

CETRA²⁰¹⁴

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

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A NEW APPROACH FOR DEFINING THE IMPROVEMENT PLANS OF RAIL NETWORKS

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Abstract

Railway operations are the result of the complex interaction among infrastructure and signaling, rolling stock and timetable. This interaction is further complicated by a number of human factors and other unpredictable phenomena and stochastic disturbances. The key role in this complex mix is played by the timetable, which allows smooth operation by shaping the services to fit the demand and the characteristics of the network and the rolling stock. Different strategies might be implemented: in some countries the new lines and stations are very flexible towards different timetable concepts, while in others, such as in Switzerland, the are lines specifically designed for a given timetable. Both extreme approaches show significant drawbacks: a higher flexibility is normally obtained at a significant cost, while a very rigid infrastructure might require remarkable investments to be adapted to different needs. In this trade-off a certain balance might be obtained by analyzing several timetable and infrastructure configurations. However, this task appears particularly time-consuming and strictly related to the experience of timetable planners: thus, normally very few scenarios are considered.

To fill this gap, by significantly reducing the time required to prepare a scenario, a new approach was developed. It is based on an automatic timetable generation tool that allows quickly creating timetable drafts on a quite detailed infrastructure model. The model and its application to the Norwegian rail network will be presented in the paper.

Keywords: railway capacity, timetable reliability, stochastic simulation

1 Introduction

Railways are struggling to compete with the other transport modes, which have the advantage of a remarkably higher flexibility in the operations. To increase the competitiveness of railways during this economic downturn it appears important to be able to select the investments that are effectively necessary to improve the quality of service where the demand might effectively increase as a consequence of the improvements.

Railway operations are the result of the complex interaction among infrastructure and signaling, rolling stock and timetable. This interaction is further complicated by a number of human factors and other unpredictable phenomena and stochastic disturbances. The key role in this complex mix is played by the timetable, which allows smooth operation by shaping the services to fit the demand and the characteristics of the network and the rolling stock [1]. Different strategies might be implemented: in some countries the new lines and stations are very flexible towards different timetable concepts, while in others, such as in Switzerland, the are lines specifically designed for a given timetable. Both extreme approaches show significant drawbacks: a higher flexibility is normally obtained at a significant cost, while a very rigid infrastructure might require remarkable investments to be adapted to different needs.

In this trade-off a certain balance might be obtained by analyzing several timetable and infrastructure configurations. However, this task appears particularly time-consuming and strictly related to the experience of timetable planners: thus, normally very few scenarios are considered. In this paper an approach is presented, in which timetables are generated semi-automatically using a timetable generation algorithm. The obtained timetable can be refined by the planner, and its core parts can be tested using microscopic simulation to estimate robustness under real conditions. Different scenarios are easily created preparing the infrastructure model and then running the timetable generation algorithm again. In this way it become possible to create and compare several scenarios even under the normally constrained time.

2 Approach

In the proposed approach, the rail planning process is viewed as a loop, whose central element is a timetabling algorithm, which allows automatically creating a timetable that contains the expected services, scheduled considering the constraints due to the network (including its interlocking and signalling system).

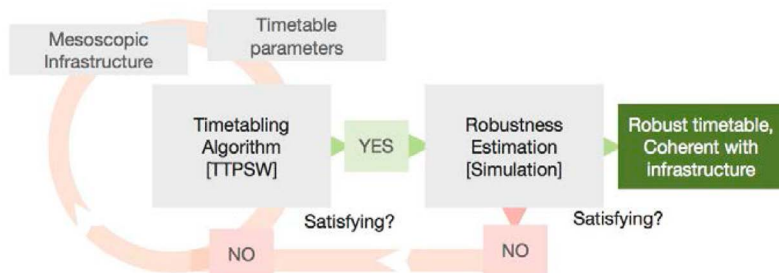


Figure 1 Block diagram of the approach

The planning process (Figure 1) starts with the definition of the required services and of the preliminary infrastructure. The services are defined by their origin and destination, stopping pattern and type of trainset. Some additional parameters are required by the timetabling algorithm as additional costs to be used in the objective function: a cost for increasing the running time, adding a stop, reducing the buffer time between two services and breaking a connection. The infrastructure is represented using a mesoscopic graph, which offers an ideal compromise between macroscopic and microscopic graphs, and appears very suitable for timetable generation. On the mesoscopic graph, a timetable is created as the best solution obtained using an automatic timetable generation algorithm, specifically designed to allow planners to interact with its results. The first result of the timetable generation is a feasibility check. In fact, the algorithm might be unable to schedule all required services.

In this case, the planner might try to remove some constraints to the timetable (connections, maximum running time, etc.) and repeat the generation or – should this not prove possible or sufficient – improve the infrastructure.

Supported by the infrastructure saturation levels shown graphically by the blocking times steps, and considering the list of services that could not be scheduled, the planner can identify a (set of) network improvement measures. They are easily implemented in the mesoscopic model, and a new timetable can be generated on it. This “inner loop” is repeated until a timetable proves feasible.

The robustness of the feasible timetable can now be verified, to assess whether the services could be operated with satisfying reliability levels, especially on the most complex or densely-used sections of the network. Microscopic simulation is used to perform, obtaining as output the same delay and punctuality indicators used by rail operators to measure real delays.

Should the timetable not prove robust, planners would be required to further improve the infrastructure (or – when possible – remove some timetable constraints) and then perform the simulation again. The block diagram of the approach is presented in Figure 1. The key elements of the approach are presented in detail in the following sections.

3 Infrastructure model

The infrastructure model used as a basis for planning the timetables is a key element in the planning process [1], since it must be defined quite easily but also represent all characteristics of the network that are relevant for calculating the running times and the occupation time of each train. Compared to a macroscopic model, in which stations are represented in a simplified way and fixed running times are used, a microscopic model appears significantly more accurate in the estimation of the key parameters used in timetable planning, such as the running and blocking times.

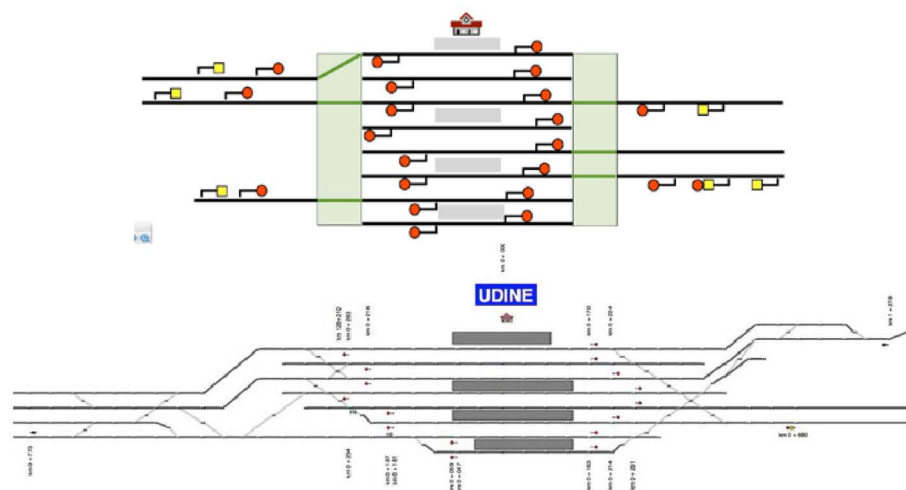


Figure 2 Mesoscopic (above) and microscopic model of a station

Most algorithms that solve the TTP problem are based on a macroscopic model, while some others, such as [4] and timetabling tool DONS [5], introduce a two-level approach. They use a macroscopic model to create draft timetable that will subsequently be checked for feasibility on a microscopic level for the principal station areas of the country. In any case, none of the two works consider the blocking times.

In order to combine the advantages of micro and macroscopic models some authors proposed algorithms for an automatic generation of a macroscopic model based on the corresponding microscopic one [6]. In the same framework, a microscopic model less detailed than the conventional ones was used Caimi [7] to represent the station areas.

In this work a mesoscopic model is introduced. It includes most of the accuracy of a microscopic model, but it also maintains a reasonable complexity. Its aim is to allow the generation a network-wide timetable in a reasonable time without the necessity of resorting to two-level approaches -level approach. Similarly to the macroscopic models, the network is rigidly separated into stations and line sections.

The station features of our mesoscopic model are the station tracks, the line tracks of the lines converging to the station, the distant and home signals at their distance from the station building; and a switch region at each side of the tracks (except, of course, the dead-end stations): each line is connected to all tracks; a set of matrices contains the possible and

impossible routes and their compatibility. Figure 1 shows the mesoscopic model of a station. The line features of the mesoscopic model include all signals, the speed limits, the gradients and the curve radii.

The running time of each train is calculated by solving the motion equation, considering the exact train routing and signaling system as well as the characteristics of the rolling stock. Together with the running time on the default track, also the running times within each station of all possible routings are calculated. The result is model in which the running times are estimated with the same accuracy of the microscopic ones, while the blocking times and the definition of conflicts appears slightly simplified.

4 Timetable generation algorithm

Key factors for the acceptance of a software tool such the Timetable Planning Software (TTPSW [2]) are its perceived usefulness and the perceived ease of use. Within this framework, the final user, i.e., the timetable planner should not feel losing the control of the planning operations in a domain where he assumes to have some critical informal knowledge that cannot be easily transferred to an information system. In addition, as in a real environment the criteria defining the optimality of a timetable are often quite fuzzy, the final user should also be able to influence the structure of the timetable that the TTPSW picks up among the feasible ones.

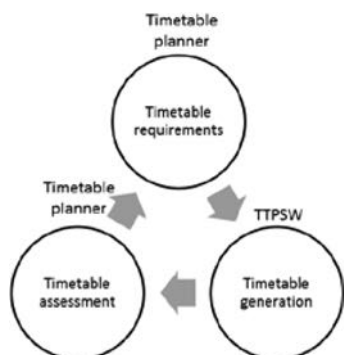


Figure 3 Timetable generation circle.

The aim of TTPSW is to allow the planner to iteratively generate different timetables in a reasonable time in order to assess them also in the light of the of its informal knowledge and to provide new (or different) constraints and objectives to the TTPSW for the generation of a new round of timetables. The algorithm tries to define a (sub)optimal timetable which includes each of the families of trains given as inputs. The timetable is generated by implementing a local search heuristic whose pseudocode.

The heuristic iterates within two cycles: an internal one and an external one. At each iteration a new timetable is generated and its cost is assessed. If this cost is less than the cost of the currently best timetable, the currently best solution is updated with the newly determined timetable.

The algorithm generates a new timetable at each iteration according to a greedy procedure, which defines the schedule and the associated penalty costs for the trains of a family at a time. The families are scheduled according to their priority.

To allow the exploration the space of the possible solutions, the algorithm perturbs both the priorities and the desired departure times of the train families. At the end of each internal iteration the priority of the families is varied randomly, so that at the next iteration the sequence in which the different families are scheduled may change. The internal cycle is iterated times for every iteration of the external cycle.

The output of the TTPSW is a complete timetable for each train of the families in C that TTPSW has been able to schedule. Specifically, the software reports the arrival time, the departure time, the platform and the route of the train in each station, junction or halt that the train visits along its line.

5 Estimating robustness

A timetable created by the TTPSW is normally feasible, but it appears important to verify its robustness, at least on its core sections. Microscopic simulation represents the most accurate tool for reproducing railway operations including their stochastic components. Simulators such as OpenTrack [8] can reproduce most processes involved in rail traffic and comprehend not only its deterministic aspects, but also human factors. This is particularly relevant in order to simulate traffic under realistic conditions, considering variability at border, various driving styles and stop times [9].

In the approach presented in this paper, stochastic microscopic simulation is used to estimate the delay measures that would be obtained operating the timetable obtained using the TTPSW on the infrastructure defined previously and under given variability. A combination of mean delay, punctuality and of the Frequency of Delay Index is used to evaluate the quality of operations. Should a timetable not prove robust, the planner can decide to add buffer times which are a characteristic of each train group or release other timetable constraints and then run the TTPSW again.

6 Case study: Norway

The Norwegian Rail Administration JBV manages about 4100 km of lines, mostly single track. It is pursuing an ambitious improvement plan that will gradually improve the capacity of the network, especially on the most-densely used lines. The core of this project will be the new 20 km-long tunnel of the Follo line (Follobanen), a 22.5 km long double-track line built for 250 km/h: it will triple the available capacity on the saturated section of the Ostfold line between Oslo and Ski allowing more frequent and faster services also on the branch lines. Selected sections of the long-distance corridor connecting Oslo with Trondheim will be doubled, as well as a part of the Ostfold and Vestfold lines; besides this major improvements, a series of smaller measures will allow operating the target volume of services on each line.

JBV started a project, called R2023, to select and define the key requirements of the investments effectively required to reach the target capacity and robustness of the operations by at-the-same avoiding unnecessary expenses. The project is an ideal case study for the approach, since different scenarios of infrastructure timetable have to be created to allow selecting the best combination of improvements, by at-the-same-time considering the constraints of rail operations. The entire network was modelled using the mesoscopic model, obtaining very satisfying results especially in the estimation of the running and blocking times to be used as input for the TTPSW: they are calculated in less than 5' on a standard desktop PC.

The usability of the TTPSW proved less satisfying: multiple testes were required to estimate a set of parameters – in both absolute and relative terms – that lead to a realistic timetable structure and infrastructure utilization. Coherently with the operating principle of the algorithm, an inappropriate set of parameters results in a timetable with too long running time margins at some trains or with some missing trains and not in long computational times.

The algorithm is currently able to create a timetable for a significant part of the network in less than 10 minutes, although it is not always able the same number of trains as a skilled planner. To cope with this weakness, the TTPSW was «guided» adding or releasing constraints until all expected services were scheduled. Further tests are currently being performed, especially in order to identify the sets of parameters and the number of iterations that most frequently lead to satisfying results.

7 Conclusions and outlook

To gain competitiveness in a rapidly changing economic context, railways need efficient and effective improvements, which allow facing strength market conditions. The impact of such improvements has to be precisely evaluated, to allow choosing interventions and combining them in long-term development programs.

The presented methodology allows a realistic and efficient planning of railway timetables and networks, creating several alternatives that can be compared easily.

The first large-scale application is showing promising results, with very satisfying results especially in terms of computation times. The tests show that the model is able to compute realistic solutions in a few minutes: the position of the slots on the timetable graph appears similar to that used in the timetable created by practitioners.

The promising results obtained in the first large-scale tests foster further improvements to the algorithm and the whole approach, in order to make it more reliable and understandable for practitioners, especially concerning the selection of the constraints and parameters.

The method used to estimate mean blocking times on line sections will be improved, while its effective accuracy will be estimated, especially considering longer distances between stations. Results obtained in the most used part of the network will be compared to micro-simulation in order to estimate the difference between micro- and mesoscopic models in terms of blocking times and conflicts effectively considered.

While all mentioned improvements appear relevant in order to benchmark the quality of the results their applicability to very large networks, the most extensive tests will be carried out in order to find some general rules that allow defining the parameters and constraints that lead to a realistic timetable structure.

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