assistance.
- a train path insertion,
- the capacity study.

In figure 2, we show an example of insertion of freight trains in base timetable.
- **Simulation tool:**

This simulator is developed by using Discrete Events and Multi Agents System methodology. It is also based on the abstract model and it allows a simulation on a mixed description of infrastructure.

The possibilities of this simulator are extensive but the most important elements are:

- the validation of optimization solution,
- precise conflict detection,
- determination of important set of indicator (utilization of infrastructure, ...),
- determination of robustness by a big set of simulation,
- injection of multiple incidents and evaluation of consequences.

For example we show on the figure 3 the consequences of time delay at the station.

- **Robustness and evaluation tool:**

This service is composed of two parts. The first part is a generator of experimental design to evaluate the robustness. It consists on doing an optimal set of simulation scenarios based on different configurations of the railway system. The second part defines the set of analysis functions to determine the relevant statistical indicators. For example, on figure 4 we give a recovery time indicator after an incident.
This evaluation method requires an important set of independent simulations. To solve the problem of calculation time we developed a specific grid computing method. The gain of performance is proportional to the number of available processors (or computers).

**Graphic user interfaces**

In this project, the development of an advanced graphic use interface is highly important. The ergonomic aspects improve the productivity and are a major factor for the acceptance of the tool by the users. In figure 5, we show as an example different prototypes of new interfaces.
Conclusion

With this tool, a new era opens for capacity management. It will permit an important improvement of the infrastructure use in a realistic and robust manner as well as a better punctuality in operation.

New advanced functions are integrated in the same tool for the timetable design: time table optimization, capacity analysis, conflict detection and robustness evaluation. Timetable designers will share the same production environment, which will facilitate the integration of the different transport activities (freight, intercity, regional, suburban traffic).

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References


