PLASA – Smart Planning and Safety for a safer and more robust European railway sector

D2.1 – Summary of state-of-the-art in simulation

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The present document sets the basis for the research carried out in the Smart Planning subproject of Shift2Rail project PLASA. The objective is to analyse railway stakeholders' planning activities in order to clearly define the requirements, potential impact, and scope of innovation of the Smart Planning methods developed in the project. This deliverable aims to give an overview of the current state-of-the-art in simulation for railway traffic planning. It should cover both, the academic perspective and the applications and software tools that are used by planning experts of different railway companies.

The summary covers both, microscopic and macroscopic techniques for railway simulation and it compares the advantages and disadvantages of the different approaches and software tools.

The document is structured as follows:

Chapter 1 is the introduction, and outlines the objective and scope of this deliverable.

Chapter 2 discusses the planning processes which are in project scope, and gives a working definition of the term "Smart Planning" in the context of PLASA. It also contains an overview of state-of-the-art of Smart Planning models and methods for railway simulation.

Chapter 3 gives an overview of the results of former EU projects in the Smart Planning context.

Chapter 4 summarizes the results of a survey concerning the state-of-practice for smart planning models and railway simulation at relevant railway stakeholders across the EU. Available software tools and the range of application of smart planning tools are described.

Chapter 5 delimits the scope of innovation of the current project within the potential applications of Smart Planning tools in the railway sector.

Chapter 6 is the conclusion, and summarizes the main achievments of the task covered by the deliverable.

<u>Possible links of results with other deliverables, outputs to other WPs or tasks</u>

WP 2 and WP 3 of PLASA are based on the results of the "scope of innovation" chapter of Deliverable 2.1. Deliverable 2.1 sets the foundation for all the following Smart Planning deliverables, since it contains an analysis of the current Smart Planning status which PLASA wants to improve and it sketches the scope of innovation. Thus, affected deliverables are D2.2, D2.3, D3.1, D3.2, D3.3.

PLANNING PROCESSES AT IM AND RU

There are many different planning processes at IM and RU companies which vary significantly in terms of planning horizon as well as required effort and resources that are concerned. This section will give an overview of the most relevant of these planning processes that may be supported by future Smart Planning simulation approaches. Several, but not all of these topics are addressed by PLASA.

Planning processes are most commonly classified according to their respective planning horizon. Planning processes that concern the current timetable are called ‘short term’ and have a planning horizon of less than one year. Processes that regard the timetables of the next years are called ‘mid term’. Planning processes that take into account the far future (usually these are high invest projects) are called ‘long term’.

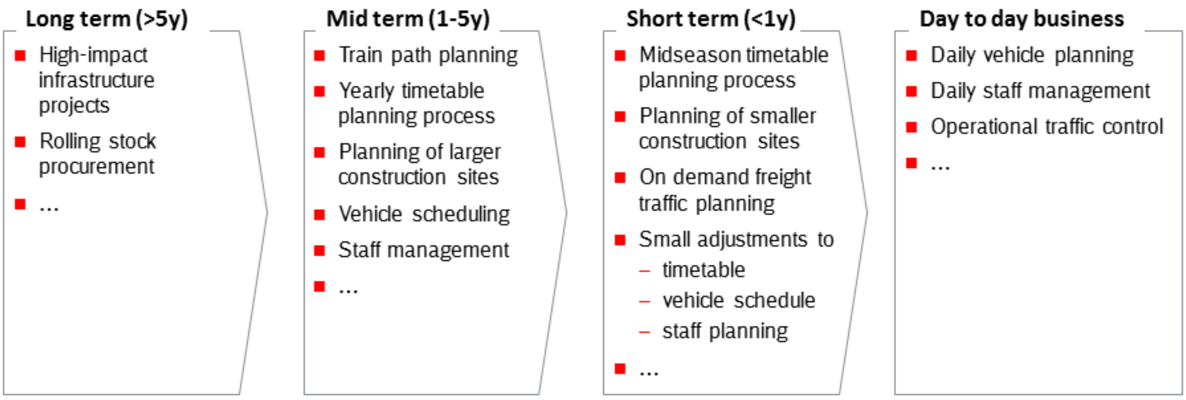

Figure 1. Overview of different planning processes and their classification

<u>Long term planning: (>5 years)</u>

- High-impact infrastructure projects (IM)
    - In railway networks, the construction of a new infrastructure is often planned more than a decade in advance and is characterized by high costs and a huge amount of planning efforts. Every high-impact long term infrastructure project has its own characteristics and thus its own individual planning process, hence most of these projects cannot be standardized.
    - Smart Planning approaches enable simulating the global impact of infrastructure changes on railway traffic . Therefore, they can have a significant impact on the planning process, by providing the possibility to measure the relevant effects on the railway traffic.
- Rolling stock procurement (RU)
    - Similar to the planning of a new infrastructure, the procurement of new vehicles is also a planning step with a long planning horizon. Especially for new types of high-speed trains (e.g. TGV and ICE), the development of new technologies and the test phases will take up some time. Hence, the procurement of new vehicles has its own individual planning process which cannot be standardized. For the planning processes, one must distinguish between the development of new vehicles and a reordering of already tested an proven vehicles (which is a far less complex task).

- Future Smart Planning approaches will be able to simulate the effect of different vehicle technologies (e.g. improved acceleration, changes to max. speed, etc.) and thus may help to decide, whether given timetable concepts can also be realized with the new vehicles

Mid-term planning: (1 - 5 years)

- Train path planning (valid for several years) (IM & RU)
  - Timetables are not totally restructured every year. In general, frame contracts regulate the framework conditions for train paths and thus also for all the constructed timetables. These train paths give both, the IM and the RU a certain planning stability. The planning process varies for long-distance trains, regional trains and freight trains, since all three types have different requirements and planning horizons.
  - Changes to the train paths will influence the timetables of the next years significantly. Here, Smart Planning simulation approaches can help to. identify train conflicts in advance and thus lead to more stable and robust timetables.
- Yearly timetable planning process (December) (IM & RU)
  - For all states in the European Union, the yearly timetable changes take place in December (usually the second weekend). Here, major changes (e.g. new train routes) are integrated in the timetables for the following year. Detailed information about the process and current discussions about a redesign can be found at http://www.rne.eu/ttrproject
  - During the timetable planning process, many important decisions have to be made in a relatively short amount of time. Here, a significant improvement of the process can be achieved with the help of new Smart Planning simulation approaches, since they are able to measure the impact of changes to the timetable with respect to the quality of the whole network along different KPIs such as punctuality, robustness, throughput. As a result, critical bottlenecks can be identified and, if possible, removed.
- Large, high impact construction sites (IM (& RU))
  - The planning of high impact construction sites strongly depends on the characteristics of the given task. Here, several planning aspects have to be considered. In most cases, the timetables of the RUs have to be adapted to the reduced infrastructure capacity. In addition, the actual construction site has to be planned (procurement of necessary resources, assignment of external companies, etc.).
  - From a Smart Planning perspective, the integration of construction sites into the given timetable is of highest importance. Especially if the infrastructure has a reduced capacity or is temporarily unavailable, Smart Planning approaches are important to estimate the impact of the construction site on the operational quality (bottlenecks, quality reduction, etc.).
- Vehicle scheduling (RU)

- A lot of effort is currently made for the optimization of vehicle schedules. Especially for more complex timetables, a good planning is crucial, since the vehicle schedule must fulfill several characteristics, such as availability of replacement vehicles or repairing cycles of the vehicles. Every RU has its own planning process, depending on the network size, fleet diversity, fleet size and availability of repairing capacities.
- There are already several tools that assist the planners in the vehicle scheduling process. The challenge for future Smart Planning approaches will be to develop an integrated approach, in which the vehicle scheduling planning process is combined with other planning processes, e.g. timetable planning, staff management, etc.

- Staff management (IM / RU)
  - For both, IM and RU, a good planning of the staff is crucial for a high quality railway operation. Here, most of the staff planning processes have their own specific characteristics. Hence, no standardized process can be given for all staff management processes.
  - The schedules of conductors and train drivers are a potential bottleneck for the quality of the railway system. If the connection between two consecutive trains of a train driver is risky, delays may be propagated from one train to the next one. Here, Smart Planning simulation processes will help to quantify such risks.

<u>Short-term planning: (<1 year)</u>

- Midseason timetable planning process (June) (IM & RU)
  - Minor adjustments to timetables are made midseason once a year in most European countries.
  - As with the yearly timetable planning process, a significant improvement of the process can be achieved with the help of new Smart Planning simulation approaches, by enabling planners to quantify the impact of changes to the timetable.
- Planned temporary infrastructure restrictions (IM)
  - IM need to schedule small interventions that temporarily restrict infrastructure availability, e.g. small construction sites or power shutdowns.
  - Smart Planning simulations should enable a global perspective on this scheduling process, allowing planners to take into account the effects of planned activities in one part of the network when scheduling activities in another part. As with larger construction sites, Smart Planning approaches are important to estimate the impact of the construction site on the operational quality (bottlenecks, quality reduction, etc.).
- Scheduling of on demand trains (IM & RU)

- IM and RU need to plan train paths that fit into the given timetable for trains that operate irregularly (e.g. trains for special events, on demand freight traffic).

- Adjustments to vehicle planning (RU)
  - Short-term adjustments to vehicle planning may become necessary, e.g. if a train must be repaired and the given timetable must be adapted. Since many trains have long turnaround cycles, these adjustments can have complex network effects. Decision support through Smart Planning techniques has the potential to minimize the negative effects of necessary adjustments.

Day to day business: (< few days and operational business)

- Daily route, staff and vehicle planning (IM & RU)
  - In day to day business, the requirement is to adapt existing plans in accordance with relevant information that only becomes available on a very short timescale. Examples include the availability of infrastructure, rolling stock, and crew. In principle, the goals and methods relevant to planning in this context are the same as for Smart Planning in the short term. The critical issue is whether these methods can deliver results fast enough to support decisions.
- Operational traffic control (IM)
  - Operational traffic control requires an estimation of the effect of specific dispatching decisions on the overall network, e.g. in terms of punctuality. If Smart Planning methods could deliver results in real-time, it would be possible to optimize these decisions, and take global effects of operational decisions into account, which currently cannot be considered due to the complexity of network effects and the required decision speed.

2. SMART PLANNING IN THE CONTEXT OF PLASA

2.1 Planning processes in project scope

The range of planning processes in railway operations includes mainly timetable, infrastructure, vehicle scheduling, construction sites and crew management. There are also different planning horizons in which these processes can be considered. The most general classification corresponds to the underlying railway operations management processes for strategic planning, tactical planning as well as operational traffic control and train driving. The planning processes within the scope of the project are medium-term planning (1-5 year), short-term (daily time table up to 1 year) and operational traffic.

Medium term planning processes include the annual timetable, major capacity constraints (e.g. larger construction sites with high impact) as well as vehicle and crew management, short-term planning include minor capacity constraints (e.g. minor construction sites) as well as adjustments to vehicle and crew management. Daily adjustments are made for crew and vehicles management and operational traffic consider dispatching and handling disturbances.

The planning processes in the project scope that are aimed at to be improved include planning activities of various stakeholders in the railway system by means of precise railway simulation and optimisation. The methods will capitalize on the increasing amount of digitalized and automatically collected data. Its concept will cover railway tactical planning and will include an outlook on operational process. Thus, the focus of the study is tactical planning and operational processes, where the overall objective is to investigate new methods based on simulation that can also help in the later stages of the planning phase. Methods for re-planning of timetables to mitigate the effects of disturbances during the tactical and operational phases are considered. The approach is based on a combination of precise railway simulation and scheduling methods.

Today, simulations are mainly made in the pre-planning phase of the annual timetable especially planning of traffic for next timetable, planning major disturbances such as bigger maintenance activities and its effects on the traffic. In the annual timetable, simulations are made to get the timetable conflict free and study its' robustness. The process for timetable planning and operation is harmonized in Europe by Rail Net Europe, European legislation, Network statements and European corridors for freight traffic.

Figure 2 illustrates the process for timetable planning for the Swedish Traffic Administration – Trafikverket. The planning is divided into an annual timetable and ad hoc adjustments of the timetable. The ad hoc timetable process is the interface between tactical and operational process. There is a need for better connecting timetable planning and operational methods due to an ongoing trend of the tactical timetable planning process and operational processes merging. In tactical planning simulation and optimization methods improve the planning process and interaction between the Infrastructure manager (IM) and Railway Undertaker (RU). JNB (Järnvägsnätsbeskrivningen) is the Swedish network statement, providing the pre-requisites for planning.

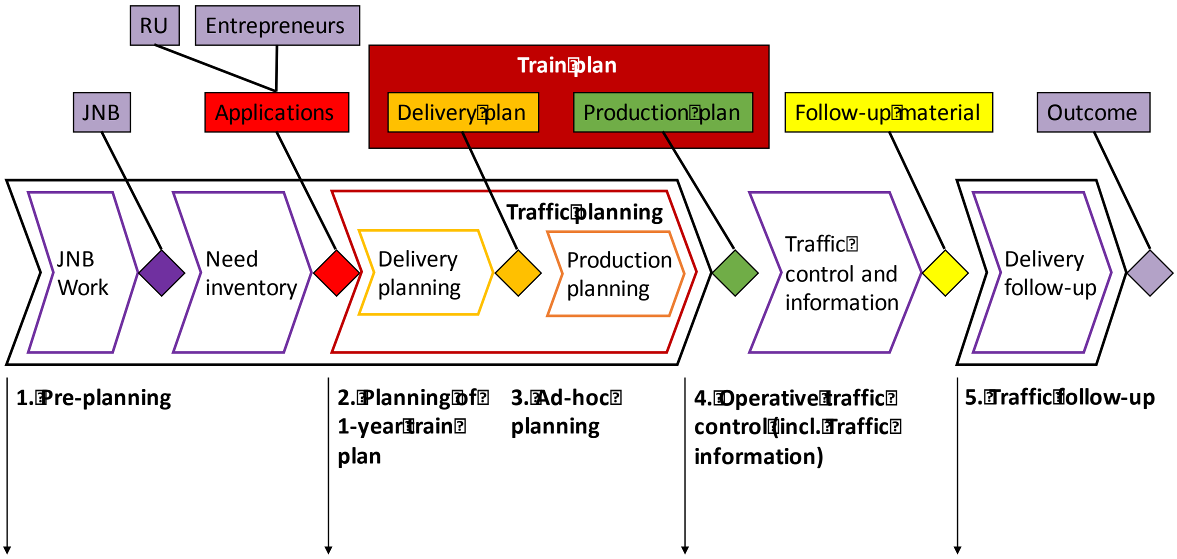

Figure 2. Planning process at Trafikverket (Swedish Transport Administration)

2.2 Definition of Smart Planning

The PLASA definition of smart planning is the use of **simulation, optimization** and **data analysis** for time table planning, including infrastructure work and RU resource planning. The focus of the project is planning in a short and medium time perspective (from daily planning up to 5 years into the future). However, what ultimately defines a smart planning method is the performance of the timetabling process and operational traffic outcome.

For timetabling process and operational traffic one important part is to consider timetabling KPIs e.g. feasibility, capacity utilisation, stability, robustness, resilience, travel times and energy efficiency.

The PLASA project comprises initial actions to the development of a smart planning tool, using simulation, optimization and data analysis as main technologies. The main drivers behind the project is the increased automation throughout the railway sector. Increased automation generates new data which in turn can be used to automate processes and make better decisions. For example, a higher level of automation using new planning and simulation tools such as RailSys and TPS in the annual and ad-hoc process generates new data that can be connected to the data generated from the operational process. Connecting multiple data sources such as these can generate new insights useful for both the planning process and for operational traffic. The LUPP tool at Trafikverket is used to collect and analyse data from the Swedish railway system about disturbances, delay propagation and punctuality.

Traffic simulation, optimization and Lupp data analysis are complementary methods to handle timetable adjustments to fulfil the requests on daily timetable and operational traffic KPI.

Important strategic questions to answer regarding these changes are the following.

- How does a higher level of automation affect the planning process?
- How far have the optimization and traffic simulation approaches come?
- How useful are approaches for robustness, critical points, new KPIs etc.

2.3 Planning models - scientific approaches for timetable planning (state-of-the-art)

Survey planning models and methods (state-of-the-art), models from the academic perspective can be defined as research approaches whereas models for best-practice consider applications and software tools that are used by planning experts of different infrastructure managers and railway companies. Thus, this part considers underlying research approaches for these applications and tools. As there is no clear research area defined for smart planning, the remaining section outlines scientific approaches for timetable planning.

It is also worth noting that today's common system for timetable planning use rather strict constraints for arrival and departure times regardless of the train type or priority. For infrastructure managers, it may therefore be reasonable to define tolerances for individual timetable constraints (stopping location, times) in order to be able to solve conflicts automatically and without user interaction (because changes are done within acceptable tolerances). This prerequisite to automation of timetable planning has been noted by several researchers; see for example (Aronsson, 2015) and (Caimi, 2015).

Railway timetabling is the process of determining time points (arrivals and departures) for events in a railway network for a set of trains, given constraints regarding travel times, waiting times, waiting patterns, performance of train units, service and quality commitments. Typically, the goal is to utilize the infrastructure as efficient as possible (capacity utilization). Naturally, a core part of railway timetabling is then the allocation of the resources (line and station tracks) to be used during its process; however, the focus has traditionally been mostly on the line resources, and the track allocation at stations is typically not considered explicitly. However, it is important to realise that for a timetable to be feasible, there must exist a resource allocation such that all safety constraints are satisfied. This holds for the railway line tracks, where the temporal occupancy of any pair of trains of a single-track segment must respect safety constraints on headway and minimum signalling time. Worth mentioning is also the inherent trade-off between the various goals of timetabling. For example, Abril (2008) states that "there is a trade-off between capacity and reliability/robustness", which also could be interpreted as a difference between technical (theoretical) and feasible (practical) limits of capacity in terms of robustness.

The timetabling problem can be divided into two kinds: the periodic and the aperiodic and whether they model tracks or events (Harrod, 2012). In the periodic variant, the aim is to find a timetable that is cyclic, that means repeats after a, typically short, period of time (for example an hour) while in the aperiodic variant, the goal is to schedule trains for a longer period before repeating (for example a full day). A cyclic timetable is attractive to customers as it is easier to remember, but also requires less effort in timetable planning including connections at high frequencies than an aperiodic. The drawbacks include a reduced capability to handle a service demand which occurs irregularly or less frequently, as is often the case on low-volume routes. If this type of demand is common, then the periodic timetable variant is likely unsuitable for that route.

Four methods for solving the timetabling problem can be characterized, namely Mixed integer sequencing linear programs (MISLP), Binary integer occupancy programs (BIOP), hypergraphs and Periodic event scheduling problems (PESP), where the three first mentioned are suitable for aperiodic scheduling and PESP periodic (Harrod, 2012). MISLP and PESP are event-based, while BIOP and hypergraphs also explicit takes track layouts into account.

One underlying assumption in the models above is that all the trains will run per the timetable without any disturbances. In real operations, this is not a valid assumption as trains will get delayed and the delays will propagate in the network and affect other trains as well, i.e. dynamics in terms of operational perturbations occur. Methods in the literature that deals with uncertainty in data (in the context of optimization) can, according to Fischetti and Monaci (2009), be divided into stochastic programming methods and robust programming methods. Stochastic programming methods often tend to become too complicated. Robust programming algorithms, according to Fischetti and Monaci (2009), are often easy to use and to solve. Cacchiani and Toth (2012) underline the efforts made to develop methods and models for producing robust timetables.

Salido et al. (2012) propose analytical and simulation methods to measure robustness in a single railway line. They designed an optimal passenger train timetable by means of journey time, also taking into account typical train delays but treat production factors as circulation time constant. The authors analytically derive total stochastic expected passenger time as a closed formula, linearize it and use it as an objective function for optimizing the timetable using a Mixed Integer Linear Programming (MILP) model.

Hassannayebi et al. (2014) developed a two-stage GA-based simulation optimization approach in order to minimize the expected passenger waiting times. The optimization is intended to adjust headways through simulation experiments to achieve robust timetables for operation of an urban transit rail system. A further developed methodology with robust multi-objective stochastic programming models for train timetabling is presented by the same author (Hassannayebi et al., 2016).

Fischetti and Monaci (2009) have proposed a method called Light robustness to solve LP-problems with uncertainty in data. In this approach the maximum objective value deterioration is fixed and a "robustness goal" is modelled using a classical robust optimization framework. Compared to some stochastic programming models, of various complexity, they conclude that Light robustness seem to be the most suitable tool to solve large-scale real scenarios. The approach and others are applied to timetabling in Fischetti et al. (2009).

Forsgren et al. (2013a) and Forsgren et al. (2013b) introduced the planning approach of successive allocation of train paths (referred to as Successiv tilldelning in Swedish). They developed a method for optimization of timetables by redistribution of buffer time to minimize train running times by reallocation of train crossings, with regards to robustness. The same thoughts on flexibility in timetables appear in D'Ariano et al. (2005, 2008). The authors claim less (rigid) timetable planning in favour of operational decisions within the buffer time would benefit overall punctuality. Jovanovic et al. (2016) focused on optimal distribution of buffer times based on priority of events, modelled as a knapsack problem, not to consume too much capacity.

Robustness in critical points (RCP) is a concept for improving the punctuality for single trains. Critical points refer to very time-sensitive dependencies between different pairs of trains at different locations in the network (Andersson et al., 2013 p.7). The amount of and distribution of margin time in the timetable has impact on the overall robustness. A Mixed Integer Linear Programming (MILP) model was proposed to redistribute the margin time in an existing timetable. Applied to a realistic example the model achieved a 28 % reduction in total delay at the final destination compared to a not optimized timetable (Andersson et al., 2015).

Some examples of Linear Programming (LP) approaches includes Pouryousef et al. (2016) who uses a multi-objective linear programming model called "Hybrid Optimization of Train Schedules" (HOTS) together with a rail simulation tool (i.e. RailSys) to improve capacity utilization or level of service. The HOTS model uses both conflict resolution and timetable compression techniques but has no strong focus on dynamics in the operations, i.e. to minimize delays. Chen et al. (2014) developed a timetable generator which optimizes the travel time, with consideration of train circulation including service times. Sensitivity analysis shows the effects in case of delays. A similar approach did Xie and Li (2012) who used integer linear programming to solve the scheduling problem with respect to circulation issues and connecting trains.

Lamorgese et al. (2016) consider an exact approach for train timetabling based on a microscopic-macroscopic decomposition model taking into account both operational and cyclicity constraints, for example on routing in stations. The approach is evaluated on a case study of small instances on a railway section in Norway.

Numerous scheduling/timetabling studies for rail services in different aspects have been conducted, including optimization as well as simulation studies of rail capacity. A conclusion of the literature review is however that combined optimization and simulation techniques to achieve optimal performance could be found in other areas, but in rail applications to solve the timetabling problem, most are focused on either optimization or simulation, or limited approaches in combining the methods. The potential benefit of combining optimization and micro-simulation including the infrastructure is the ability to create and evaluate robust timetables.

To be noted is also the previous work regarding optimization of timetabling for the Iron Ore Line (Aronsson et al. 2015) using the timetable tool developed by SICS (Forsgren et al. 2013b), and the work by Schlechte et al. (2011) on track allocation. Worth mentioning is also that there is significant overlap in methods and technology with train dispatching, as discussed in the next section.

2.4 Microscopic and macroscopic planning methods

Both microscopic and macroscopic techniques are used for railway simulation and a comparison can be made over the advantages and disadvantages of the different approaches and software tools. Evaluation and survey of existing software tools is elaborated in chapter 4.2.1.

Microscopic and macroscopic methods are commonly used for strategic purposes considering the annual timetable planning, through either detailed local computations or network optimization.

Microscopic methods consider local computations such as calculating running times and blocking times for a given infrastructure and signalling configuration, as well as for conflict detection and computing capacity consumption.

The methods could also be used within a tactical timeframe considering major disturbances. There are also re-planning methods related to traffic management at the operational level to handle minor disturbances.

There is a current trend that timetable planning and operation is merging. In operational process traffic management systems have functions for optimization and the role of the dispatcher is changed to be more of an operational planner. In Sweden, the new national traffic control system is specified to control by planning.

There is a current trend that timetable planning and operational traffic processes are automated. Timetable planning is to plan trains and trainpaths but also to plan maintenance and infrastructure work.

3. SURVEY OF RESULTS FROM FORMER EU PROJECT ON-TIME AND CURRENT EU PROJECT CAPACITY4RAIL

Existing models, methods, state-of-the-art as well as best practice have been studied in the former EU projects ON-Time and current EU project Capacity4Rail. The main outcomes of these projects are described in section of the report.

Table 1 presents the research projects related to PLASA, valuable input extracted from them and project members previously involved. The emphasis of this survey is on the EU projects related to the smart planning sub-project in PLASA and to the planning processes in railway management and operations i.e. 'On-time' and 'Capacity4Rail'.

Project Name	Valuable Input to PLASA[2]	Liaison
ON-Time (FP7, 2011 11 – 2014 10, Ref: 265647)	▪ Capacity restriction problem and existing approaches ▪ Generic framework for IM planning processes, studying processes in 5 EU countries ▪ Method for handling minor perturbations, possible to automatize ▪ Method for handling major disturbances, interaction between IM and RU	▪ Trafikverket ▪ SNCF ▪ ASTS ▪ DB
Capacity4Rail (FP7, 2013 10 – 2017 09, Ref: 605650, current project)	▪ Experience on the usage of simulations and models in the planning processes ▪ Overview of European systems for timetabling and simulations ▪ Analyses of existing methods for tactical planning and operational traffic control	▪ Trafikverket ▪ ASTS ▪ DB

Table 1. EU research projects related to the smart planning sub-project in PLASA

3.1 ON –TIME

Summary

The project ON-TIME (Optimal Networks for Train Integration Management across Europe) has developed new methods and processes to help maximise the available capacity on the European railway network and to decrease overall delays to both increase customer satisfaction and ensure that the railway network can continue to provide a dependable, resilient and green alternative to other modes of transport. In the project, specific emphasis was placed on approaches for alleviating congestion at bottlenecks. Case studies considered included passenger and freight services along European corridors and on long distance main-line networks and urban commuter railways. Current best practices were identified and developed by examining national projects previously carried out. A description of the estimated TRLs prior to project start in regards to six innovations within railway planning and operations management is set out in the Table 2:

	Innovation	Current TRL	Planned TRL after ON-TIME
Innovation 1:	Standardised definitions and methods	**2**	**7**
Innovation 2:	Improved methods for timetable construction	**3**	**6**
Innovation 3:	Algorithms to either automatically provide control, or provide decision support to controllers	**3**	**7**
Innovation 4:	Methods, processes and algorithms that are able to provide decision support when events occur that require the disposition of assets and resources	**2**	**6**
Innovation 5:	Interoperable approaches for the communication and presentation of information	**3**	**6**
Innovation 6:	An information architecture to support the communication of standardised and contextualised train control data	**2**	**7**

Table 2. TRL levels before the start of the ON-TIME project and the planned step changes

Relation to this project

The overall aim of the ON-TIME project was to improve railway customer satisfaction through increased capacity and decreased delays for both passengers and freight. This was achieved through new and enhanced methods, processes and algorithms. Within the European research project, seven sub objectives were set to fulfil the overall aim, the objective that relates the most to this project is sub-objective two as it is in line with the area of interest of this study, namely smart planning:

“Objective 2: To reduce overall delays through improved planning techniques that provide robust and resilient timetables capable of coping with normal statistical variations in operations and minor perturbations. “

Other objectives also accounted for in the ON-TIME project;

Objective 1: Improved timetabling techniques and real-time traffic management.

Objective 3: Improved traffic management techniques

Objective 4: Providing effective, real-time information to traffic controllers and drivers, thus enhancing system performance.

Objective 5: To provide customers of passenger and freight services with reliable and accurate information that is updated as new traffic management decisions are taken, particularly in the event of disruptions.

Objective 6: To improve interoperability; whilst also increasing the energy efficiency of railway operations.

Objective 7: To better understand the dependencies between train paths by considering connections, turn-around, passenger transit, shunting, etc.

Research outputs and valuable inputs to PLASA

The key outputs of the research have been:

- The development of common railway timetabling and capacity estimation methods appropriate for use by all EU member states that reflect customers’ satisfaction and enable interoperability, more efficient use of capacity, higher punctuality and less energy consumption;
- Further development of methods for robust cross-border timetables and integration of timetables between different regional and national networks improving interoperability and efficient corridor management including standardised approaches for exchanging timetable information between stakeholders;
- Improved timetable quality, stability, robustness, reliability and effectiveness;
- Validated development methods, through benchmarking, using a number of standard, real-world case studies.

The key academic work that has been undertaken is:

- Development of micro-macro network transformations;
- Microscopic conflict detection and capacity consumption;
- Macroscopic network timetable optimization including stochastic robustness evaluation;
- Computation of energy-efficient speed profiles;

- Stochastic optimization of optimal energy-efficient timetables on corridors between main nodes.

Valuable inputs to PLASA can summarized accordingly:

- Capacity restriction problem and existing approaches
- Generic framework for IM planning processes, studying processes in 5 EU countries
- Method for handling minor perturbations, possible to automatize
- Method for handling major disturbances, interaction between IM and RU
- Experience on the usage of simulations and models in the planning processes
- Overview of European systems for timetabling and simulations
- Analyses of existing methods for tactical planning and operational traffic control

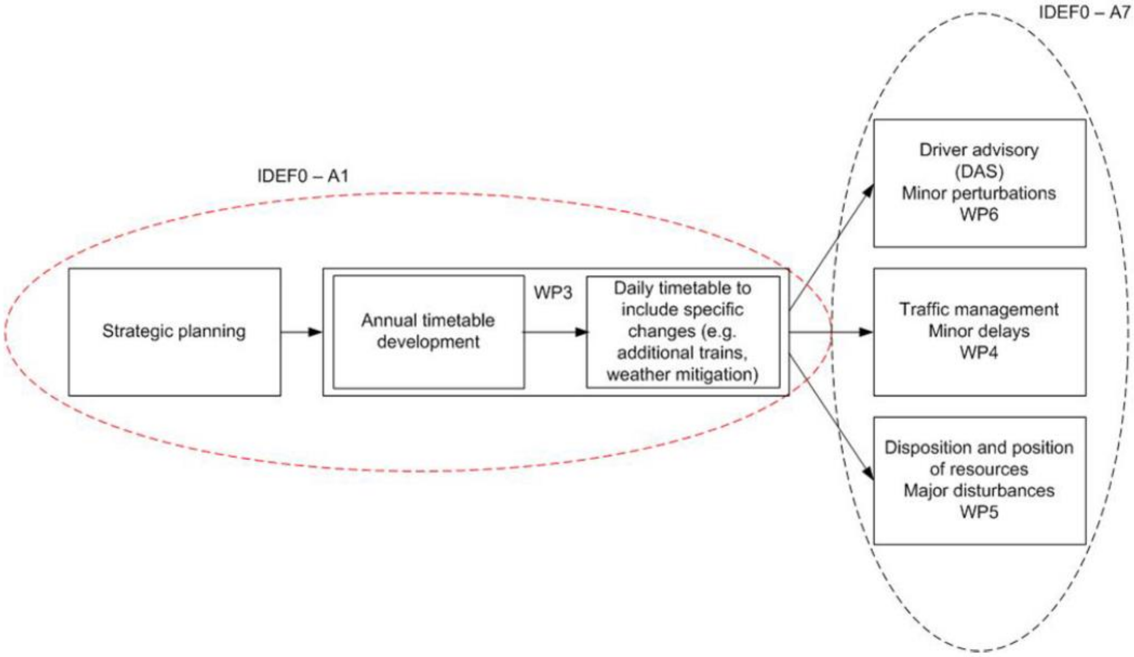

Figure 3. Planning processes considered in the ON-TIME project

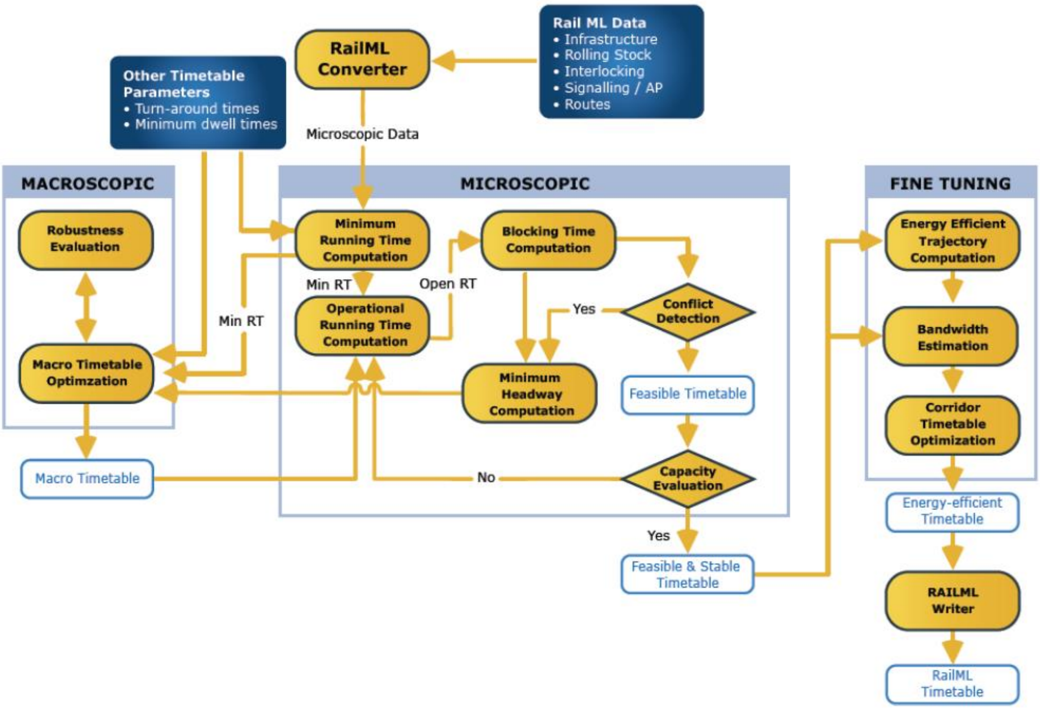

Figure 4. Three level approach to timetabling design provided by the ON-TIME project

Deliverables and results

The main results of this part of the project (i.e. relating to timetable planning) are summarized in the following reports:

- D2.3 A strategy for putting methods into practice and a formal evaluation of demonstrators
- D3.1 Methods and algorithms for the development of robust and resilient timetables;
- D3.2 Benchmark analysis, test and integration of selected timetable tools.

The following software modules were developed or extended in the project:

- Microscopic timetabling models by TU Delft
- A macroscopic timetable optimization model by University of Bologna
- Energy-efficient speed profile computations and stochastic optimization of corridor timetables by TU Dresden.

REVIEW OF TECHNOLOGICAL DEVELOPMENTS AND TECHNOLOGY READINESS LEVELS

Table 3. Research approaches

Research Approach	Author	Description	Comments
Analysing stability and investments in railway networks using advanced evolutionary algorithms	(O. and M. 2004)	In this paper a network of periodically running railway lines is considered. A cost-benefit analysis of investments is derived, where the benefit is measured in reduced waiting time for passengers changing lines. The actual mean waiting time is also estimated with simulation.	The optimisation described is proven to produce Pareto optimal timetables, with cost-benefit analysis in consideration. It also allows estimation of "turning points" for the timetable synchronisation.
Cyclic Railway Timetabling: a Stochastic Optimization Approach	(Kroon, Maroti et al. 2008)	The paper describes a stochastic optimisation model to minimise the average delay of a single train on a number of consecutive trips along the same line. The model can be applied to find an optimal allocation of the running time supplements of the train. It can also be used to improve a given cyclic timetable for a number of trains on a common infrastructure.	The research proved that stochastic optimisation is a useful approach to improve cyclic railway timetables. By re-allocating time supplements and buffer time, delays can largely be reduced.
Fast Approaches to improve the robustness of a railway timetable (ARRIVAL)	(M., D. et al. 2007)	In this paper the authors proposed and analysed four different methods to improve the robustness of a given Train Timetabling Problem solution for the aperiodic (non cyclic) case. The approaches combine Linear Programming (LP) and ad-hoc Stochastic Programming/Robust Optimisation techniques.	The robustness improvement models are evaluated in terms of validated cumulative delay. Light Robustness is proved to be the fastest method for large-scale real scenarios. It is also accurate and easy to be embedded.

Light Robustness (ARRIVAL)	(Fischetti and Monaci 2009)	In this paper a timetable optimisation model for uncertain input data is proposed. The model is called Light Robustness. It couples robust optimization with a simplified two-stage stochastic programming approach.	The model proves to be flexible, easy to use and can produce high-quality solutions with less effort and time.
Railway Timetabling with the model of the Periodic Event Scheduling Problem	(Liebchen 2005; Liebchen and Peeters 2009)	The papers summarised traditional models of the Periodic Event Scheduling Problem (PESP). An integration of network planning, line planning and vehicle scheduling is proposed for periodic timetabling, by a simple extension of PESP.	
Design of a new railway scheduling model for dense services	(Caimi, Burkolter et al. 2009)	This paper is focused on the timetabling and routing problem in condensation and compensation zones. A policy is introduced to schedule trains using a time discretisation.	Results show fast generation of timetables for large stations.The main problem is to find a balance between adequate slack time and timetable stability. The coordination between the condensation and compensation zones is also a concern.
How regular is a regular-interval timetable? An operational tool to assess	Tron D., and Tzieropoulos P. (2009)	The paper describes a piece of software developed to automate the assessment process	The software is proved to provide some comprehensive indexes covering the whole network and

regularity		of the regularity of timetables.	services. Yet it may raise some tricky aggregations and weighing issues.

3.2 CAPACITY4RAIL

Summary

The CAPACITY4RAIL project is a EU FP7 funded industry lead initiative which aims to answer the question “How to obtain an affordable, adaptable, automated, resilient and high-capacity railway; for 2020, 2030 and 2050?”

The project aims at providing an overall increase in railway capacity by developing a holistic view on the railway as a system of interacting technical components driven by customer demand. In SP3 of the Capacity4Rail project the objective is to increase capacity by better methods for timetable planning and operational traffic and to analyse and evaluate capacity of infrastructure and new traffic systems.

In the study four planning horizons for railway planning and operations management are identified; strategic level (constructing infrastructure), tactical level (timetabling), operational level (short-term rescheduling and dispatching) and driver advisory system (real-time). At each level in the planning process, the capacity use is determined by demand and supply. The supply of capacity is controlled by the IM, whereas the demand requires forecasting. Figure 5 gives an overview of various aspects of demand and supply of the railway capacity in the following perspectives:

1. Strategic level – socio-economic analysis, cost benefit analysis, multi-criteria decision making, integrated multimodal transport models, etc.
2. Tactical level – macroscopic simulation, stochastic simulation, optimisation, and improving timetable robustness, resilience and stability
3. Operational level – microscopic simulation, optimisation, monitoring and short-term prediction
4. Train control – driver advisory systems

Figure 6 shows the framework for micro- and macroscopic simulation and optimization as support in rail planning processes in existing planning horizons provided by Capacity4Rail.

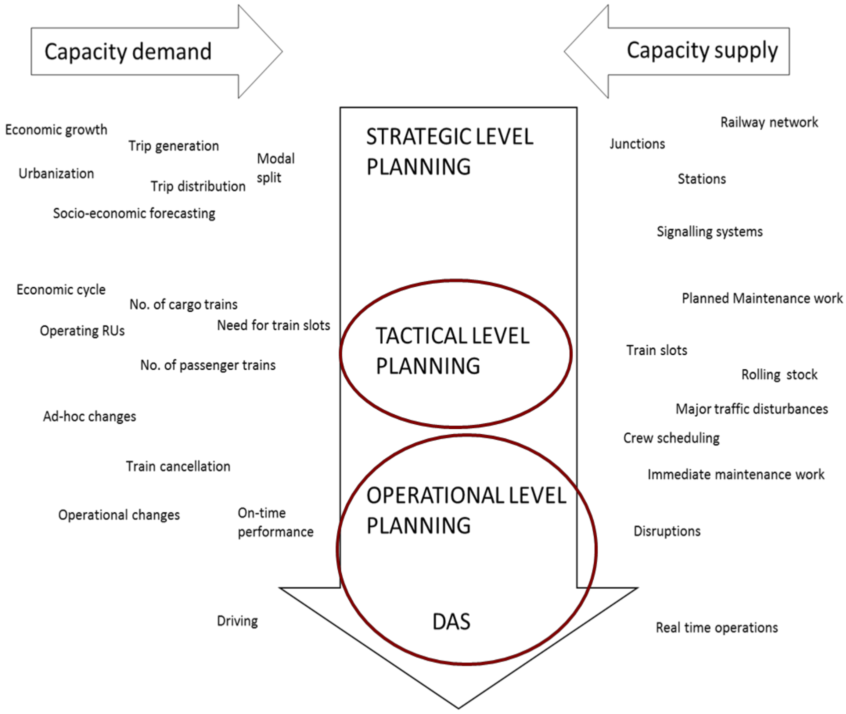

Figure 5. Aspects of demand and supply of the railway capacity provided by the Capacity4Rail project.

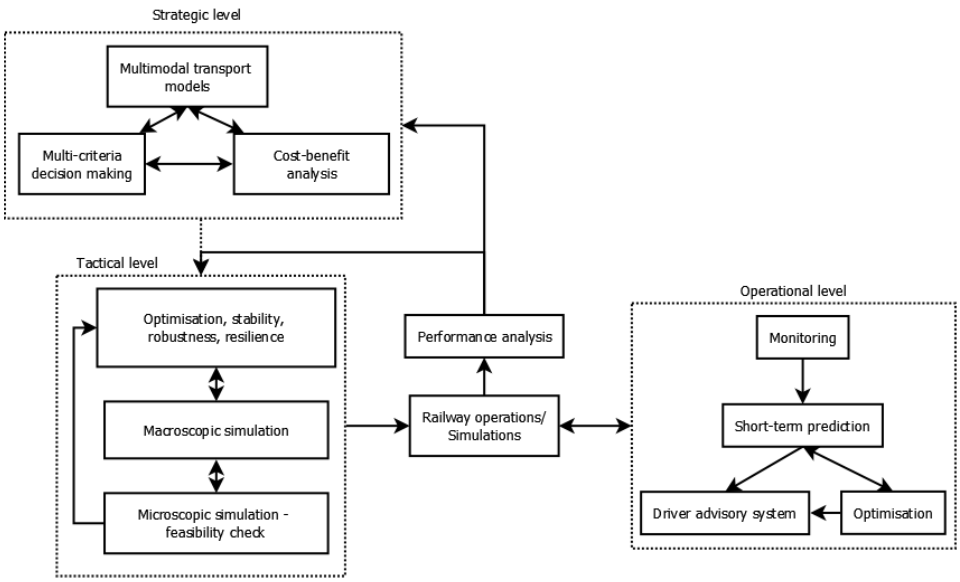

Figure 6. Existing framework for decision support in planning processes of railway operations provided by the Capacity4Rail project.

Research outputs and valuable inputs to PLASA

The project presents the prevailing praxis in strategic, tactical and operational rail capacity planning processes, as well as driving advisory systems (DAS), in several European countries, and how modelling tools and simulation are utilized in planning and controlling. The work contains a state-of-the-art description with respect to the research approaches.

The study also presents a gap analysis, with the viewpoint from the Infrastructure Manager (IM), where improvement needs at the IMs are identified, which can be a combination of both that the research approaches needs to be extended, or that there is a gap between the research approaches and the current best-practise. A summary of the improvement needs follows:

1. Improving processes and flexibility in timetable planning

- Improve Infrastructure Manager – Railway Undertaker process in timetable planning and also during operation regarding timetabling issues
- Improve processes and information to increase the flexibility in the timetable, especially for ad-hoc process, and methods for utilizing the residual capacity in the timetable planning.

2. Better planned timetables by improved methods for traffic simulation analysis and evaluation of punctuality from historical data

- To develop methods and IT tools that supports to plan timetable at microscopic level that are conflict free.
- To make better stochastic simulations of disturbances to ensure that the timetable fulfil robustness requirements.
- To be able to evaluate and analyse the punctuality statistics.
- To identify causes and efficient measures (cost effective measures) to increase punctuality

3. To develop standards and data management for system simulation

- There are microscopic models at national level for timetable planning and simulation. Next step is to expand the models to European networks with many countries.
- Standards should be set.

4. To develop decision support algorithms and to automatize timetable planning and operational traffic

- To make simulation systems even more powerful to be able to simulation international corridors, and also to include better dispatching algorithms in simulation systems.
- Short term forecasting is an important issue.

5. Operational information systems and DAS

- To close the loop in operational information systems so that the potential of DAS is realized.

6. Open source and open data

- Increase the flexibility of systems and improve the enhancement speed by using open source software and open datasets.

Valuable inputs to PLASA can summarized accordingly:

- Experience on the usage of simulations and models in the planning processes
- Overview of European systems for timetabling and simulations
- Analyses of existing methods for tactical planning and operational traffic control

Deliverables and results

- Public deliverable D 3.2.1
- Public deliverable D 3.4.1

Deliverables 3.2.1 analyse the existing methods for the tactical and operational levels from the aspect of their application for the enhancement of capacity utilisation. Improved methods in analytic, simulation and optimisation models for operational traffic control will increase either capacity utilisation (number of trains) or the punctuality. Operational control of railway traffic is recognised as the critical point in railway systems that requires an improvement. The application of novel computer-based decision support systems is recognised as a potential approach. The discrepancy between the current state of the existing tools for real-time traffic control and the practical operational requirements is identified as the main gap.

Deliverable 3.4.1 focuses on data formats and models for data exchange used in the railway sector with considerations of alternative approaches in other transport modes. The focus is on open data formats that have the potential to substitute proprietary data formats in the future. It analysis three usage scenarios, where data exchange is and will be important to guarantee effective usage of railway capacity:

- Consistent cross industry infrastructure data;
- Effective usage of multimodal transport systems;
- Real-time operations across organisational and member state borders.

4. OVERVIEW OF STATE-OF-PRACTICE FOR SMART PLANNING MODELS AND RAILWAY SIMULATION

This chapter gives an overview of the state-of-practice for planning and simulation tools. Before the development of a new simulation prototype can start it is necessary to know which systems are available on the market. From the academic point of view this task is handled in the previous chapter. But it is also necessary to know which applications and software tools are actually used by planning experts of different railway companies and how they are used.

4.1 METHODOLOGY

To find out which software tools are used by the planning experts a survey consisting of 25 questions for the used simulation tools and 7 questions for the planning tools has been created (see chapter 4.1.1). The survey was designed in collaboration with persons who are in close contact to the infrastructure managers and reviewed by all partners of the PLASA – Smart Planning Project. The participants of the survey are planning experts from railway infrastructure managers. Next to the infrastructure managers that are participating in the PLASA project, also other IMs were invited and asked to answer the questions. In order to obtain a good picture it was tried to have survey participants from a wide range of European countries. After identifying the right contact person in the company, the questionnaire and fill out request were delivered to them.

When the names of the used systems were communicated by the contact person, a search to get more information about the software started to have a good knowledge and understanding of it. The results of the questionnaire and the investigation of the tools are presented in the next chapter 4.2.

4.1.1 Questions of the survey

Simulation Tool

1. Do you use a traffic simulation system?
2. Do you use the simulation system for support of the planning, real-time or for other processes?
3. If you choose Other, please note.
4. Do you use nearly the whole (more than 80%) of the functionality of the system?
5. Which functionality is most important for you; which do you use most often?
6. Is the simulation tool integrated in the planning system?
7. If no, has the simulation system an interface to the planning system?
8. To which systems the simulation tool has an interface?
9. Who works with the simulation system? (e.g. the planner, research people, …)
10. Do you consider the results of the simulation directly during timetable planning?
11. What do you do with the results of the simulation?

12. Which running times do you use for the simulation? (new calculated running times or fix, standard running times)
13. What is the basis for the running times, a microscopic or macroscopic network?
14. Does the system use an asynchronous or synchronous simulation?
15. Does the system use a microscopic or macroscopic network for the simulation?
16. Does the system have single or multiple (stochastic) simulation?
17. If both, what do you use most?
18. Does the system have control means for injecting disturbances into the simulation?
19. If yes, how are the disturbances modelled (e.g., delay probability distribution functions associated to timetable, event probability distribution functions associated to rolling stock, infrastructure, …)?
20. Is there a capability to enter the disturbance itself into the system, like e.g. a fault of a switch?
21. Does the system have control means, e.g., disposition rules for dispatching decisions during simulation?
22. If yes, are the disposition rules microscopic or macroscopic?
23. Do you use empirical data to adjust the simulation?
24. If yes, which elements are adjusted (disturbances, disposition rules, …)?
25. Which statistical or reporting output does the system provide?

Planning Tool

1. Does the system use microscopic or macroscopic data (or both) for the planning?
2. Does the system calculate the running times or do you use fix, standard running times?
3. Are the running times generated on a microscopic or macroscopic basis?
4. Does the system have a function for conflict detection?
5. If yes, which rules does the system use (e.g., track occupation overlap, macroscopic capacity rules, …)?
6. Does the system integrate and consider (i.e., detect/resolve conflicts with) planned possessions and/or other types of infrastructure restrictions during the planning of the timetable?
7. Please describe the steps you perform in the system for planning the timetable (high level description).

4.2 Results

Every one of the contacted persons from the IMs gave a response and answered the questionnaire. Figure 7 shows the participants of the survey.

The results were analysed and then shown in an anonymous and aggregated way. That makes it impossible to trace back single answers to a specific company.

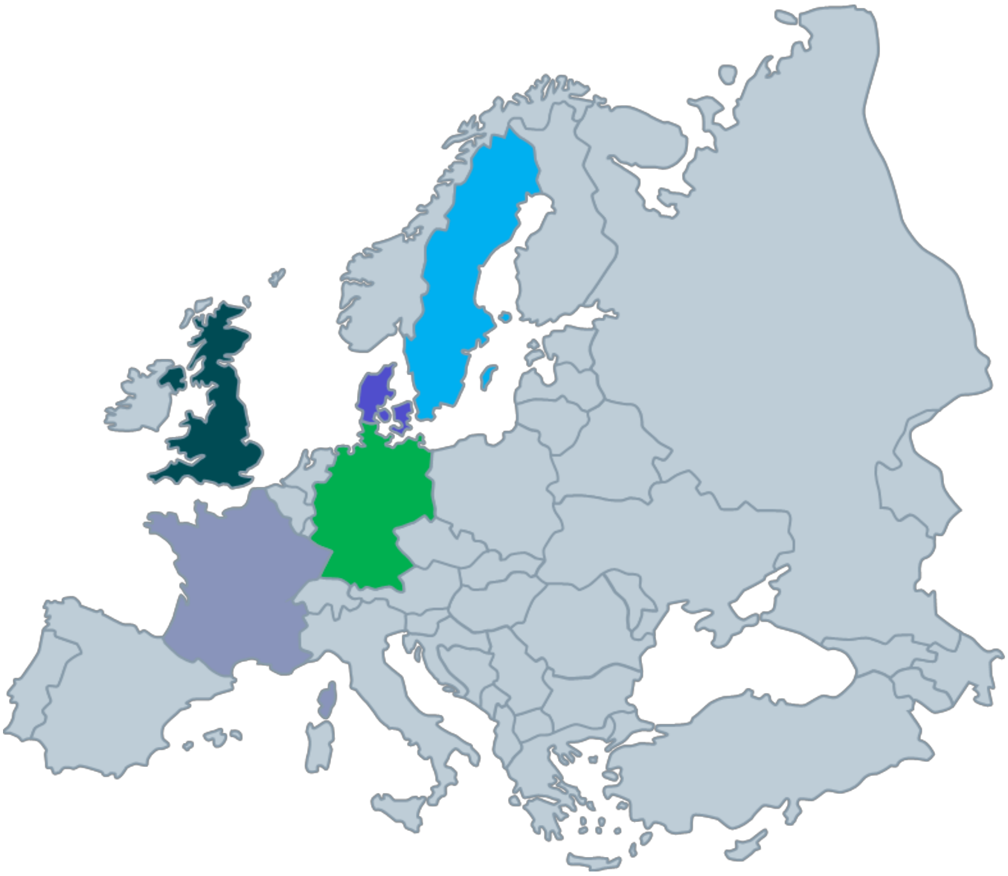

Figure 7. Participants of survey

4.2.1 Available software tools

In the area of simulation most of the participants answered that they use RailSys as simulation tool. But also Open Track is a tool for the simulation of railways that is used in several countries. For planning the timetable there exists different software solutions – RUT-K, TrainPlan, THOR and TPS. The participating infrastructure managers that use TrainPlan and THOR are on the process to replace their timetable planning systems in short time by TPS as well.

Simulation tools

RailSys

In 1999 the railway traffic management- and software development company Rail Management Consultants GmbH (RMCon) was founded, which market the software RailSys.

The software tool RailSys is not a pure simulation tool. Next to the simulation functionality it is also possible to do a technical as well as an operational planning for railway transport. RailSys uses a microscopic model with a synchronous simulation.

RailSys is separated in three parts: the infrastructure manager, the timetable- and simulation manager and an evaluation manager.

The following simulations are possible in RailSys:

- Timetable simulation
- Operational simulation
- Possession simulation

Timetable simulation Operational simulation	Possession simulation
Synchronous simulation	Consideration of works planned in the actual operation
Timetable simulation with evaluation and solution of conflicted timetables	Rerouting
Operational simulation with evaluation of robustness and quality of timetables planned	Feasibility study
Comparison of variants	

Table 4. RailSys simulation functionality

RailSys References as simulation tool:

- Deutsche Bahn AG
- DSB
- Network Rail
- Trafikverket
- Jernbaneverket
- And other

OpenTrack

OpenTrack is a railway simulation and planning tool which was developed at the ETH Zurich. In 2006 OpenTrack Railway Technology Ltd. was founded as a spin-off-company of ETH Zurich. The company was based on research results of ETH Zurich. From this time on OpenTrack Technology Ltd. further develops and markets the simulation tool OpenTrack.

What is OpenTrack?

- A virtual railway laboratory

- A railway planning and simulation tool
- A tool to bring the reality of the rail operations into the users office
- A tool to manage, simulate, evaluate and document rail projects of the users
- A tool to communicate between the user and his customers, partners and public bodies

What can OpenTrack simulate?

- All relevant processes on a given rail network
- Train movements (position, speed, acceleration)
- Behaviour of the signalling system (signals, routes)
- Dispatching of train services (priorities)
- The consequences of delays, failures and incidents

Typical tasks

- Comparing future infrastructure scenarios
- Analyzing the capacity of lines and stations
- Rolling stock studies (e.g. future rolling stock)
- Timetable construction and robustness analysis
- Calculation of power and energy consupmtion
- Analysis, design and comparison of signaling systems

OpenTrack References:

- Jernbaneverket
- SBB
- DB Netz AG
- SNCF
- NSB
- And other

Planning tools

TPS

In 1984 the railway traffic management- and software development company HaCon was founded. TPS is one of the products which is marketed by HaCon and was first put into operation in 2002 by the Danish state Railways. The software TPS is a planning tool that combines infrastructure, timetable and train path management as well as interaction. The entire network is always taken into consideration during all types of planning, while the local planning priorities are also carefully observed.

With TPS, planners work efficiently with three screens: The infrastructure editor, the timetable editor and the graphical editor. The timetable editor contains simulation functionality, too.

Main functions of TPS are:

- Timetable management
  - Runtime calculation
  - Seamless integration of closed tracks and speed limitations
  - Automated search for conflict-free train paths and synchronization with the current timetable
  - State-of-the-art graphical features: track infrastructure, graphical timetable, track occupation plan and various output options
- Sophisticated data integration via various interfaces
- Static or dynamic access to occupation data
- End-to-end bid-offer process for infrastructure managers and train operating companies
- Real-time module for conflict detection and resolution with comprehensive review and preview functionality
- Integrated simulation functionality

TPS References:

- Network Rail
- DSB
- SNCF
- Jernbaneverket
- Trafikverket
- And other

RUT-K

The planning tool RUT-K (Rechnerunterstütztes Trassenmanagement – Konstruktion) is a product of the DB Systel GmbH. It is a client-server-system for timetable planning with a centralized oracle database.

The main functions of RUT-K are:

- Accurate timetable construction
- Efficient calculation of running times
- Display of occupation conflicts
- Graphical and interactive workability

RUT-K References:

- DB Netz AG (Germany)

TrainPlan

Train Plan is a timetable planning tool that was originally developed by Comreco Rail Ltd. After several sales of the tool it is now marketed by Trapeze.

The main functions of Train Plan are:

- Graphical display of the topology
- Graphical construction of the timetable
- Management of trains, train path and status
- Availability of infrastructure
- Automatic conflict detection
- Automatic conflict resolution
- Timetable construction in all planning horizons

TrainPlan References:

- Trafikverket (Sweden)
- Romania
- Australia

THOR

THOR is a timetable planning tool that was developed by SNCF and is only in use within SNCF. The main focus of THOR is the calculation of the trains.

4.2.2 Range of application of Smart Planning tools

Most of the respondent infrastructure managers use simulation tools. They are used to support their planning processes by guiding the timetable planners to approve the timetable, but simulation tools are also used to support strategic investment decisions for example. The simulation functionality is not integrated in the planning tool, but some of the IMs use interfaces from the planning system to the simulation tool to have a real timetable for performing realistic simulations. The participants indicate that no other interface from or to the simulation tools are available.

The people who are working with the simulation tool are most often timetable developer and railway capacity experts for infrastructure investments. According to the responses, nearly the whole functionality of the system is used in all cases. The most important functions for the respondents were:

- Runtime calculation
- Conflict detection
- For working area: timetable and timetable quality functions
- Real interlocking modelling

If available within the simulation system the multiple (stochastic) simulation functionality is performed by the user. Multiple (stochastic) simulation means the simulation runs several times using stochastic delays during simulation to investigate their influence on a given timetable.

Participants of the survey were also asked to specify in more detail the calculation of the running times and the resolution of the network that is used by the simulation system. In all responds the running times are calculated – no standard times used - and the basis for the calculation was a microscopic network.

The type of simulation is always, if known by the respondent, identified as asynchronous. If a simulation is done, it can be performed as synchronous or asynchronous. When using a synchronous simulation all reproduced sequences of operations are event-driven or in a time step procedure. That makes it possible to model the operating schedule. The asynchronous method for simulation, instead, is a static copy of the timetable construction or of dispositions in the operation. Thereby it is possible to perform runtime calculation or connections without simulating the whole sequence of operation.

The participants were also asked if it is possible to inject disturbances into the simulation and to give more details about this. In all tools it is possible to enter disturbances. The disturbances are modelled as delay probability distribution functions associated with the timetable. A functionality to enter the fault itself into the system, like switch fault, is not available in all systems, but it is worked on to realize it. Additionally, for all simulation tools disposition rules can be entered on a microscopic basis for dispatching decisions during simulation.

Another question concerned the adjustment of the simulation by empirical data. In most of the applications the injected delay data is adapted to reproduce the real world as nearly as possible.

The participants were also asked for the reports the systems provide. Following some of the answers:

- Arrival/departure delay at a single selected station or several stations
- Punctionality for trains per each station
- Time for each train

The participants were also asked some questions about their used system for planning timetables. The first question was about the network, i.e. the level of detail of the data for planning. Here the answers vary. Two of the planning systems use microscopic data, one uses both and one uses macroscopic data. Also in the second question about the type of the used train running times the answers are not equal. Some use microscopic calculated runtimes and some use standard, fix train times or both.

All planning tools of the participants have a conflict detection function. In most systems the rules for the conflict detection is based on track occupation overlap. Even if every planning system has a conflict detection function, it is not used by every company. Some participants perform the conflict detection manually or do it with the simulation system.

The question concerning the possibility to integrate planned possessions in the planning tool is answered by only one participant with No. The other systems can integrate and consider the possessions, i.e. they have the ability to detect and resolve conflicts with planned possessions and other types of infrastructure restrictions during the planning of the timetable.

For a whole picture and summary of the answers please see Annex 1.

5. SCOPE OF INNOVATION FOR PLASA

This chapter details the scope of innovation of the PLASA project regarding Smart Planning technologies and methods. Based on the different types of planning processes for which Smart Planning could in principle generate benefit, we outline which approaches will be addressed by the present research, and why.

The state-of-practice in railway simulation is currently divided into two different approaches, which are employed in different contexts and with different goals in mind:

1) Macroscopic simulation for large networks, but not on a detailed level, because it is difficult to model the infrastructure-train-interaction or the delay propagation between trains properly.

2) Very detailed microscopic simulation. In this approach, it is difficult to simulate larger networks properly, and very high effort is required for model calibration. In addition, the computational effort is high computational for large networks.

PLASA aims at bringing these two approaches together by using microscopic information where such a level of detail is needed, and by combining microscopic and macroscopic techniques to a mesoscopic approach with stochastic aspects known from macroscopic simulation techniques.

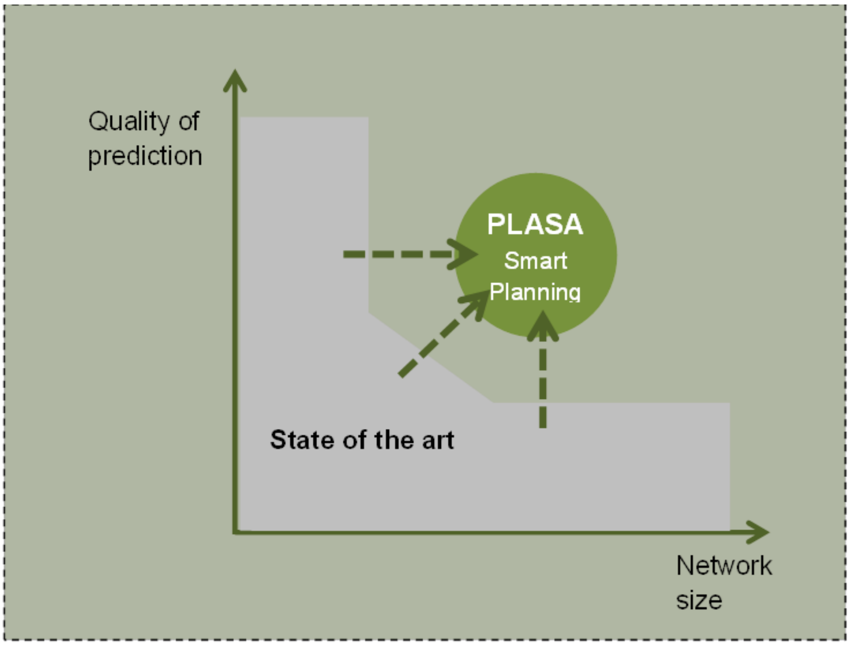

Figure 8. Scope of innovation

In addition to the level of detail, the applicability of the simulation is also crucial for the success of Smart Planning models. In order to change the scope of application of smart planning approaches from a strategic to a more tactical level (i.e., changing the scope from mid-term to short-term planning), it is necessary to reduce the computational and personnel effort of the simulation. For a tactical smart planning concept, simulation times (working time of the person who executes the simulation plus computation time) should be less than one day.

The Smart Planning simulation concepts developed within PLASA will lead from a regional to a global perspective (by increasing the network size that the simulation can handle). Especially larger networks like the German railway network or international corridors and the use cases addressed by PLASA are out of scope for current simulation techniques.

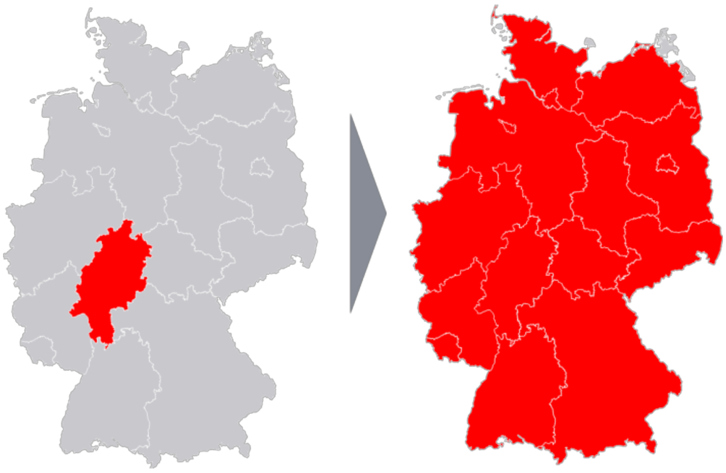

Figure 9. PLASA will change the range of Smart Planning simulation approaches from regional to whole networks (e.g., German railway network)

In addition, PLASA changes current planning approaches from an isolated to an integrated concept, by regarding import aspects simultaneously. Thus, new significant potentials for improvement can be activated.

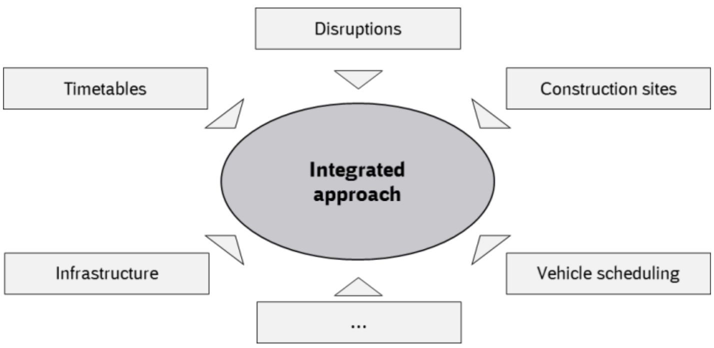

Figure 10. One key aspect of PLASA is the integrated approach which considers all relevant aspects of the railway business simultaneously

PLASA aims to improve the current state-of-the-art for tactical simulation. Hence, the planning horizon of the Smart Planning use cases will be reduced significantly at least to a simulation of the next days. The final goal of Smart Planning approaches will be to simulate railway traffic on an operational level. Here, PLASA aims to investigate current technological limits in terms of computation time and manual effort required.

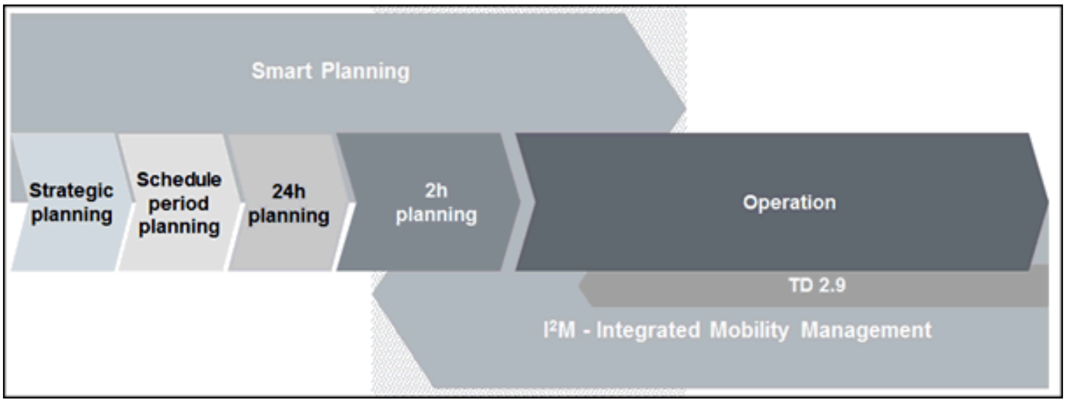

Figure 11. Comparison of Smart Planning and I²M goals regarding planning horizons.

For being able to estimate the quality of a planning result, it is necessary to simulate the timetable in real-life conditions. Thus, PLASA aims to create a high quality stochastic disruption model that is able to reproduce real-life disruption patterns, but which is also editable by the user (e.g., to simulate the effect of reducing certain infrastructure disruptions). The research of PLASA will be validated with a proof of concept by implementing a software prototype.

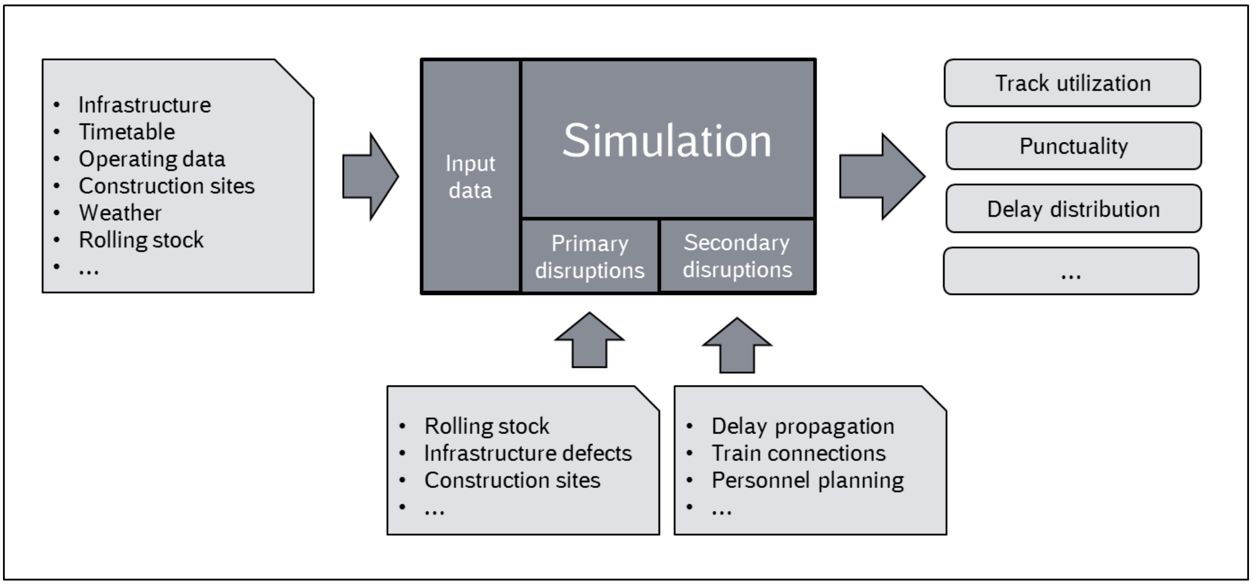

Figure 12. Draft of the PLASA software prototype.

The concept of the different modules (data input, disruption model, level of detail of the simulation, etc.) will be implemented with a clear distinction between data interface and internal computation. Thus, future enhancements (e.g., results of GoSafe or PLASA 2) can be integrated into the simulation concept without great efforts. Such a modular structure also enables future changes for the regarded level of detail. Here, more microscopic aspects can be integrated where needed and a more stochastic, macroscopic relaxation can be used, where the complexity of the model is in conflict with the runtime goals.

Future improvements can easily replace given modules, e.g. by enhancing the given disruption models or by implementing improved dispatching rules.

The output of the simulation will contain certain quality measures, like track utilization, punctuality, delay distribution, etc.

6. CONCLUSIONS

In the present document, different planning activities at RU and IM were examined, with a special focus on the potential for Smart Planning methods to improve the present state. Furthermore, the state of the art and the state of practice of railway planing where described, and results from relevant former EU projects in the topic area summarized. Finally, the scope of innovation for the current project was defined.

The main achievments of this deliverable are:

- A definition of Smart Planning in the context of PLASA
- A comprehensive overview of the state of the art in timetable planning
- An overview of the planning tools used in practice by railway stakeholders
- A clear vision of the gap in current planning capabilities that future work in project PLASA will attempt to fill

The objective was to analyse railway stakeholders' planning activities in order to clearly define the requirements, potential impact, and scope of innovation of the Smart Planning methods developed in the project. This objective was met.

The deliverable aimed to give an overview of the current state-of-the-art in simulation for railway traffic planning, covering both, the academic perspective and the applications and software tools that are used by planning experts of different railway companies. The academic perspective was addressed in section 2.3, while the applications and software tools are covered in chapter 4 and specifically in section 4.2.1.

A further goal was to cover both the microscopic and macroscopic techniques for railway simulation, and to compare the advantages and disadvantages of the different approaches and software tools. It turned out that at least for timetable planning, both in the state-of-the-art and state-of-practice microscopic approaches are far more prevalent, so the focus of the analysis was on those methods.

Overall, the analysis revealed that one potential area of improvement for Smart Planning is that the methods developed will allow to get simulation results that are good enough to be of practical use without having to specify in detail all the parameters required for a microscopic simulation. This will allow these methods to be used for questions where the specification of these details is either not possible, or not feasible given the timeframe in which a result is required. Thus, the methods developed in PLASA need not be strictly superior to current state-of-the-art methods in terms of quality of prediction. Rather, the goal is to make a sufficiently high level of prediction quality and detail available in a wider variety of scenarios than is currently the case. It is evident from the survey results presented in chapter 4 that all responding infrastructure stakeholders would profit from such a development.

The work carried out in this work package did not reveal any obstacles to the original plan proposed for the Smart Planning part of PLASA. Work can continue as planned, and build upon the results described in this deliverable.

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ANNEX 1: ANSWERS OF THE QUESTIONNAIRE

Simulation

Do you use a traffic simulation system?
Yes: 5; No: 3

Do you use the simulation system for support of the planning, real-time or for other processes?
Planning: 4; Other: 3

If you choose Other, please note.
- traffic simulation is used for: timetable planning and infrastructure investments including ERTMS, traffic simulation for real time process is done in research
- Studies
- The simulation is also used for evaluating the impact of certain measures outside of the planning process.

Do you use nearly the whole (more than 80%) of the functionality of the system?
Yes: 5

Which functionality is most important for you; which do you use most often?
- Running time calculation, conflict detection, multi-cycle-simulations
- For working area: timetabling and timetable quality following functions are most important.
- Real interlocking modeling and running time calculation
- Evaluating effects on punctuality

Is the simulation tool integrated in the planning system?
No: 5

If no, has the simulation system an interface to the planning system?
(Yes): 3; No: 2

To which systems the simulation tool has an interface?
- From planning tool to simulation tool. It requires some manual steps.
- Transfer timetable information from timetable tool to our simulation system
- To timetable planning tool and Spurplan
- RailSys, PTV Visum

Who works with the simulation system? (e.g. the planner, research people, …)
- Infrastructure and timetable developers.
-

Railway capacity experts
* infrastructure investments and ERTMS studies
* timetable planning and timetable quality

Outside of infrastructure manager:
* consultants

* research and education
- Long term planning responsible, engineer
- Employees of EBWU (after a declaration conversion and 6 month period of vocational adjustment)
- Consultants, Data scientists

Do you consider the results of the simulation directly during timetable planning?
Yes: 3; No: 2

What do you do with the results of the simulation?
- They are part of the decision basis of the management to approve a timetable.
- Guiding the timetable planners working in timetable planning tool.
* headway calculations
* congestion plans in main city areas train path structure, capacity limit
* quality check of timetable to detect that it is conflict free (detect conflicts)
* to define timetable structure for reinvestments and capacity limit number of train paths
- the results are used for strategy of investment, timetabling strategy, performance of interlocking system, ...
- guidance of sector organizations
- projects of punctuality
- Use them for consulting decision makers and planners.

Which running times do you use for the simulation? (new calculated running times or fix, standard running times)
Calculated: 5; Standard: 1

What is the basis for the running times, a microscopic or macroscopic network?
Microscopic: 5; Macroscopic: 1

Does the system use an asynchronous or synchronous simulation?
Asynch: 2; Don´t know: 1; Synchron: 2

Does the system use a microscopic or macroscopic network for the simulation?
Microscopic: 5; Macroscopic: 1

Does the system have single or multiple (stochastic) simulation?
Both: 3; Single: 2

If both, what do you use most?
Multiple: 3

Does the system have control means for injecting disturbances into the simulation?
Yes: 5

If yes, how are the disturbances modelled (e.g., delay probability distribution functions associated to timetable, event probability distribution functions associated to rolling stock, infrastructure, …)?
- Delay probability distribution functions associated to the timetable (single trains or train groups). Trains can be delayed at their departure from a station (dwell time extension) or they can enter the areal of analysis with a delay.
- * IM has delay distributions for departure first station, dwell times and running simulation

* calibration and validation have been made based on realtime data
* Methods for delay distribution is an area to develop for traffic simulation
* to model fault of a switch is possible in next simulation tool version
- Event probability distribution from real traffic.
- Entering of break-in and initial delay of defined areas (at signals or stops)
- Delay probability distribution associated to infrastructure and train type

Is there a capability to enter the disturbance itself into the system, like e.g. a fault of a switch?
No: 3; Yes: (1)+2

Does the system have control means, e.g., disposition rules for dispatching decisions during simulation?
Yes: 4; No: 2

If yes, are the disposition rules microscopic or macroscopic?
Microscopic: 4

Do you use empirical data to adjust the simulation?
Yes: 4; No: 1

If yes, which elements are adjusted (disturbances, disposition rules, …)?
- Delay probability distributions. It takes a big effort to adjust the simulation model to reproduce real world delay statistics.
- Empirical data is used by collecting data from Lupp - data is used for start delay, dwell time delay, primary delays
- Data of LEIDIS (delays and reason of delay)
- Disturbances, reduction of delays

Which statistical or reporting output does the system provide?
- A wide range of the commonly needed statistics such as: mean arrival/departure delay at a single selected station or several stations (line section). These can be represented as e.g. cake or pillar-diagrams
- Different kind of simulation statistics of punctuality for trains per each station
- some results on time for each train, using of infrastructure, delay for each train, recovery time, ...
- Main characteristic: Shift/Change of delay and 50-100 other simulation statistics
- For every train the delays over the track, for every train type the sum of delays by certain causes, overall punctuality

Planning

Does the system use microscopic or macroscopic data (or both) for the planning?
Microscopic: 1; Macroscopic: 1; Both: 2

Does the system calculate the running times or do you use fix, standard running times?
Calculated: 4; Standard: 2; Other: 1

Are the running times generated on a microscopic or macroscopic basis?
Microscopic: 5; Macroscopic: 1

Does the system have a function for conflict detection?
Yes: 6

If yes, which rules does the system use (e.g., track occupation overlap, macroscopic capacity rules, …)?
- The conflict detection is based on the blocking stairs model.
- To detect block sections conflict though the model is less detailed than the simulation system. Because of that the IM check that timetable are conflict free in the simulation system.
- real interlocking system.
- track occupation, but we have the functionality turned off and rely on manual conflict detection
- Track conflicts (succession of trains, crossing of trains etc.), station and stop conflicts (track occupation, exclusion of running track, train length on track, re-allocation of tracks …)
* depending on data maintenance
* final examination by the EIU

- Conflict detection based on blocking stairs theory

Does the system integrate and consider (i.e., detect/resolve conflicts with) planned possessions and/or other types of infrastructure restrictions during the planning of the timetable?
Yes: 5; No: 1

Please describe the steps you perform in the system for planning the timetable (high level description).
- We follow the Rail Net Europe timetabling process in detail. Link: http://www.rne.eu/timetabling-documents The different steps/phases in this process are also done by the IM
- see answer to DB about timetable planning process.
- Import TOC requests for train schedules, de-conflict, manual validate against timetable planning rules and publish the timetable
- Detailed planning of future cycle systems, detailed planning of yearly timetable (incl. interface to EIU), detailed planning of short term planning (excl. short term possessions)
- see Ril 402 and dependant processes