Capacity for Rail

Towards an affordable, resilient, innovative and high-capacity European Railway System for 2030/2050

Evaluation measures and selected scenarios

Date: 1 July 2015

Public deliverable D 3.2.1

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605650

Collaborative project SCP3-GA-2013-60560
Increased Capacity 4 Rail networks through enhanced infrastructure and optimised operations
FP7-SST-2013-RTD-1

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EXECUTIVE SUMMARY

The purpose of SP3 of the Capacity 4 Rail project 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. We have identified four planning horizons, which are strategic level (building of infrastructure), tactical level (timetabling), operational level (short-term rescheduling and dispatching) and driver advisory system (real-time). This deliverable 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 raise 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. The focus of the future work will therefore be in overcoming the obstacles that are preventing a straightforward application of the laboratory tools in a real-world environment.

A set of potential scenarios that are required to validate the approaches is presented. The scenarios comprise the potential environments where the enhanced models could be applied. Different perspectives for defining the scenarios are considered. The scope and size, traffic heterogeneity, signalling system, the current level of traffic control and the availability of data are recognised as the crucial criteria for defining the scenarios. Finally, the Swedish southern mainline is recognised as the potential scenario that could be an appropriate instance for validation and evaluation of the models.

Next steps are: Task 3.2.4 Enhancing frameworks for simulations and modelling and Task 3.2.5 Initial evaluation of scenarios.

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ABBREVIATIONS AND ACRONYMS

Abbreviation / Acronym	Description
CC	Capacity Consumption
DAS	Driving Advisory System
ETCS	European Train Control System
GPS	Global Positioning System
IM	Infrastructure Manager
IT	Information Technology
RFC	Rail Freight Corridors
RNE	RailNetEurope
RU	Railway Undertaking
TOC	Train Operating Company

1 INTRODUCTION

Railway capacity can be considered in many ways, depending on the perspective. The description on the capacity varies with respect to the planning perspective, for example, the time horizon, the size of the considered geography, resource type (infrastructure, rolling stock, staff etc.). We concern models for analyses of railway capacity, and the use of available capacity within strategic planning (long-term infrastructure construction), tactical planning (yearly timetabling) and operative planning (daily dispatching). Closely related to the operative planning are also driver advisory systems.

In the work package WP32 we see simulation and models as a method for evaluating enhancement in the capacity. Many such models are developed and implemented on various stages; some are currently part of the daily working processes at the European infrastructure providers, whereas others are still at an early research state. It is important to identify the potential of improvements for demonstrating the enhancement in railway infrastructure and operational processes.

A state-of-the-art description should cover various types of models, reaching from commercial models of traffic simulation and timetable planning via optimisation and analytical models, and methods for making traffic forecasts and future scenarios, to decision support systems, open models and demonstrators. Some of these models may not be further considered in subsequent WPs.

Clearly, the aim is to implement modelling tools and simulations in the working processes in the railway branch, mainly by infrastructure managers and operators. In this report we focus on the infrastructure manager's perspective. Models and methods, which are not applicable for the owners of the capacity problems, i.e. the users, are only of an academic interest. Therefore we must understand the planning processes and identify where and how to improve them.

To change processes there is also a need of new methods, typically in form of available software, which is implemented, verified and tested for commercial use. Today, there are many software tools available as decision support, some of which are partly overlapping each other's functionalities. For timetable and traffic simulation systems there are a few dominating systems used in many countries. There are also lots of activities with innovations at the different countries with tenders and implementation of new systems. A better understanding of available software and best practice are important when designing better planning processes.

For infrastructure managers and railway undertakers the processes for timetable planning and operational traffic are developing. The annual timetable planning and the operational planning are coming closer together. New information systems and simulation methods make timetable planning and operational planning linked together.

Also the models and methods, of course, could be approved and made more efficient. This is a major task for academic research, and it is important that it is well connected to the commercial software development feeding the end users' need. Some of these may not (yet) be in daily use at the operators and infrastructure providers.

1.1 Scope

The scope of SP3 of the Capacity 4 Rail-project is

- to increase capacity by better methods for timetable planning and operational traffic;
- to analyse and evaluate capacity of infrastructure and new traffic systems.

In WP32, the scope is to analyse and evaluate capacity of infrastructure and to design new traffic systems. This will take requirements from the Freight and Infrastructure SPs as well as WP31.

We have identified four planning horizons, which are strategic level (building of infrastructure), tactical level (timetabling), operational level (short-term rescheduling and dispatching) and driver advisory system (real-time).

- Best practice
- Gap analysis and conclusions
- Models are identified but have not been finally selected

This report is a first delivery from WP 32. It will outline the problems addressed and serve as a plan for the subsequent work.

1.2 Initial plan

From contract (DoW):

The existing approaches to increase capacity will be evaluated and their potential to solve capacity problems will be described. Methods to measure and evaluate capacity utilization will be described. Capacity innovations will be grouped along with how to assess them in modelling and simulation. Scenarios will be defined using these groupings. A plan for initial enhancement of models and simulations is created.

The scenarios are based on both existing and enhanced infrastructure capability utilising the predicted freight and passenger demands of the future.

The plan will be further developed the succeeding task 3.2.4.

The result of the task is the deliverable D3.2.1 (Evaluation measures and selected scenarios). D3.2.1 also includes results from T3.2.1 and T3.2.2. The delivery is led by Trafikverket.

2 PRELIMINARIES

This work package is about simulation models to evaluate enhanced railway capacity with respect to infrastructure and operations. A starting point for the work is the infrastructure manager's planning process. How do the infrastructure managers plan the use of railway capacity and what are the needs for a better planning?

Special interest is of course given to the usage of simulation in planning, and we illustrate this by examples from several European countries. A gap analysis identifies the need for further developments.

2.1 PROCESSES AT INFRASTRUCTURE MANAGERS

This chapter explores existing planning processes at an infrastructure manager level. Timetable design and operational traffic management including train dispatching can be considered a central task for infrastructure managers, wherein the actual timetable and resource plan is transferred into an operational process.

The timetable process is harmonised in Europe. The Network statement is the basic document describing all the rules and conditions of the operators or "Railway Undertakings" (RUs) for entering the national railway network. The Network statement includes basic general rules, more specific rules, priority and conflict rules, charging rules (railway access fees), annexes with network maps and route parameters, and more. All the Network Statements follow the unified rules of RNE (RailNetEurope).

Processes which will be presented in this chapter are infrastructure capacity analysis, timetable planning, and operational traffic planning. Infrastructure capacity analysis is implemented to explore infrastructure investments, future traffic scenarios and patterns, vehicles, signalling systems, switches and speed profile at the strategic and tactical planning levels.

In Milestone 3 section 3.2–3.4, timetable planning and operational traffic management is discussed under the sub headings of planning process for the cases of Great Britain, Sweden, and Germany. The experienced problems and innovations will also be generally identified. Following this in 3.6, best practice from each of these cases will be identified and utilised as input to a generic framework for the Infrastructure manager planning process.

A key element for facilitating access to the European rail network is a harmonised timetabling process for international train path requests. It is RailNetEurope's (RNE, 2104) role to continuously improve and further develop this process. The RNE path management processes for the annual and the running timetable is given in Figure 1. Harmonised procedures and deadlines that are valid for all Infrastructure Managers (IMs) and Allocation Bodies (AB) within the RNE network benefit the entire rail industry.

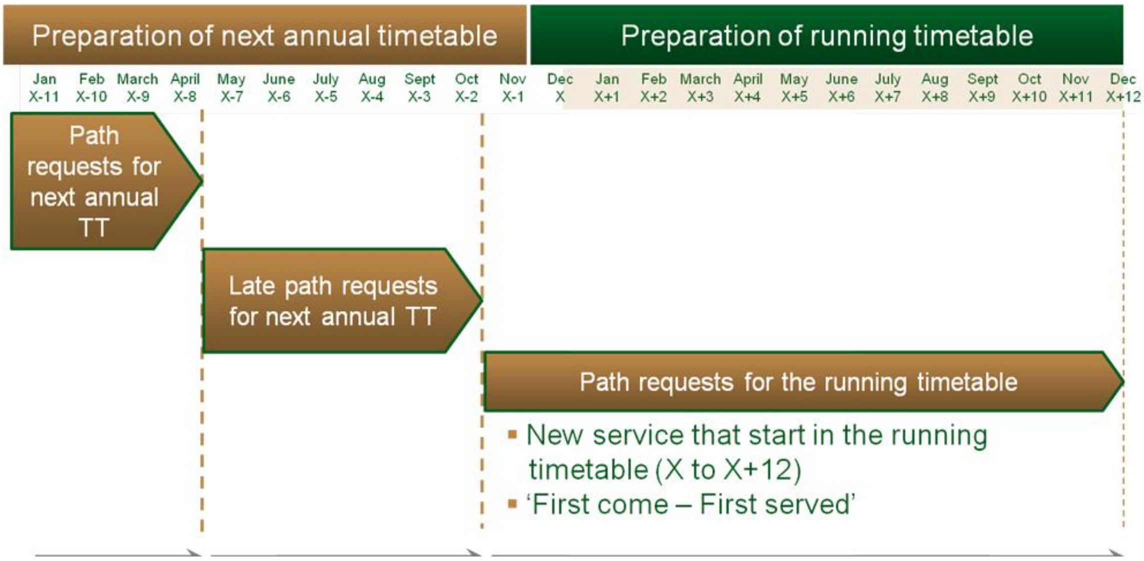

Figure 2: RNE path management processes for the annual and the running timetables (RNE, 2014b).

Path Coordination System (PCS, formerly PATHFINDER) is a web application provided by RNE to IMs/ABs and Path Applicants which handles the communication and co-ordination processes for international path requests and path offers. This tool may also be used for placing feasibility studies. As an alternative, a path request form (paper version) for international train path requests and studies – which is accepted by all RNE members – may be used. The completed form should be sent to one of the members of the One-Stop-Shop network.

Initial requests for international paths in the annual timetable are to be made by the 2nd Monday in April at the latest. By doing so, these path requests will be treated by the IMs according to Articles 18 – 22 of European Directive 2001/14.

Applicants may also request and obtain international paths for the next annual timetable after the 2nd Monday in April, and this until eight weeks or more according to the calendar agreed each year before the new timetable starts. Allocation for 'Late path requests' will be treated in the order in which requests were made, but these will have a lower priority than initial requests that were made on time.

Applicants may also request and obtain international paths during the running timetable. IMs will respond to ad-hoc requests for individual train paths as quickly as possible, and in any event, within five working days.

Feasibility studies make a significant contribution to the efficiency of the path management process. They allow applicants' service plans to be checked for feasibility and, if necessary, to be taken through further iterations.

The feedback from a feasibility study does not represent any binding commitment to the allocation of paths and does not exempt the applicant from applying for a path in the normal way.

In the following sections we describe the planning processes for Network Rail, Trafikverket and DB Netz, i.e. the infrastructure managers in Great Britain, Sweden and Germany, respectively.

2.2 Best practice

In this section, we summarize the development need. The primary viewpoint is from the infrastructure managers' perspective: In what areas and in what ways should the processes and tools be further enhanced to increase the capacity utilization, and what research is thus needed to support this need, or in what areas is there an important gap between research and actual practice and research? This gap analysis should be seen as an introductory analysis, it will be further developed in this work package (WP32) as the "scenarios" are developed (WP32 Task 3.2.3).

The gap analysis span over both strategic, tactical, and operational planning stages, but the handling of larger disturbances in operational planning is treated in forthcoming report from the Capacity4Rail-project. We also refer to the reports from the OnTime-project (http://www.ontime-project.eu) for further gap analysis.

2.3 Strategic aspects

One improvement area is to harmonize the systems used for timetable planning and traffic simulation. There are a small number of commercial timetable systems and traffic simulation systems that are dominating, while the use of in-house developed timetable systems and traffic simulation systems decrease. Still, the IMs, RUs and system suppliers need to co-operate about development, methods and measures to improve processes. There is a need to harmonize the standards, processes and systems used for timetable planning and traffic simulation so that integration across Europe is simplified.

Also, the systems and models microscopic timetable simulation and planning need to be enhanced to handle larger areas, like European networks and European corridors.

There is also a lack of unified understanding of capacity definitions.

2.4 Tactical aspects

For the tactical aspects, the improvement areas are grouped into three parts: the integration between IM and RU, timetable optimization and better timetable planning tools.

Regarding the **integration and collaboration between IM and RU**, the following areas are important to enhance:

- In the timetable process, both the annual and in the ad-hoc process, better information about requirements for train paths, maintenance and punctuality are needed.
- Need for improved handling of flexibility in the ad-hoc process
- Need for better flexibility in the time table to handle bigger disturbances
- Better optimisation methods for planning and utilization of the residual capacity in the timetable planning (saturation problem).

- To improve interaction between IM and RU in both the annual timetabling process and the ad-hoc process. The processes need to be fastened and the methods need to be lean and more automated.
- Freight timetabling must be made too long time in advances. Freight timetabling can be improved by an adhoc timetable planning process supported by efficient IT tools, methods and process.

Regarding **timetable optimisation and on-time performance**, the following is especially important improvement areas:

- Rules and methods how to prioritize trains in the timetable planning.
- Rules and methods how to prioritize trains in operation.
- Methods how to maximise customer satisfaction and handle demand of the on-time performance.
- Knowledge and methods about how to plan the timetable in order to maximise customer benefit, and also to ensure punctuality high on-time performance, robustness and time for maintenance.
- There are no unified criteria for timetabling assessment and evaluation.

Regarding better **tools for timetable planning**, the following is particularly interesting to develop:

- Existing tools for railway planning and timetabling mainly act as a computer aid system without decision support and optimisation functions.
- To develop methods and IT tools that on a microscopic level, support planning of conflict free timetables
- There is a lack of consistent and integrated processes to support the different levels of planning (and associated modelling).
- Tools for stochastic simulation of disturbances to ensure that the timetable fulfil the requirements of robustness and resilience.
- Tools to evaluate and analyse the punctuality and to how the railway system adapts after a disturbance.
- Tools for handling and utilizing flexibility in the timetable, for example with regard to cancelled departures and successive allocation of new train slots.
- There is a lack of commonly accessible data standards /interfaces/ (tool chains).
- Timetable construction and simulation requires significant a priori knowledge.

2.5 Operational planning and control

Models for operational capacity typically deal with re-scheduling of trains, and possibly also other resources (crew and rolling stock). They often rely on models for estimating delays, which is complicated in large-scale networks. Data collection is an important issue for this.

With the availability of fast and efficient algorithms for the real-time optimisation of train traffic, the following challenges arise:

- Models for perturbation management often act on defined regions of limited size (e.g. a station area, a line etc.). The interaction of algorithms over different neighbouring areas represents an important area for future research.
- Data models and data exchange processes for the consideration of RU information in the traffic management need to be further developed.
- Rules and objective functions for optimisation processes need to be further examined and harmonized with track access charging systems and delay penalties between railway undertakings and infrastructure managers.
- Data on real-time occupation of passenger trains, including those from booking systems, passenger counting systems and electronic ticketing systems, should be used for dispatching decisions, especially when dealing with situations of heavy disruptions (large events).
- The migration strategy for optimisation of operation needs to be carefully defined. Especially in the next few years, when algorithms become more powerful, the ways of interacting with the human traffic controllers needs careful consideration, so that algorithms and human can actually collaborate.
- Models for short-term forecasts are important and are still not in use to the extent it could.
- Most models for conflict detection and resolution act are based on fixed –block signalling. Modern CBTC systems already installed on urban and suburban lines are able to operate trains at moving block distance. The algorithms need to be extended to consider this behaviour and guarantee stability of operation.

2.6 Driving Advisory Systems

Regarding Driver Advisory Systems (DAS), there are several mature systems available on the market or in a prototype stage. These systems both optimize the energy and support the traffic flow. An important challenge is the design of the user environment so that the systems provide the driver with the necessary information, in a way that it both supports the driver and makes the driver motivated to follow the advices. A DAS has to have a real-time connection to the train control to make the DAS have an important impact on the capacity utilization. This far, such systems are only used on specific lines, where the necessary supporting systems are available.

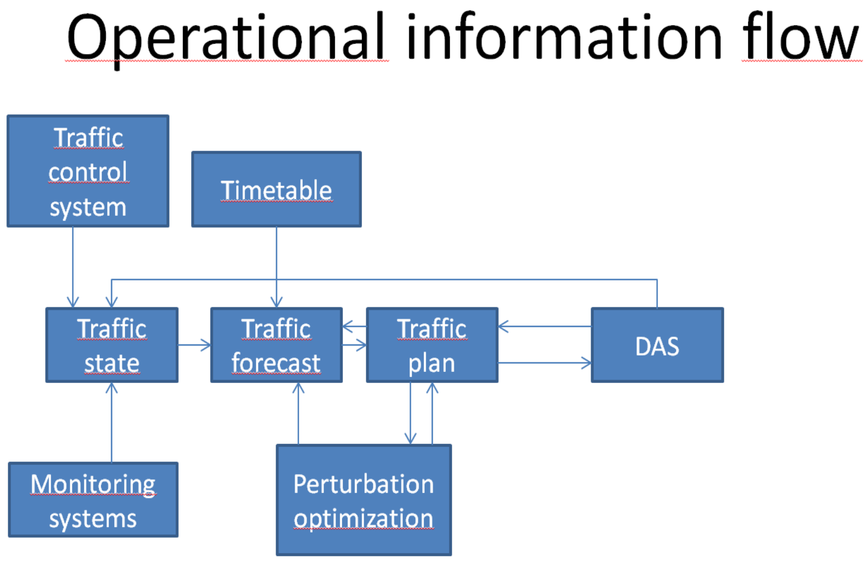

Figure 3: The flow of information in operational planning related to DAS.

The *Traffic State* represents a view of the current momentary situation. The Traffic State is created by the *Monitoring Systems* and data from the *Traffic control system*. The *Traffic Forecast* is the short term prediction (1-2 hours into the future, depending on the scale of the network under consideration) of the traffic situation, given the Traffic State and the *Timetable*. The Traffic forecast may be constructed by a forecasting system, but very often it is up to the traffic controller to make this prediction. Based on the traffic forecast, the controller makes a *Traffic Plan*. The traffic plan includes the actions taken by the controller, to make the future traffic look like expected. To assistance in the creation of the Traffic plan, the controller may have a tool for *Perturbation Optimization*. The perturbation optimization may have an impact on the traffic forecast or on the traffic plan. The traffic plan is in some way communicated (e.g. by speed recommendations or target points) to the driver via the *DAS*, so that the drivers can fulfil the plan.

For an efficient capacity handling on the operational level, all the “boxes” in Figure 3 are dependent on each other and should be developed to a consistent level, e.g. work with the same data model (speed limits, train models etc.). The efficiency of the operational capacity handling is dependent on the completeness of the whole system. Having one “box” in a much less mature state may have serious impact on the positive effects from other “boxes”. In particular, the power of the DAS depends on that all “boxes” are in place.

DAS can provide an important piece in capacity enhancement. While there are rather mature DAS systems, they still have limited usage. The challenge is to make connected DAS usable on more the specific lines. For this to happen, the supporting systems must provide the necessary data on a broader basis. This includes both standardizing the communication between DAS and ground systems, and that the trains management systems should provide the relevant data (like operational timetables, target points or recommended speeds) based on the traffic state and its forecast.

Standardization for communication between DAS and ground systems has been proposed in earlier EU-project (EETROP from Railenergy project (RailEnergy, 2010)). This has not yet been accepted as a standard. Communication protocols have also been studied in the EU-project OnTime (OnTime, 2014).

The other key to make connected DAS used on a broader scale is that the ground systems (or train management system) should provide relevant traffic state data. One crucial data is the traffic plan, and for the plans to be valid, they must be built upon good traffic forecasts.

Further, a good tool for making traffic plans is dependent on that traffic forecasts are correct and that there is good decision support in perturbation optimization tools. Otherwise, the plans may be built upon wrong assumptions about the future state of the system, or in cases of less mature perturbation optimization, there is a risk that non-optimal decisions are taken in cases of perturbations. And further on, a good forecasting tool is dependent on good data from monitoring systems.

A conclusion is that an efficient operational capacity handling and in particular to get full use of the DAS, the whole chain should be in place; from data collection about the traffic state up to communication of driving instructions via a DAS. With one piece missing or in a less mature state, the resulting total system may have much less efficiency and the operational capacity cannot be controlled in an optimal way.

2.7 Miscellaneous tools and software

Available commercial or academic simulation tools consider one or only few of the different national operating rules and signalling systems, and often only in very much simplified versions. Therefore, users of simulation tools often have to make compromises in simulation accuracy, and need to be careful in the interpretation of the results.

The development of open-source software could help overcoming this dilemma, if these are designed in a modular way. Open source software development implementations are driven by the users and therefore, it is possible to match the needs of users in different countries (e.g. IM, RU, R&D) concerning their special view on railways. Then, national systems and rules can be easily integrated in simulation models. Simulation results would therefore better reflect reality than those obtained with existing commercial tools. Such an open-source environment could be a key enabler for future research and application projects in the field of traffic management, as future research and development projects can build upon the same platform (e.g. running time simulation etc.) and proven standardization approaches for data (e.g. RailML). This should allow different optimisation algorithms to be validated in the same scenarios with the same simulation environment. Another key is open data. At the moment, most European infrastructure managers own the data on their network and restrict its use to internal applications. Future research requires open access to data in standardised ways. The Norwegian infrastructure manager Jernbaneverket e.g. published a description of its entire railway network on the internet freely available in the RailML format (http://www.jernbaneverket.no/en/startpage1/Market1/Model-of-the-national-rail-network/, Access: March 31, 2014.

On the contrary to closed-source software, the open-source environment can be maintained by a whole group of people, which is expected to increase the lifetime of software tools because new requirements can be adopted faster. Bug and security fixes can be made by a huge group of experts of both programming and traffic sciences and will be therefore done faster and will provide a good quality of the software product.

2.8 DEFINITION OF MODELLING AND SIMULATION TOOLS

The aim of this report is to analyse “modelling and simulation tools” By modelling and simulation tools we mean advanced decision support tools based on for example simulation, optimisation or analytical models. We also include driver advisory systems (DAS)

For strategic planning (capacity analysis) the tools in scope include:

- Traffic simulation system, based on micro simulation perspective with static information
- Traffic simulation system, based on micro simulation perspective with stochastic information
- Macro simulation systems with static information

The tools for tactical planning (timetable planning) include:

- Timetable planning system with macro simulation
- Traffic simulation system with micro simulation and static information
- Traffic simulation system with micro simulation and stochastic information
- Optimisation models

For operational planning and control, tools that are used for handling smaller disturbances include:

- Traffic simulation system, micro simulation static information
- Traffic simulation system, micro simulation stochastic information
- Optimisation models
- Real time simulator i.e. Hermes
- Decision support modules i.e. pmm
- Driving advisory systems

For operational planning and control with scope to handle larger disturbances, the tools include:

- Algorithms for decision support
- Optimisation model

However, tools for handling of larger disturbances are out of scope for this report.

For Capacity4Rail definitions have been derived for the following key aspects of the vision for the European rail network of 2050**:** ***affordable, adaptable, automated, resilient and high capacity***. This is published in D5.1.1 “*Railway road map – paving the way to an affordable, resilient, automated and adaptable railway*”.

In task 3.2.3, scenarios about approaches to increase capacity and their potential to solve capacity problems are described and reported in D3.2.2: “*Capacity impacts of innovations*”.

2.9 IDENTIFIED MODELS AND SIMULATION TOOLS

In chapter 2.9, we describe usage of simulation and models at different IMs.

Models and tools for all stages of the planning process are included, both strategic capacity planning, tactical planning and operational control.

Commonly used tools include:

- ISOŘ KADR, provided by Oltis Group
- See http://www.oltisgroup.com/
- OpenTrack, provided by OpenTrack,
- see http://www.opentrack.ch
- Samurail, provided by Corys,
- http://www.corys.com/
- Railsys: provided by RMCon,
- see http://www.rmcon.de/
- Viriato, provided by SMA und Partner AG,
- see http://www.sma-partner.ch
- VISION, provided by DeltaRail,
- see http://www.deltarail.com
- TPS, provided by HaCon,
- see http://www.hacon.de/In
-

In Europe there are two dominating commercial timetable systems Reference [MW3]. The systems are Hacon-TPS and ATOS (former Siemens) – Roman. Hacon-TPS are used by: Jernbaneverket Norway, BaneDanmark Denmark, Network Rail United Kingdom and RFF France. ATOS Roman is used by: ÖBB Austria and RFI Italy.

In the OnTime-project (OnTime, 2014) it is proposed that the timetable models can be structured from their scope (microscopic or macroscopic) and method (deterministic or stochastic). This result in the following four different aspects of the timetable:

- **Timetable feasibility**: The ability of all trains to adhere to their scheduled train paths
- **Timetable stability**: The ability of a timetable to absorb initial and primary delays so that delayed trains return to their scheduled train paths without dispatching
- **Timetable robustness**: The ability of a timetable to withstand design errors, parameter variations, and changing operational conditions

- **Timetable resilience**: The flexibility of a timetable to prevent or reduce secondary delays using dispatching (re-timing, re-ordering, re-routing)

3 RAILWAY CAPACITY

3.1 DEFINITION OF RAILWAY CAPACITY

It is generally accepted that railway capacity is an elusive concept that is not easily defined or quantified. Therefore, railway capacity is often understood and defined differently, depending on the context and often in a theoretical way. A starting point for the definition here has been the handbook UIC 406 in its first (UIC, 2004) and second (UIC, 2013) editions. Railway capacity has also been described by e.g. Kontaxi and Ricci (2009).

In UIC406 (UIC, 2004) it says that capacity as such does not exist. Railway infrastructure capacity depends on the way it is utilised. The basic parameters underpinning capacity are the infrastructure characteristics themselves and these include the signalling system, the transport schedule and the imposed punctuality level. Different views of capacity are shown in Table 1 below.

Table 1: Different views of capacity (UIC, 2004)

Market (customer needs)	Infrastructure planning	Timetable planning	Operations
• Expected number of train paths (peak) • Expected mix of traffic and speed (peak) • Infrastructure quality need • Journey times as short as possible • Translation of all short- and long-term market-induced demands to reach optimised load	• Expected number of train paths (average) • Expected mix of traffic and speed (average) • Expected conditions of infrastructure • Time supplements for expected disruptions • Maintenance strategies	• Requested number of train paths • Requested mix of traffic and speed • Existing conditions of infrastructure • Time supplements for expected disruptions • Time supplements for maintenance • Connecting services in stations • Requests out of regular interval timetables (system times, train stops, etc.)	• Actual number of trains • Actual mix of traffic speed • Actual conditions of infrastructure • Delays caused by operational disruptions • Delays caused by track works • Delays caused by missed connections • Additional capacity by time supplements not needed

Ultimately, the capacity of a railway can be considered to be the quantity of passengers and goods that the railway can transport over a given time period. It is often expressed in terms of the number of passenger kilometres per year and freight tonne kilometres per year, or passengers per hour and freight tonnes per hour. This relates to the carrying capacity of the railway and reflects both infrastructure capacity and train capacity. However, while this concept is often used to express the scale of a railway in comparison with other railways or with other modes of transport, it is rarely used in day-to-day railway operations. In practice, railway capacity is often associated more with the ability of the infrastructure to accommodate train traffic. Below are examples of this type of definition.

UIC 406 leaflet (UIC, 2004) was issued after three years of study and consultation within many European railways. Railway capacity is assessed by means of the capacity consumption method as shown in Figure .

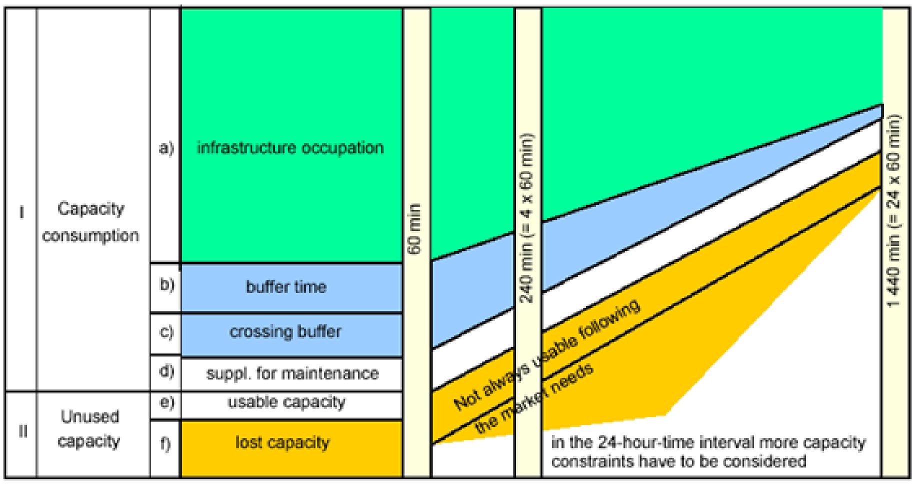

Figure 3: UIC Method of determination of capacity consumption (UIC, 2004).

In 2010 a new project was established to enhance the method and in 2013 the second edition of UIC 406 (UIC, 2013) was finished. There was lots of work with the calculation method.

Railway capacity is assessed by means of the compression method as shown in Figure 4igure3. Compression has to be carried out for the line section and is already done in the Figure 3.

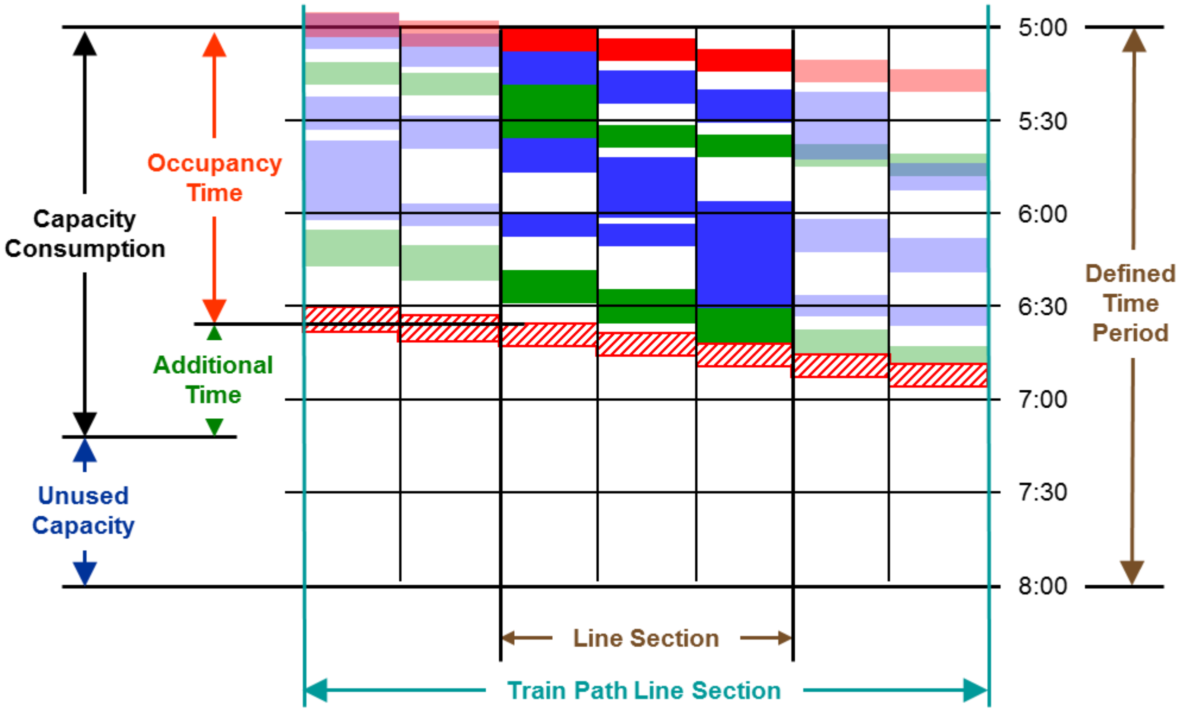

Figure 4: UIC Method of Determination of Capacity Consumption

The formula for determining capacity consumption is as follows:

$$\text{Capacity Consumption [\%]} = \frac{\text{Occupancy Time + Additional Times*}}{\text{Defined Time Period}} \text{ x } 100$$

*) any time value added to secure quality of operation (buffer time, quality time etc.)

The timetable compression method, which reveals the time shares of a non-compressed timetable and of a compressed timetable, can be used to determine the capacity consumption components in the above equation. For compression purposes, all single train paths are pushed together up to the minimum theoretical headway, according to their timetable order, without recommending any buffer time. This compression can be done by constructing a graphical analysis, using suitable tools, or by analytical calculation.

In comparison to the 1st edition of 2004 the 2nd edition of UIC 406 has following news:

- A calculation procedure of a node is described. A node is divided into switch areas and track areas. Compression is made for each separately.
- For capacity calculation of double track lines the calculation procedure was developed. A new term “train path line section” was defined to insert new train paths on marketable sections. The enhanced method can be used to decide when inserting or excluding a train path.

- A procedure for insertion of additional train paths or exclusion of original train paths is outlined (see figure 3 below).

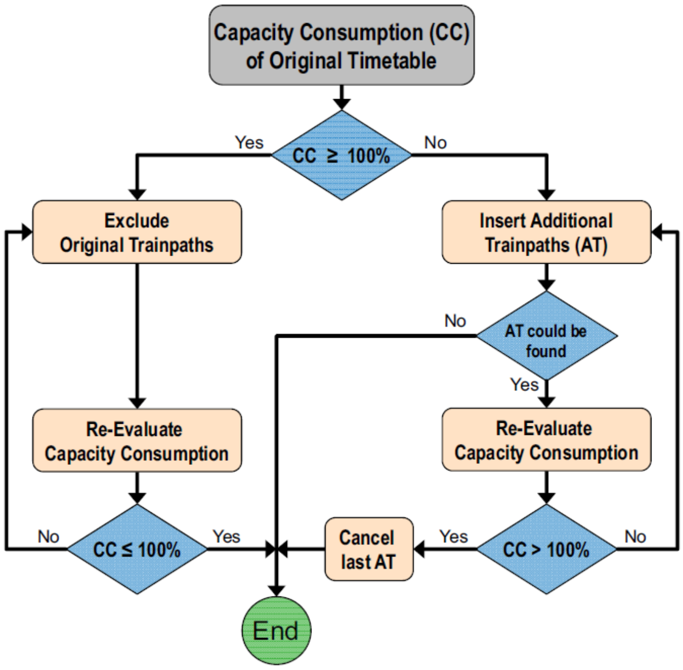

Figure 5: Work flow process for determining capacity (train paths) (UIC, 2004).

There is a current UIC project to assess capacity calculation according to the enhanced method. The project is called ACCVA (Assessment of Capacity Calculation Values) and deals with various specifics of the compression method like the influence of line section lengths on capacity consumption, specification of threshold values for node capacity, stating a handsome procedure for track areas´ capacity calculation etc. The ACCVA project is expected to be finished by the end of 2014.

3.2 Capacity on a strategic level (infrastructure planning)

In Subproject 3.1 Capability trade-offs capacity at the strategic level is wide. The task is to identify the interim steps to achieve the future adaptable, resilient, automated transport network.

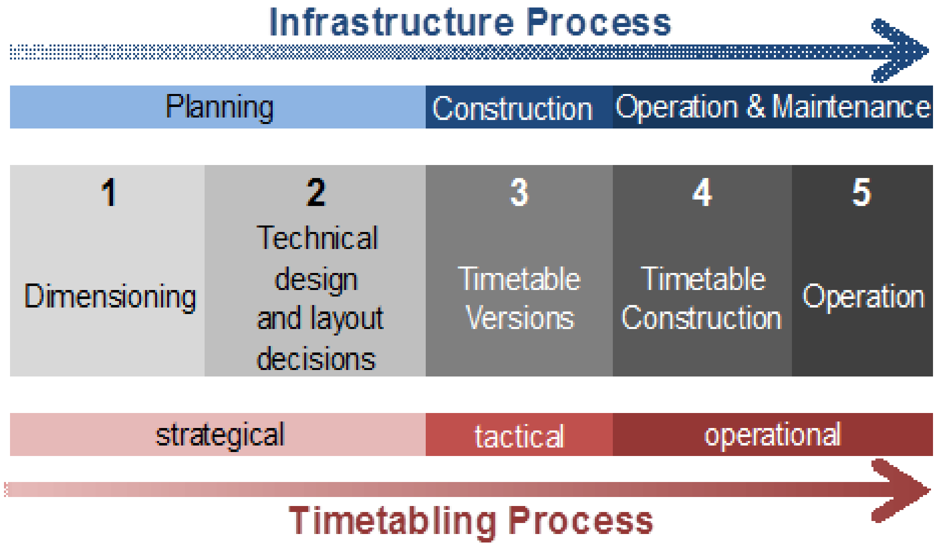

Figure 6: Timeline diagram for infrastructure and timetabling process (UIC, 2013).

In this subproject we have narrowed capacity on a strategic level. Figure 6 depicts a schematic diagram for the infrastructure and timetabling processes. Our view of strategic capacity is based on following text, taken from UIC 406 (UIC, 2013). Examples of models and methods IM use are described in chapter 5.

Infrastructure managers (IMs) offer infrastructure capacity to railway undertakings (RUs). There is traffic demand from RUs, and IMs supply the infrastructure capacity. For planning new or upgrading existing infrastructure, the process normally begins 3-10 years in advance (or even longer). To perform an infrastructure study, the traffic volume has to be predicted.

The traffic volume is based on traffic strategies (market analysis, traffic scenarios, etc.) and the studies are focused on infrastructure and on identifying bottlenecks. The process for tactical and operational traffic planning usually begins 3 years in advance and continues until operations commence. When performing a timetable study, the infrastructure is known. The studies are focused on bottlenecks, timetable structure, timetable alternatives and quality of service.

Infrastructure planning and bottleneck analysis:

- Dimensioning new lines and stations and upgrading existing infrastructure.
- Technical infrastructure planning (additional tracks, switches or signals, etc.) on existing infrastructure.

Timetabling:

- Tactical traffic planning: traffic demand is known; infrastructure and infrastructure restrictions due to construction work are known. Study of different timetable alternatives.
- 1-year timetable application process from RU´s, construction of a timetable. Major maintenance works are known.
- Operational process handling minor changes in infrastructure and/or timetable.

A capacity issue on strategic level are the corridor arrangements. RNE (2014a) simplifies and allows for so-called corridor management. Its role is to achieve “high-level” paths seamlessly crossing the borders, to set single “Corridor OSS” for each corridor, and to harmonise the access rules among the corridors, concerning the “913 Corridors” defined in the 913/2010 EC Regulation.

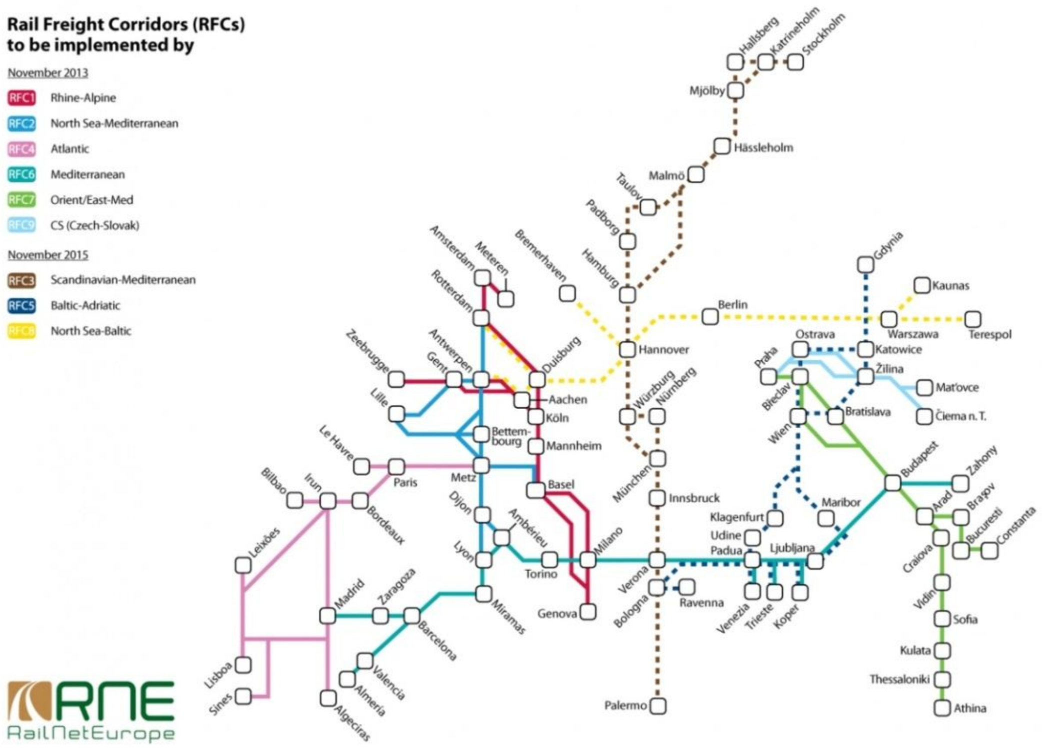

Figure 7: Geographical dimension and implementation schedule of the 9 RFCs.

The Regulation concerning a European Rail Network for Competitive Freight (Rail Freight Regulation 913/2010) entered into force on 9 November 2010. A geographical overview of these corridors is given in Figure 6. This Regulation requests Member States to establish international market-oriented **Rail Freight Corridors (RFCs)** to meet three main challenges:

- strengthening co-operation between Infrastructure Managers on key aspects such as allocation of paths, deployment of interoperable systems and infrastructure development;

- finding the right balance between freight and passenger traffic along the Rail Freight Corridors, giving adequate capacity for freight in line with market needs and ensuring that common punctuality targets for freight trains are met;
- promoting intermodality between rail and other transport modes by integrating terminals into the corridor management process.

4 SIMULATION FRAMEWORKS

4.1 RAILWAY ROAD MAPS AND EXISTING PROCESSES TO IMPROVE CAPACITY

For capacity4Rail projects railway road maps and existing practices to improve capacity have been studied in SP 5 "*Migration*", SP 3.1 "*Capability trade-offs*" and in SP 3.2 "*Simulations and models to evaluate capacity*". This have been documented in D51.1 "*Railway road maps*" and D31.1 "*Review of existing practices to improve capacity on the European transport network*" and SP3.2 MS3 "*Specification of modelling tools and simulations*"

In the Capacity4Rail project the focus should be on

- Freight traffic, especially long distance freight traffic
- But also on infrastructure for passenger traffic and methods for better maintenance of infrastructure.

For SP3 the keywords are *adaptable* and *resilient*, automation is a way to improve capacity. The simulation frameworks is hierarchical planning, with increasing level of detail.

4.2 DEMAND FOR AND SUPPLY OF CAPACITY

Railway capacity can be analysed on various levels and with various time perspective. In this work we distinguish between four levels: strategic planning (more than two years ahead), tactical planning (between 1 day and two years ahead) and operational planning (less than 24 hours ahead). In addition to this we also add driving advisory systems, which are supposed to give instant decision support.

Traffic simulation in general is a model of the market between supply and demand, and any changes will affect both sides. Some effects are instant, and others are slower. Typically measures are taken on the supply side, that is, about what capacity resources there are available, and we want to evaluate the induced effects on the demand side, that is, for the traffic, but the opposite is also possible: What will be the remaining capacity for not planned disturbances, when a certain traffic is planned for.

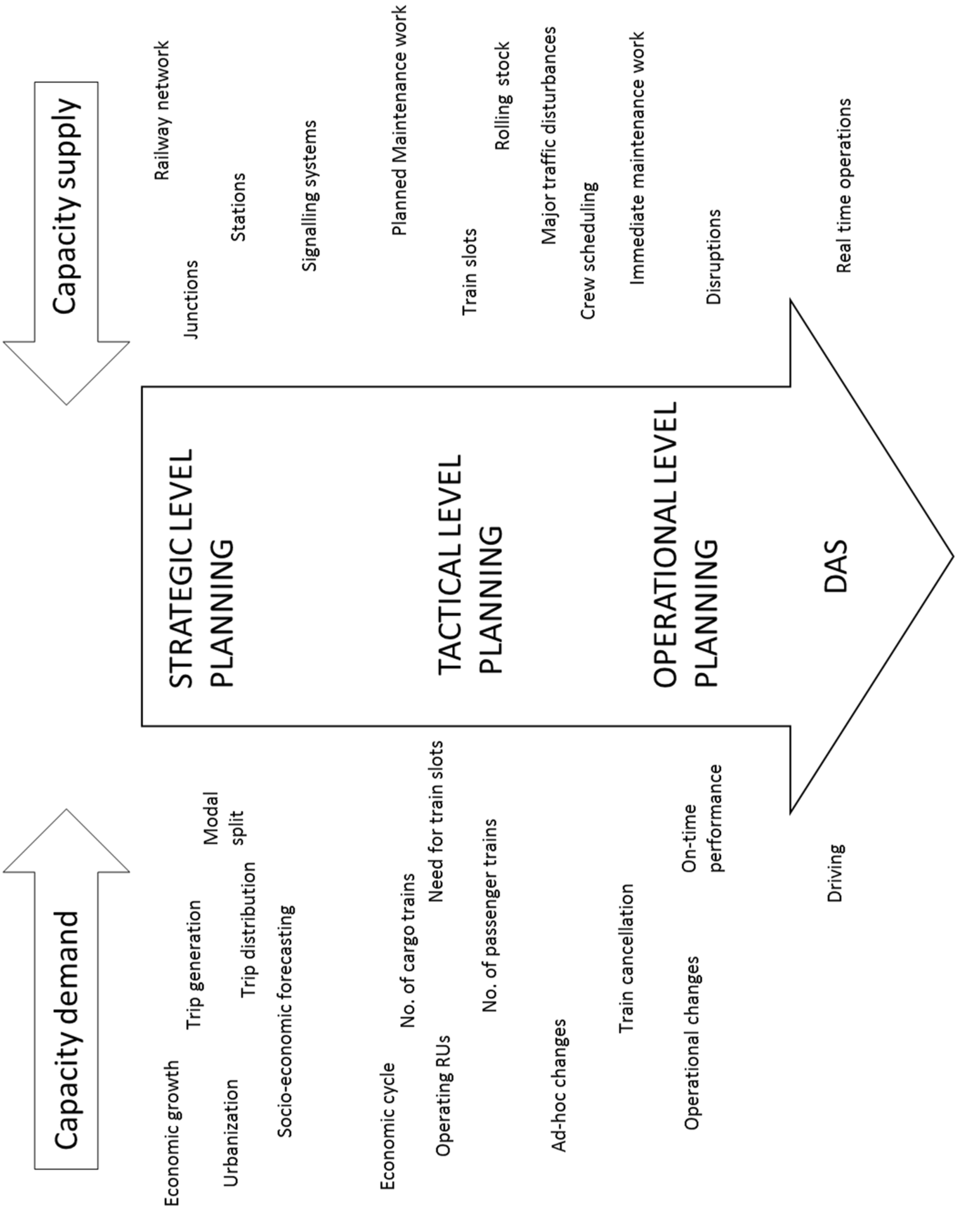

Figure 7: Railway capacity strategic level, tactical level and operational level.

4.3 Generic method to analyse capacity

To analyse railway capacity is a general process and can be described as following. .

1. To define the question to analyse
2. To decide method, IT tool and data sources
3. To plan and perform a capacity analysis

For strategic planning (capacity analysis) the tools in scope include:

- Traffic simulation system, based on micro simulation perspective with static information
- Traffic simulation system, based on micro simulation perspective with stochastic information
- Macro simulation systems with static information

The general process is to be used for capacity analysis. The process can be described in more detail for different type of capacity analysis.

Following example is for traffic simulation with stochastic information

1. Capacity question and project plan

First step is to further describe the capacity question and what analysis to be done. To describe method and to plan the study. How much personmonths and a project plan for activities.

For traffic simulations with stochastic data it is important to have a good management of Data. That means updated infrastructure, rolling stock, timetable and information about disturbances and punctuality. It is important to have well defined methods and IT tools.

2. Simulation of a Base alternative

The first task is to construct your model and to do a simulation of a base alternative. A simulation of a base alternative often includes calibration and validation of the model.

3. Simulation of alternatives

The alternatives to study are depending on the capacity question.

The analysis is often made as an iterative process between the person doing simulation and persons responsible to define the questions and conditions for the study infrastructure, traffic, timetable, priorities and strategies for operation etc.

A traffic simulation can be made for various purposes with different time horizons:

- investments in new infrastructure – new lines i.e. Göteborg region 2028/2035, new high speed network Stockholm-Göteborg-Malmö
- dimensioning of new infrastructure and track layout
- maintenance of infrastructure

- a timetable plan for a region
- Smaller investment to raise capacity new meeting stations, new switches, new signals

4. Results of a traffic simulation

Results of a simulation is quantitative and qualitative results, the result give answers according to the questions task of the analysis. That often include traffic, timetable, infrastructure, capacity utilisations and bottlenecks, infrastructure maintenance aspects, disturbances, punctuality and robustness of the system.

Quantitative analysis and qualitative analysis can be done.

Working tasks are:

- Upgrading infrastructure from traffic requirements
- Analysis of traffic and maintenance
- Analysis of traffic and timetable strategies
- Analysis of capacity increase by better rolling stock, signalling system or improved traffic management systems.

Measurement of a simulation are:

- Passenger kilometres of different journeys
- Ton kilometres of different products
- Journey time
- Handle minor perturbations
    - Punctuality – for trains, stations
    - Disturbances and delay propagation
    - Number of train paths
    - Train paths – time margins
- Robustness of the system
- Capacity consumption, headway calculation and running time calculation

Often simulations are done in an aggregate level and are strategic decision in infrastructure investment, maintenance planning or timetable planning.

The details of parameter input and output is depending on purpose of the study.

An important method for capacity calculation is the UIC 406 method. UIC 406 is to calculate number of train paths with a robust traffic.

4.4 Strategic Capacity issues and locations

At strategic level capacity is depending of the market and need of passenger journeys and transport. From market information Infrastructure managers do forecasts and capacity studies about the need of long distance, regional and short distance passenger and freight transports, and maintenance.

The strategic capacity issues needs to be further described.

The corridor Stockholm – Palermo have been selected for demonstrations in SP3.

4.5 Tactical level models and simulations

We refer to the tactical perspective as planning from 1–2 days up to 1–2 years ahead. Railway planning on a tactical level basically consists of timetabling. Infrastructure is considered to be a given input to this planning. Typical planning questions arisen at the IM are how to construct the timetable, and what trains to remove if an infrastructural resource is oversaturated. Also the RUs are deeply involved in the tactical planning, which for them covers planning of their resources; rolling stock and staff, and also travel demand forecasting in a time-perspective for yield management with demand-responsive tariffs.

Models and simulations for tactical level for further work needs to be decided and to specify research needs and innovations in this project. Decide models and specify research needs (input Ch 2.3)?

4.6 Operational level models and simulations

The operational level covers short term planning, up to 24 hours ahead. Typical planning issues are operational control (dispatching) and disturbance driven rescheduling. Current approaches mostly rely on computing capacity consumption based on the projected train traffic volume and plans and forecasts defined in the strategic or tactical stage. Estimated capacity (consumption) of railway infrastructure depends on the way it is *planned* to be utilised.

Models and simulations for operational level for further work needs to be decided and to specify research needs and innovations in this project. Decide models and specify research needs (input ch 2.5).

4.7 DAS – Driver Advisory Systems

DAS constitutes the last step towards automatized driving and connects online dispatching with driving.

Models and simulations for DAS system for further work needs to be decided and to specify research needs and innovations in this project. Decide models and specify research needs (input ch 2.5)?

5 ENHANCEMENTS OF MODELS AND TOOLS

How much can capacity be increased by improved methods in timetable planning and operational control.

5.1 INNOVATION GAPS IN TIMETABLE PLANNING AND OPERATIONAL CONTROL

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.

    - Develop methods and IT tools that supports to plan timetable at microscopic level that are conflict free.
    - Make better stochastic simulations of disturbances to ensure that the timetable fulfil robustness requirements.
    - Be able to evaluate and analyse the punctuality statistics.
    - 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.

5.2 VISION 2020

Vision Timetable planning 2020

- Improved planning of maintenance work (strategies and processes).
- Further developed ad-hoc planning (new/cancelled trains)
- Improved international timetable planning, more flexible and business oriented.
- Better follow-up of performance, disturbances and traffic quality.
- Better analyses of current and future timetables.
- Developed IT systems, module based standards for deregulated market with several actors.
- Developed methods and processes, IM – RU/other actors.

Vision Traffic control 2020

- Implemented Driving Advisory Systems, DAS.
- Traffic dispatching system with electronic timetable plan.
- Decision support systems for minor traffic perturbations, towards full automatized.
- Decision support systems for major traffic perturbations, improved processes and routines.

- Closed loop, Traffic control ↔ Driver.
- Short-term predictions.
- Better traffic dispatching systems.

5.3 WORK OBJECTIVE FOR WP 3.2

5.3.1 PROBLEM DESCRIPTION AND PROPOSED SOLUTION

The previous sections presented the state-of-the-art in modelling and simulation tools for tactical planning and operational control of railway traffic. The gaps in the existing tools were identified and summarised in a vision for improvement in the coming years. This section presents the focus of research in WP32 of the Capacity4Rail package. The current practice in tactical planning and operational control was analysed from the aspect of the existing and a potential impact of decision support systems on the corresponding processes. Moreover, the current work on the objectives to fulfil the Vision 2020 needs to be analysed in order to avoid multiple parallel approaches to the same problem by the academic community. Therefore, in this section the main direction of the work in WP32 will be described with respect to the existing gaps and the current focus of the relevant research groups from the field of railway operations.

The timetable construction in the phase of tactical planning is often supported by advanced mathematical models and optimisation tools in many European networks with dense traffic. The potential improvements of the existing tools were recognised in the fields of robustness and resilience of the resulting timetables (as defined in Section 2.9). An overview of robustness in railway timetabling is given by Andersson (2014). The feedback from the historical traffic data is recognised as an effective manner to improve the future timetables. Goverde (2010) presented a deterministic model for evaluation of timetables. Numerous approaches followed to extend this approach by considering stochasticity and uncertainty in the phase of timetable realisation. Medeossi et al. (2011) and Bueker and Seybold (2012) presented efficient tools for analysing the timetable robustness. The problem to ensure robustness in critical points is addressed by Andersson et al. (2014). The resilience of timetables was addressed by Goverde et al. (2013).

Further aspects of timetable planning, such as improving processes and flexibility of timetable planning and the standardisations of data formats and databases for the timetable construction, were to a large extent addressed in the predecessor project ”ON-TIME”. The applications and publications on that work are expected in the coming period.

On the other hand, the analysis of operational traffic control practice across Europe, reveals that it still mainly relies on the experience and skills of traffic controllers. The complex tasks of controlling the train traffic in real-time still relies on the manual efforts of the traffic controllers. The limited computer support is provided only by means of the automatic route setting and monitoring systems which does not decrease the cognitive workload for traffic controllers and has little effect on the traffic reliability and performance indicators. The automatic route setting systems set routes for the approaching or departing trains. Any potential conflicts that may arise from the traffic density and minor disturbances are solved by the simple first-come-first-served principle or predefined what-if scenarios. This may lead to suboptimal solutions that can have a negative impact on the network wide traffic conditions.

Monitoring and short-term prediction tools have lately been included in traffic control systems. STEG in Sweden or RCS-DISPO in Switzerland provide traffic controllers with the actual train positions and expected arrival times. This gives the dispatchers more time to decide on the necessary dispatching actions and enables a proactive in contrast to reactive approach to traffic control. However, the actual dispatching decisions are still derived by dispatchers without any computer support.

This comes as a surprise, having in mind that the rescheduling models were in the focus of numerous approaches in the current scientific and academic literature. The majority of the existing tools were focused on developing sophisticated algorithms that can tackle the computational complexity of the rescheduling problem in an efficient manner. The rescheduling problem addressed in the literature can be summarised in the following definition: given the current delays of trains in the network that indicate infeasibility of the planned timetable, find a feasible schedule with the minimum deviation from the timetable. Overcoming the combinatorial complexity of the problem was a challenging task for the development of new algorithms and little work has been done on adapting these tools for application outside of a laboratory environment.

The basic structure of most rescheduling models is that they consider a vast number of potential solutions (schedules). Each potential solution results in a certain predicted value of the objective function and the task is to quickly find the solution that has the (nearly) optimal value of the objective function. The major drawback of the existing approach is that the predictive component of the rescheduling models is not based on the advanced prediction tools (Kecman & Goverde, 2014). In other words, the future evolution of traffic, after a dispatching action that is evaluated, is predicted based on the offline computed process times. The actual traffic condition in the network which may have a big impact on running and dwell times is disregarded. An important aspect is also to include the impact that the dispatching action may have on future process times.

Since the application of rescheduling and dispatching models can have a major positive impact on capacity utilisation and consumption, we aim at bridging the gap between the theoretically developed concepts and practice. The key steps needed to implement the dispatching decision support tools in reality need to be investigated. In order to accomplish that, a set of relevant scenarios is selected that accurately represent the possible environments for rescheduling tools in Europe.

5.3.2 Potential application and impact on capacity utilisation

The positive impact of traffic control on capacity consumption was emphasised in the previous sections of this deliverable. It is intuitively clear that dispatching actions such as:

1. changing the order of trains in case of delays
2. changing the planned routes in case of disruptions

3. cancelling malfunctioning trains

have a positive effect on reduction of delay propagation and travel time of all trains. In that context, the application of sophisticated computer tools that are able to compute optimal dispatching actions clearly has a positive impact on capacity utilisation and traffic reliability.

The proposed enhancements to the existing tools would improve their validity and applicability in practice. The integration of the phenomena of railway traffic and variability of train running and dwell times is important to improve the online character of dispatching models. It ensures that that the models will aim to choose the optimal scenario for future traffic evolution from a number of *realistic* alternatives. This is an improvement compared to the current state of the models where the validity of the considered alternatives is compromised by imprecise estimates of process times which are computed offline. This may severely affect the feasibility of proposed solutions. Therefore, the improvements that we are suggesting represent an important step towards practical applications of dispatching decision support systems which will consequently be beneficial for capacity consumption.

6 SCENARIO FOR IMPROVED OPTIMISATION OPERATIONAL TRAFFIC CONTROL

6.1 INTRODUCTION

This section presents the general ideas for the definition of scenarios that could be used to analyse an enhancement in analytic, simulation and optimisation models for operational traffic control. In that context, a scenario can be defined as a case study that can be used to investigate the contributions of the corresponding models to improving capacity utilisation and consequently the reliability of railway traffic.

Before defining the scenarios, it is important to analyse the criteria and requirements with respect to the potential application of the proposed enhancements to the existing models. The scenarios will be selected from the following perspectives:

- Process perspective – infrastructure, timetabling and operation. Future and historical analyses.
- Infrastructure perspective – cross border, national, corridor, smaller network, line and complex node
- Disturbance perspective – smaller disturbances that can be automated or bigger disturbances that need other approaches

However, the choice of an appropriate scenario may also depend on other factors. Possibly the key factor in choosing the suitable scenario is the actual objective of the analysis that directly follows from the particular model that needs to be tested and evaluated. On top of that, there are practical issues that determine the way a model can be tested for applicability in different networks which may differ according to data availability and quality, properties of the current practice for timetabling and traffic control, signalling systems, and traffic heterogeneity, among other things.

For that reason we maintain the concept of the above mentioned perspectives and add more requirements that indicate the applicability of the defined scenarios. All possible directions from the infrastructure perspective are maintained. However, for this case study the analysis is limited to how improvements in real-time operation and control could influence capacity utilisation.

6.2 REQUIREMENTS FOR SCENARIOS

The first aspect concerns the **size and scope** of the scenario. This comes from the computational requirements for real-life applications. A direct consequence of the significant computational complexity of the railway traffic models is that a trade-off between the levels of detail in modelling and scope and size has to be considered for each case study. Therefore, traffic scenarios have to span from the level of a complex node to the large areas that may comprise several national networks. The different performances of different modelling granularity levels can be presented in order to adopt the appropriate precision for each case study.

Secondly, **the availability of traffic and infrastructure data** on all levels from micro to macroscopic is required to find an appropriate granularity of modelling. It would be very beneficial to determine the dependence of the presented approaches on data granularity, precision and quality. Such analysis could give insight into which data sources are the most appropriate for each level of modelling. Another requirement is to test the value of information. The update frequency of train positions and different spatial and temporal resolution of train positioning need to be considered to evaluate the effect of data quality and accuracy on the developed online models.

The **impact of an existing traffic management** or driver advisory system has been explained in Section 2. Therefore, testing the models in different environments controlled by traffic control systems is necessary. Moreover, the analysis of historical traffic data in order to capture the possible effect that certain dispatching actions or driver advice may have on the process times would be beneficial. Such effects can be quantified and included in perspective capacity utilisation models.

Finally, **heterogeneity of railway traffic** turned out to have a major impact on capacity utilisation and schedule reliability. On top of that, a deregulated railway market imposes a new constraint to prioritising running trains by traffic dispatchers. The concept of equity between train operating companies can have a great impact on the so far typical prioritisation scheme between freight and passenger trains. If such different prioritisation could be captured and quantified for particular instances from the historical data, those values can be used to calibrate the corresponding coefficients of the optimisation models.

6.3 PROPOSED SCENARIOS

Having in mind the requirements mentioned in the previous section we can define for each requirement a possible and desirable set of options:

1) Scope of the case studies
    a) complex node
    b) corridor
    c) sub-network
    d) national network
    e) networks spanning several national networks
2) Granularity of historical data
    a) data from the train detection sections (track circuits)
    b) data from the signalling system (signal passages)
    c) data about realised station events (arrivals, departures, passages)
    d) train event recorder data
    e) GPS data with different update frequency
3) Traffic control systems
    a) no decision support
    b) automatic route setting (ARS)
    c) driver advisory systems (DAS)
4) Signalling system
    a) conventional three-aspect signalling (network specific)
    b) interoperable ETCS Level 2
5) Traffic properties
    a) dominant passenger or freight traffic
    b) mixed traffic
    c) dominant train operating company
    d) multiple train operating companies

Note that scenarios are given as a list of options. In cooperation with the infrastructure managers and train operating companies (TOC's) included in the project the available combination of described directions will be determined.

Figure 8 gives the possible alternative scenarios that could be defined based on the operational constraints and characteristics of railway traffic, data, and infrastructure. Each directed path through the graph represents a potential scenario. The arrows represent the possible combinations of requirements. Notice that there is an assumed equivalence of infrastructure based data sources and GPS for the corresponding levels of granularity: high, medium or low frequency GPS data can be considered.

Two main groups of scenarios can be identified.

1. The first group is focused on the level of a (highly utilised) corridor with heterogeneous, i.e., mixed traffic. Furthermore, a number of sub-scenarios can be defined for a particular existing level of traffic control and for the signalling system. The proposed enhancement and models need to be applicable to different signalling systems. The envisaged shift to the interoperable ETCS Level 2 signalling system requires adjusting the existing models which are based on the conventional 3-aspect fixed-block signalling. Moreover, the proposed models need to be tested in different environments w.r.t. the existing level of traffic control. We have identified DAS and ARS as the most common train and traffic control support systems. Thus the integration with them needs to be considered
2. The second group is related to a subnetwork of the national network. We aim to isolate a heavily utilised and congested parts of the network to evaluate the impact of the model enhancements. Similarly to the first group, the model integration with the existing dispatching and traffic control support systems and signalling needs to be examined.

With respect to the potential geographical reference points for defining scenarios, the proposed freight corridor Stockholm-Palermo offers many possible points of interest that fulfil the requirements defined above. An example of the appropriate case study can be the Swedish southern main line between Stockholm and Malmö. The highly deregulated market and an important role of freight traffic fulfils the criteria to consider heterogeneous traffic of trains operated by multiple train operating companies. The corridor structure of the case study would enable testing of the detailed models on a highly utilized corridor. That would represent a challenging instance for the development and testing of the existing models and decision support systems. The recent advancements in traffic control systems in Sweden represented by the decision support system STEG and driver advisory system CATO also offer interesting options for calibrating the models and investigating the contributions of traffic control and driver decision support systems.

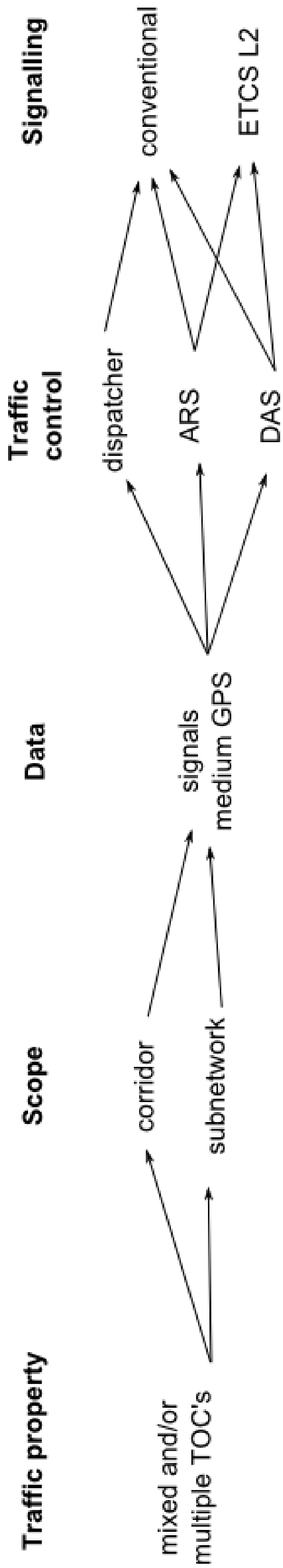

Figure 8: Alternative scenarios for validating the models

7 CONCLUSION AND NEXT STEPS

This deliverable analysed the existing methods for tactical planning and operational control from the aspect of their application for the enhancement of capacity utilisation.

A scenario for improved optimisation operational traffic control was defined.

Improved methods in analytic, simulation and optimisation models for operational traffic control will raise either capacity utilisation (number of trains) or the punctuality.

Next steps are:

- Task 3.2.4 (M10 – M24) Enhancing frameworks for simulations and modelling. To define more scenarios and how to evaluate the scenarios
- Task 3.2.5 (M10 – M24) Initial evaluation of enhancements in timetable planning and operational control. To proceed with the defined scenario Optimisation operational traffic control. To further describe the scenario and specify the innovation and demonstration. To do research.

Operational control of railway traffic was recognised as the critical point in railway systems that requires an improvement. The application of novel computer-based decision support systems was 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 was identified as the main gap. The focus of the future work will therefore be in overcoming the obstacles that are preventing a straightforward application of the laboratory tools in a real-world environment.

A set of potential scenarios that are required to validate the approaches was presented. The scenarios comprise the potential environments where the enhanced models could be applied. Different perspectives for defining the scenarios were considered. The scope and size, traffic heterogeneity, signalling system, the current level of traffic control and the availability of data were recognised as the crucial criteria for defining the scenarios. Finally, the Swedish southern mainline was recognised as the potential scenario that could be an appropriate instance for validation and evaluation of the models.

In the coming tasks, the work on this work package will be focused on improving the rescheduling models for real-time traffic control. The work on adapting the models and algorithms for online applications will be carried out. The way to achieve that is to continuously feed the models with accurate estimates of running and dwell times, as well as the headway and connection times between all trains. The historical traffic data will be used to calibrate the models with the actually realized rather that theoretically obtained process times. The models will thus be kept continuously up to date with the estimates that may vary depending on the current traffic state. That will increase the feasibility of the computed solutions and enable their straightforward implementation.

The first step is to analyse the historical traffic data needed to build the predictive models (Kecman and Goverde, 2014). This analysis should determine the required spatial and temporal resolution of the historical traffic realisation data obtained from the train positioning systems and/or GPS.

Moreover, the value of information from the alternative sources such as train event recorders or smart card data will be considered in order to overcome the existing limitations in the predictive modelling of running and dwell times. The work on this task should result in the functional dependencies of process times on the actual traffic conditions.

Development of the methods for calibration of rescheduling models in real time is a challenging task due to the great combinatorial complexity and strict requirements for short computation times. We aim to investigate a trade-off between the requirement for realistic predictions of the future traffic evolution and computational efficiency of the rescheduling tools. The approach will be validated and evaluated on the case studies based on real-life instances as defined in the scenarios.

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