Final report – Feasibility study on using Socio-Economic Cost Criteria in Case of Capacity Shortages

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Executive summary and recommendations

There is a need to improve and harmonize railway capacity allocation methods in Europe to increase resource efficiency, simplify administration for train operators, and improve transparency, fairness, the fostering of competition and incentives for frugality in the use of scarce capacity.

This report concerns the feasibility of introducing capacity allocation across Europe according to prioritization criteria based on socio-economic valuation. A similar method has been in use in Sweden for over ten years, showing feasibility on a national scale for the annual timetabling process. Feasibility aspects that are new or more pronounced in the TTR process compared to the existing capacity allocation process include Advance planning, the process of allocating Rolling planning capacity during the running timetable period, and synchronization between countries regarding international traffic. These aspects are all topics of the current report, and particular emphasis will need to be placed on all of them in the design of a system in line with the current proposal.

Regarding Advance planning, which is the process before railway undertakers apply for train paths, we find that there is a need for infrastructure managers to valuate the utility of the targeted traffic offered in the Capacity supply. The result of such a valuated traffic offer should, if performed correctly, also attract railway undertakers and should lead to a socio-economic efficient use of available infrastructure.

The capacity for the new product segment Rolling planning is to be reserved during the Advance planning and safeguarded through annual allocation. This capacity is then available for railway undertakers to request during the running timetable period. Here the sizes of the product segments need to be determined correctly to get the best utility from the available infrastructure. The reservation of capacity for future use must be based on well-founded data and valuation methods.

Extending socio-economic priority criteria to a European level raises the question as to whether country-specific values or average European values should be used. Here it should be noted that it is not the total value of the timetable itself that is interesting, it is the conflict resolution effects on the timetable that matters. Hence it is the quotient of the cost parameters that is important, not their absolute values. The quotient of the country-specific cost parameters are fairly similar between countries, leading to small or no differences in prioritization of timetables in different countries. Therefore, prioritization will be fairly equal from country to country when using either country-specific categories or European common categories, the exception being near borders with large absolute differences in country-specific cost parameters.

We find that the method presented in this report is possible to implement and that it has several advantages compared to methods based on administrative criteria in which precedence is given based on predefined set of rules where, for example, a certain type of train service or train path is prioritized. There are, however, development needs of the method that result in a set of recommendations. These are summarized in the following bullet points.

RECOMMENDATIONS

- The proposed valuation framework works for basic valuation of adjustable train-paths that are used in advance planning (referred to as bandwidths in TTR), but there is an uncertainty regarding the amount of adjustments needed when scheduling the final train path in the annual timetable. This amount must be budgeted and cannot be measured exactly in these process steps.

- The parameter values for traffic can be either country-specific or a European average, depending on data availability and local considerations. The decision on which data source to use can be made on a national level. However, it is important to use values in a consistent way for all types of traffic within each country.
- The value of traffic may change when the train crosses the border, i.e. national socio-economic cost values may apply.
- Harmonized operational cost parameter values for Europe should be developed for passenger services, similar to those that already exist for freight services.
- The prognosticated capacity products in the Rolling planning segment should have prioritization classifications. The calculated values of traffic within the Rolling planning segment should be compared to that of the Annual timetable segment, and the amount of traffic allocated within each segment should be updated yearly with the aim to reach equal valuation in the two segments.
- The same rules and parameter values should, as far as possible, be used throughout the capacity allocation process.
- The model should include associations (relations between two trains) in the valuation, including transfers between passenger services and rolling stock circulation.
- As a first step, trains and associations can be valuated rather than passenger and freight flows. To implement a valuation calculus based on passenger/freight flows requires data that is not currently available. This is however an area for future development.
- A generalized form of association between two flows of traffic should be introduced as a new object to be published in the capacity model. This is in some respects analogous to bandwidths as a generalized form of train-paths.
- To make the model easier to understand, manage and adapt to different areas, the model should allow the possibility to define new train classes rather than only using fixed classes of specific train configurations and/or mix of passenger and cargo.
- A development work is needed to properly handle denial of capacity requests ("exclusions" in this report) and large revisions compared to the capacity request, especially for international freight traffic. We propose a direction for such development work based on the cost of using an alternative transport, railway or other transport modes, and, in some cases, the value of goods. We also propose a simplified method to be used in the meantime while the other model is developed.

Content

List of abbreviations used in the report

ASEK	Swedish appraisal guidelines
ATT	Annual timetable
ATTP	Annual Timetabling Process; refers to the TTR phase and/or current practices
BTFT	Block train
CBA	Cost-benefit analysis
CM	Capacity Model; a process step in TTR
CNA	Capacity Needs Announcement; a TTR mechanism
EKG	Effect Cost Generator; a tool used in the Swedish timetabling process
EOPT	Excursion and other passenger trains
EU	European Union
FA	Framework Agreement
FTE	Forum Train Europe
GDP	Gross domestic product
HEATCO	European appraisal guidelines
HSPT	High-speed passenger train
IM	Infrastructure manager
IMFT	Inter-modal train
JASPERS	The European Commission’s appraisal guidelines
LDPT	Long distance passenger train
MC	Marginal cost
NIPT	Night passenger train
OD	Origin-destination
PSO	Public service obligation
RFC	Rail freight corridor
RISE	Research Institutes of Sweden AB
RCPT	Regional commuter train
RNE	Rail Net Europe
RP	Rolling Planning; a product segment in TTR
RSPT	Regional standard passenger train
RTT	Rolling Planning process
RU	Railway undertaking (operator)
SERA	Single European Railway Area; an EU regulation
SPC	Swedish Priority Criteria
TAC	Track access charges
TCR	Temporary capacity restriction
TEN-T	Trans-European Transport Network; transport network referred to in EU policy
TTR	Timetabling and Capacity Redesign; initiative to harmonise and alter timetabling processes
VTI	National Road and Transport Research Institute
VTTS	Value of travel time savings
WLFT	Wagon load train
WP	Work package

WTP	Willingness to pay

1 Introduction

There is a need to develop and harmonize methods for railway capacity allocation, which has been expressed by the European commission, by railway undertakers and by infrastructure managers (IMs), e.g. through Forum Train Europe (FTE) and Rail Net Europe (RNE). This need is based on several factors. Rail's competitiveness needs to be strengthened vis-à-vis other modes of transportation for both economic and climate-related reasons. The gains to society that the railway system generates would be larger with a more efficient allocation, whilst deregulation of railway markets places new demands on the allocation methods. In addition, the timetabling and capacity redesign process (TTR), itself addressing largely the same needs, places new demands on the specific methods used by national IMs.

To make rail a more competitive mode of transport, especially for international traffic, there is a need for less burdensome administration and high-enough priority in capacity allocation in transit countries. This would simplify operations, lower costs and ensure that an attractive service can be offered to end-customers.

There are three broad groups of allocation methods. Administrative methods are by far the most common today, and typically prioritise according to segments by e.g. giving precedence to passenger services over freight services. Socio-economic allocation methods are inspired by common methods to measure the benefits of proposed infrastructure investments, and the priority criteria that are the main topic of this report belong to this group. Methods based on willingness to pay (WTP) include train-path auctions and other pricing mechanisms that aim either to balance supply and demand or to directly resolve conflicts; there is a growing interest for such methods among regulators.

There are several arguments for moving away from administrative methods and towards either socio-economic allocation or WTP-based methods, including efficiency, transparency, fairness, fostering of competition, and incentives for frugality in the use of scarce capacity.

An efficient use of infrastructure is one that delivers most benefits to society. Socio-economic allocation methods aim to achieve this by measuring the costs incurred on train operators and their customers when a train is rescheduled compared to the initial capacity request. WTP-based methods use operators' WTP (and in extension, their customers' WTP minus the operator's costs) as a proxy for the value to them of using a certain train-path.

With commercial train operators playing a large role in rail transportation and generating benefits to society, there is a need for transparency and fairness in allocation of train paths. Timetabling is a complex task and making the inevitable trade-offs often rests, at least to some extent, on the judgment of planners.

New methods can make the outcome more predictable to operators. For example, new allocation methods have the potential to improve the equal treatment of new and small operators, where it can be noted that removing any barriers for new entrants to the market will foster competition.

When capacity is scarce, there should be incentives for frugality. Socio-economic methods for prioritising give higher weight to trains that carry more passengers or more goods of higher value. WTP-based methods give increased track access charges at times of peak-demand, which provides economic incentives to use higher-capacity trains when possible.

Not all allocation methods are equally suitable in all situations and for all market segments. Administrative methods are typically the simplest to organise. Socio-economic methods have an advantage when there is a mix of traffic segments and operator principalship in the same system. WTP-based methods have a large potential when there is a well-functioning competition between commercial, profit-maximising operators, but they require further development.

With the ongoing deregulation of railway markets follows a larger and more diverse set of railway operators that share the tracks, increasing the number of conflicts in the timetabling process. To ensure that competition is free and fair, there is now a larger need for transparent and rules-based capacity allocation methods. For these reasons, the demands on allocation methods are higher than in the past.

The TTR process proposes capacity allocation at different points in time, placing less emphasis on the annual timetabling process (ATTP) than current practice. Sequential allocation will become more common and important, along with the parallel allocation principles that dominate today. These differences compared to current practices need to be adhered to in the development of new methods for national IMs.

Addressing these concerns, the present report looks at adopting a single rules-based valuation procedure that attempts to mimic the priorities made by a social cost-benefit analysis (CBA). This is done in the phases devised by the TTR initiative, from Advance planning, ATT, RTT (the process of determining, reserving and allocating Rolling Planning capacity) and Ad Hoc up to Path alteration. A single model makes for simplicity and manageability. The model deals with traffic heterogeneity more deliberately than many current practices. For instance, a freight train can be prioritized higher than a passenger service in a conflict if the delay (or even exclusion) it would otherwise bear is very large, and timeliness is important for the carried class of cargo.

A model for capacity allocation by priority criteria based on socio-economic principles is currently in use in Sweden and is referred to in this report as the Swedish priority criteria (SPC)[1]. This example provides insights into the feasibility of such a method in a national context. There are however concerns that are not automatically addressed by this example. These include availability of data; national features that place different demands on an allocation method in different countries; issues that are connected to international traffic; and issues that are connected to the TTR project and that new demands it places on capacity allocation.

A model for applying socio-economic criteria in case of capacity shortages is developed based on the procurement assignments from RNE and the results presented in section 3. Results from the model development are demonstrated in section 4.3 and example calculations are implemented in a spreadsheet model (Excel-file) that is submitted as part of this report and some examples are demonstrated in Appendix C.

There are three additional aspects that need to be highlighted before presenting the results. First, it is important to make a distinction between planning and scheduling. Planning refers to the way a task is solved, in industry often referred to as standardized methods. Different methods give rise to different activities or tasks to perform. When implementing a traffic demand, the method can be the route the train path takes through the network, which in turns gives rise to different resources being used. For the IM, resources mean tracks and line segments.

[1] The tool which creates the different priority categories' socio-economic cost parameters of the SPC is called the Effect Cost Generator (EKG).

Scheduling is assigning times to each resource’s tasks, i.e. departure and arrival times to the train path's all individual traversals on the line segments. This should be done in such a way that no resource is overloaded and all requirements of the train path are met, including associations. Deciding the methods (the routes) is therefore a more strategic task and thus plays a more important role in the capacity strategy while scheduling finalizes the timetable once it is decided which route each transportation task takes.

Second, the prioritization model for each process step must be in line with other process steps, otherwise there is a risk that what is prioritized in one step is not prioritized in the next step. Having the same principles for prioritization has been a guiding principle in the work presented in this section.

This report presents results from the feasibility study – commissioned by RNE and FTE jointly – on using socio-economic cost criteria in case of capacity shortages. The report comprises material from two intermediate reports of the feasibility study, including elaborations and extensions, as well as new results. The rest of the report is structured as follows. Section 2 provides a background to capacity allocation based on socio-economic principles, to the SPC that are in use in Sweden today, and to the TTR process. Section 3 considers the development of a socio-economic model for TTR, including subsections on standard unit values, cross-border issues, and, importantly, the alignment of priority criteria with TTR’s various capacity products and process step is discussed. Section 4 lays out the proposed capacity allocation model and describes the experiments made to validate its feasibility. A conclusion of the work is presented in section 5.

We are aware that the European Commission has issued a proposal on the use of railway infrastructure capacity in the single European railway area. However, analysing the proposal and its potential impacts is not part of this feasibility study.

2 Prerequisites for the priority criteria

Timetabling according to prioritization criteria is intended to create an efficient capacity allocation in accordance with the socio-economic framework. A method based on these principles is currently in use in Sweden, which provides us with insights on its functionality in a national context, under current rules. Beyond these insights, a new capacity allocation model for Europe also needs to be based on an understanding of international aspects and of the new requirements brought on by the TTR process.

This section describes the fundamentals that must be considered when designing a timetabling method for Europe that uses prioritization criteria. Subsection 2.1 presents the basic principles of socio-economically efficient capacity allocation. In 2.2, The Swedish Priority Criteria (SPC) are introduced, and 2.3 summarizes aspects of the TTR process that are important for this work.

2.1 Principles for socio-economically efficient capacity allocation

Many of the elements of path pricing should be based on marginal costs (MC). MC refers to additional costs that are added when a train-path is operated, such as power consumption, and can be contrasted with fixed costs, such as financing costs, which occur whether a train is used or not. MC is important in capacity allocation because in many cases it is those costs that are affected by the decisions being made.

The MC of operating a train includes both costs that affect the train operator directly and externalities, which are costs imposed on other parties or society at large. But it does not include transfers of money such as charges, taxes and revenues, since their net effect to society is zero.

Direct costs include time-related costs such as salaries; costs related to rolling stock; and costs that are borne by the transport purchaser or passenger and are passed on to the train operator through lower demand, for instance slower or less robust services.

Externalities include degradation of the tracks (as well as maintenance production costs due to increased line capacity utilization, i.e. rail infrastructure maintenance costs triggered by traffic but not caused by asset damage from traffic – see e.g., Odolinski et al., 2023); noise; emissions; accidents; and congestion. Note that congestion has often not been part of measures of MC in this context in the past, largely because it is difficult to measure and quantify the marginal increase in congestion of an additional (or altered) train-service and its monetary consequences for other parties (yet, there are values reported in e.g., Arup, 2013, Haith et al., 2015, Herrero et al., 2014, Gorman, 2009). This does not, however, imply that such costs are negligent, and could be included when possible.

Transfers are not part of MC. Examples of transfers are track access charges, revenues from ticket sales, and taxes. An important remark is that track access charges are in some countries set to equal (an estimate of) the marginal cost of rail infrastructure degradation. In some situations, it can seem as if IMs include track access charges in calculations of MC, when they in fact include the degradation, not the transfer.

Correct path pricing plays an important role in setting the correct incentives for IMs in relation to international traffic. With increasing demand for long-distance freight transport on rail comes competition for scarce capacity in central parts of the system. The IMs that are responsible for these sections need to allocate track capacity to international carriers if this increases welfare compared to other usages, such as allowing more domestic passenger traffic, according to the criteria. At the same time, enough funds should be retrieved to offset the losses to domestic traffic. This is done if path-prices are equal to a measure of MC that includes the cost of marginal increases in congestion.

2.1.1 Three types of prioritization processes

Prioritisation of scarce railway capacity is necessary when there are two or more conflicting capacity requests, and the operators cannot agree on a solution. It can be done according to either of three broad types of processes. See for example IRG-Rail (2019) for a compilation of current rules and practices implemented in Europe. The first type is administrative criteria, in which the IM gives precedence according to a predefined set of rules, for instance favouring passenger trains ahead of freight trains in a conflict.

The second type is socio-economic valuation and proxies for the same. In a true socio-economic valuation, the outcomes of different solutions to the conflict – prioritising either one or the other operator – are determined according to valuations of both changes in operating costs and in non-monetary factors such as increased travel time. A proxy for socio-economic valuation is a set of rules that are designed to resemble a proper socio-economic valuation as closely as possible. The priority criteria that are the topic of this report are an example of a proxy for socio-economic valuation.

The third type is willingness-to-pay (WTP) based allocation. This group includes auctions of pre-defined train-paths as well as auctions that are only used in a late stage of the timetabling process to resolve a specific conflict. It also includes track access charges that change dynamically to balance supply and demand for capacity.

The process of resolving conflicting capacity requests is extremely important for the functioning of open-access markets. Open access competition increases the number of capacity conflicts, i.e. situations when two or more operators have applied for access to the same track at the same time. The number of conflicts tends to increase with the amount of traffic on the network, the heterogeneity of traffic (mixing fast and slow trains), and with the number of railway operators. As all three developments are likely results of open access competition, its introduction can be expected to substantially increase the number of conflicts.

Because of heterogeneity in traffic, there is no longer any one type of allocation process that is the best fit for all types of traffic. Traffic controlled by public transport agencies can be planned reasonably well through administrative criteria or CBA, given the information necessary to assess the social benefits of alternative timetables. Commercial operators, on the other hand, are generally unwilling or unable to provide the information necessary for carrying out CBAs of alternative timetables, e.g., passenger volumes, fares, profits and marginal operating costs. For commercial traffic, WTP-based mechanisms are often more suitable to resolve conflicts.

2.1.2 Manageability, transparency and efficiency

Allocation methods should be evaluated in terms of how manageable and transparent they are, and the expected social efficiency of their outcomes.

Concerning manageability, the IM's and the operators' resource costs for the capacity allocation process must be reasonable in relation to the gains achieved by more efficient allocation outcomes. Operators also need to understand the process thoroughly in order to make optimal decisions; therefore, it must not be overly complex from their perspective. There is a limit to how long calendar time can be used; in Europe this is constrained by common dates for filing capacity requests and a common first day of operation for yearly timetables. Moreover, the changes in the timetable from year to year must also be manageable, since frequent large changes may cause substantial costs for operators in terms of vehicles and staff.

Allocation methods also need to be transparent, especially in competitive deregulated markets. To uphold competition, barriers to entry must be kept low, including risks associated with the timetabling process. If prospective new entrants to the market cannot foresee the outcome of the timetabling process, or if they fear that incumbents will be favored, they will be less inclined to enter the market. A degree of predictability is therefore required, and transparency is necessary for this. In addition, allocation methods must reliably resolve all conflicts and generate feasible timetables in order not to become reliant on unpredictable ad-hoc solutions.

How well different allocation methods perform in terms of manageability, transparency and socioeconomic efficiency depends on the type of traffic. It is useful to distinguish between traffic with long and short planning horizons, and between commercial traffic (where fares and services are decided by commercial entities) and procured traffic (where fares and services are decided by a public agency, often with subsidized fares). This distinction can be exemplified by three market segments: commercial recurrent traffic with a planning horizon of more than one year; short-term commercial traffic with a planning horizon shorter than one year; and commuter trains which are determined by (and often subsidized by) a public agency and assumed to have a planning horizon longer than one year.

Commercial recurrent traffic operators set prices freely. For passenger transport, flexible and dynamic pricing is common for maximizing profits. Because of competition, operators want to keep data on cost structures, revenue, fares and passenger numbers secret.

Short-term freight traffic has heterogeneous preferences and planning horizons. Freight traffic normally has much lower scheduling costs than passenger traffic; to be offered a timeslot one hour later than requested is often acceptable to operators.

Commuter trains usually have a planning horizon of more than one year. A common practice is for regional or national governments to plan the traffic on a railway line, and then offer it as a time-limited concession to the lowest bidding commercial operator. In Sweden, not only commuter trains but also regional traffic and long-distance traffic outside of the main corridors are operated in this way. Pricing is comparatively inflexible since fares are typically determined yearly for all departures. Total vehicle capacity is typically inflexible because of long lead-times for changing the size of the vehicle fleet.

Commuter train services are often subsidized, for several reasons. One reason is economies of scale in production costs: public transport often has high fixed costs but low marginal costs for serving additional passengers. Another reason is the Mohring effect, which is a positive externality for public transport trips: increasing demand justifies an increase in service frequency, causing waiting times for other passengers to drop. A third reason is second-best pricing of road traffic externalities. A fourth possible reason is an attempt at redistribution. Public transportation is often used more frequently by low-income groups, so subsidies can have progressive redistribution effects. Yet another reason for subsidies could be regional policy. Railway lines that need subsidies often run to or between smaller cities. Subsidizing them may be an effort to transfer funds from large cities to smaller cities or rural areas. The capacity allocation methods in use today often stem from a time when most or all railway traffic was run like procured traffic. That is one reason why they often rely on administrative procedures.

The practice of creating train timetables sometimes relies on the somewhat arbitrary judgement of an IM’s planners rather than fixed rules. This practice is not immediately replaceable in all cases, but it is preferrable to use formal, written rules when possible to facilitate transparency and fairness. Formalization of practices may also benefit international train services, as RUs that operates them are less likely to have strong personal relationships with planners at the IM of a transit country, and the train service may generate few benefits to the local economy compared to domestic traffic.

2.2 The Swedish Priority Criteria

The Swedish priority criteria (SPC) is one example of a socio-economic allocation model that has been used in practice. A brief description of this model is provided below to illustrate some of the fundamentals of this type of allocation method. However, it should first be noted that the SPC are applied as the last step in the dispute resolution process when the previous steps in the coordination of the received RU's applications for train paths have not led to a compromise.[2] They shall not, according to Swedish legislation and regulations, be applied before dispute resolution.

The SPC model provides a basis for prioritising one scheme over another through a selection function. The calculation evaluates a number of parameters (properties) in a scheme and calculates the sum of all evaluations. The scheme with the lowest sum is the preferred solution, as the calculation is based on the generalised cost of the plan.

The value of each train path is calculated based on the distance travelled and the time it takes to complete the journey. Any increase in running time and distance increases the generalised cost of the path. Displacement is considered an inconvenience cost, similar to delay, as the train path is displaced (shifted) from the most desirable departure time, which is assumed to be the one requested by the RU. If these changes are significant, the intended purpose of the requested train path is lost. Two outcomes are possible: either the train path is removed from the timetable, or a significantly different train path is offered than the one originally requested, thus constituting a different service or product.

[2] The criteria may only be applied after the infrastructure has been declared “congested” as a consequence of the coordination process not solving the conflict, see section 4.6 in the Swedish network statement 2024 - Edition 2023-12-15. The IM may then use priority criteria or auctioning as a last resort.

The aim is to value the effects of the tools a planner has at his/her disposal to regulate the requested train paths into a valid annual timetable. The current model assesses the following:

- The distance of the train path
- The duration of the train path
- The displacement of the train path in relation to its anchor point (often its departure time from the origin)

The socio-economic basis for the prioritisation criteria is found the Swedish guidelines on transport appraisal, *ASEK*, i.e., the principles and values recommended to be used in CBA in the Swedish transport sector. This contains both the passengers' and freight transport buyers' value of a transported kilometre and minute, and the (standardised) costs incurred by the operator. Standard unit values that may be used on a European scale are presented in section 3.1 below.

The current model for the SPC also includes costs for associations which considers waiting time and broken associations. Specifically, the SPC considers three types of associations: connecting freight trains, connecting passenger trains, and vehicle circulations. For passengers, the association cost is based on a value of waiting at interchange (from the Swedish transport appraisal guidelines ASEK) which is multiplied by the waiting time and the number of passengers expected to change trains. This type of value is also reported by Wardman et al. (2012).

For freight, the SPC uses the freight's value of travel time saving (VTTS)[3], the waiting time and the expected number of net tons for the interchange. In addition, an operating cost (per net ton) is included in the cost for the association and is calculated with respect to the train's waiting time that the association implies – in other words, a cargo association implies a vehicle association. Note that the operating cost is not included in the calculation of passenger trains' costs for associations since there is no extra operating cost when passengers disembark and wait for the connecting train.

There are also costs for broken associations which is based on the minimum and maximum waiting time for an association. For the SPC, these thresholds are submitted by the train operator. Specifically, the association is considered to be broken if the (proposed) timetable implies a waiting time below the minimum value since the interchange cannot be carried out for practical reasons. The association is also broken if the waiting time exceeds the maximum value, given that the train operator considers the cost to be too high. In both cases, a cost is calculated. For both passengers and freight, this cost is based on the frequency of trains and the waiting time this implies.

Breaking the third type of association, a vehicle circulation, also has a cost since this influences the train operator's use of its vehicles. Specifically, the SPC uses the vehicle's investment cost (including one renewal cost), depreciation period, rent, and utilisation rate (number of days per year) in order to calculate the train operator's cost per day for the vehicle during its lifetime. This cost is considered to be equal to the cost for a broken vehicle circulation and is calculated for three different vehicle circulation categories.

In summary, for passenger train associations, the model requires values of waiting at interchange for passengers, which are multiplied by the expected interchange time. Passenger train frequencies and their implied waiting times are required to calculate the costs of broken associations – that is, when the association is either too short or too long. The passenger train cost per day (based on investment and renewal costs, depreciation period, rent and utilisation

[3] Also referred to as value of time (VOT) in the literature.

rate) is calculated for broken associations that consider vehicle circulations. For freight trains, the cost calculations for associations make use of the VTTS for freight. One important difference compared to passenger trains is that operating costs per net ton are also included in the cost for waiting at interchange. The cost of broken associations is based on freight train frequencies, that is, the time until the next departure. A broken freight vehicle circulation is calculated in the same way as for passenger trains.

2.3 Timetabling and Capacity Redesign process, TTR

This section describes TTR, the process's components and the process steps. It forms the basis for the description in section 3 on how a method for capacity allocation that uses socio-economic prioritization criteria can be adapted to TTR.

The TTR process is described in several documents (ForumTrainEurope/RailNetEurope 2021, ForumTrainEurope/RailNetEurope 2022a, RailNetEurope 2022b,c) and starts five years before the timetable period begins, i.e. at X-60. Advance planning refers to the process up to capacity request for the annual timetable, i.e. Capacity strategy, Capacity model, and Capacity supply, see Figure 1. Advance planning ends with the event Application for capacity. After this event, the annual timetable is planned, negotiated and finally fixed. The process of allocating Rolling Planning requests starts at X-4 for the running timetable period and progresses during the whole timetable period in a rolling planning manner, as do the Ad hoc allocation of capacity.

During the process step of TTR's Advance planning, the traffic volumes are gradually refined and transformed to train paths, but not all at the same time and not even in the same process step. They could be finalized in Capacity supply, ATTP, RTT (the process of allocating Rolling planning requests) and in the Ad Hoc process.[4]

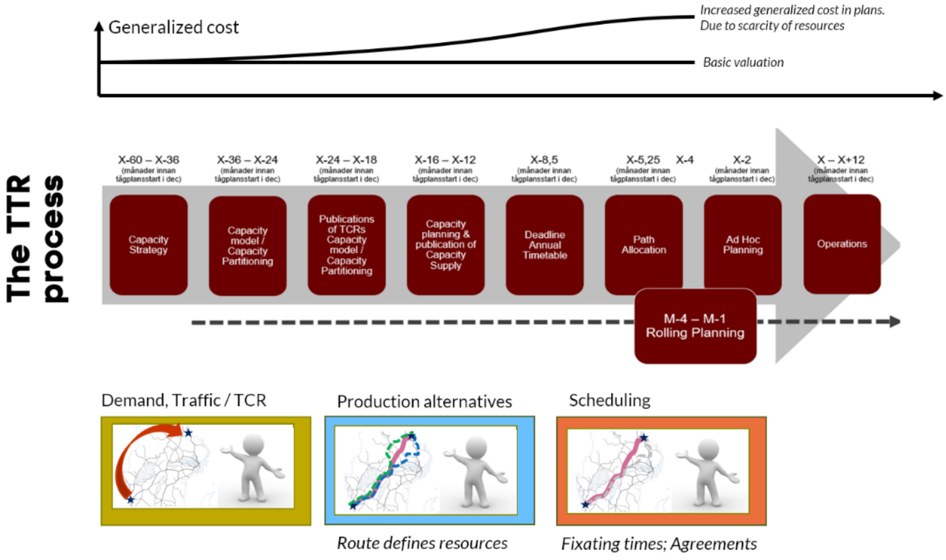

Figure 1. The TTR process with planning and scheduling incurred generalized cost as a function of process time

2.3.1 Production target

Through the Advance planning, information is gradually refined and the uncertainty about various assumptions decreases. During the Advance planning, IMs have not received any

[4] We distinguish between the process of allocating Rolling Planning products and Ad Hoc capacity since Rolling Planning is product segment while Ad Hoc is more used for deviations.

applications yet (with the exception of restrictions from Framework agreements and train paths allocated in RTT from previous years). The prognosticated or tentative traffic that IMs plan for during Advance planning must be based on some notion of what is to be produced on the infrastructure. This intended traffic is referred to as the *production target* in this report, by analogy with industry terminology. The production target describes the services that are foreseen to be produced on the railway infrastructure during the timetable period to which the Advance planning applies. This underlying 'plan' for future traffic forms the basis for decisions about what is reported in the process steps. There might be alternative scenarios/production targets as the traffic prognosis and the information available is uncertain to various degrees.

2.3.2 Capacity objects

The following sections described some of the available capacity objects, as described by TTR (ForumTrainEurope/RailNetEurope 2021, ForumTrainEurope/RailNetEurope 2022, RailNetEurope 2022b,c). Instances of these capacity objects are the ones for which a socio-economic valuation should give a value.

2.3.2.1 Prognosticated train paths, bandwidths, pre-planned paths

The production target is formulated with various capacity objects that evolve over time. It can be train paths, bandwidths, capacity reserved through regions with dense traffic etc. The demand for transport on railway is in long term prognosis represented by volumes which have to be transformed into prognosticated individual transports on the networks, expressed as Origin-Destination transports (OD-pairs), possibly with via-points and with a prognosticated departure time (or *anchor point* somewhere along its route). This object is in the report often referred to as a *prognosticated train path*. We use the term 'prognosticated train path' even though it does not necessarily have a fixed route yet (could e.g. be rerouted around TCRs) .

The prognosticated train paths have different realisation probabilities and timing probabilities in the timetable. Those with high probability and timing certainty, i.e. with small time windows, should as a result of the Advance planning be partitioned to the annual timetable, while other traffic demands are placed in Rolling Planning capacity or residual capacity for later allocation during ATT or the running timetable period.

The earlier in the process the valuation is made, the more uncertain are various properties of the transport: the number of passengers or amount of goods that can be predicted to use the transport, the vehicle types, the weight of the freight train etc. To acquire data and, to some extent, forecast other data is equivalent to do sales forecasts in other industry sectors. RUs most certainly do such activities today. With TTR it follows that IMs have to a greater extent acquire models and tools to be able to understand how the production target is to be formulated in order to match RUs' upcoming applications at X-8,5. IMs main task is to make the best usage of the infrastructure according to the society's needs.

As the departure and/or arrival of the prognosticated train path is uncertain, this uncertainty must be part of IMs representation of the prognosticated train path during Advance Planning. In this report this uncertainty is represented as a *time window* which is applied to the prognosticated train path. By this operation a *bandwidth* is born. This capacity object states that there should be room for a train path, with certain quality requirements fulfilled, inside the time window. The bandwidth constitutes the available room for adjustments for the prognosticated train path where it is still valid with respect to the assigned transport task (the assigned demand). Outside the time window, the prognosticated train path is not valid anymore but could still be useful as another product/service.[5] The point is that the time window gives the available room for adjustments[6].

More adjustments due to resource scarcity must be made through the different process steps in Advance planning as the plan gets more and more finalized, and the bandwidths are gradually transformed to *train paths*. In the Capacity supply these may be preplanned catalogue train paths, meaning that they are already planned and RUs may apply for them by their identity/name. Other train paths are formed from bandwidths and/or other capacity objects when creating tailor-made train paths after RU[7] application.

It is only in connection with the capacity supply that catalogue preplanned train paths are communicated with RU (with exception of Framework agreements which can in principle contract more or less fixed train paths). These need to be planned together with each other, but also with the bandwidths that represent the reserved capacity for identified Rolling Planning traffic and Ad Hoc. This means that the valuation methods used during Advance planning must be comparable between capacity object as well in the different process steps.

2.3.2.2 Framework agreement

Framework agreements are signed "separately" from the various process steps in Advance planning. Framework agreements are not part of the TTR process as such but may limit the available possibilities to find solutions when planning and scheduling the various capacity objects in all the TTR’s process steps. The Framework agreement may state different properties that may affect future scheduling processes. Since these are not signed as part of the TTR process and since breaching the agreements may be costly, it is still important that the framework agreement is in harmony with this process. It is therefore important that the framework agreements are signed so that the utility of the future executed traffic (the number of years the framework agreements consider) as a whole is maximized. It would therefore be natural if a socio-economic analysis is made by IMs before any framework agreement is being signed, in order to predict the impact of the framework agreement on the delivered services to society.

2.3.2.3 Associations

Associations are directed relationships between train paths that relate them to each other. Associations implement different relations between trains, such as passenger flows, switching of wagons and shared vehicle resources such as locomotives between trains.

The earlier in the process, the vaguer it is how an association is to be represented and if it is valid in different scenarios. For example. In the capacity model, where volumes of traffic are handled, the association is more of a requirement to be implemented later when the actual train paths are scheduled.

The associations are not published as part of the capacity model (RailNetEurope 2022c) but is an important object in the underlying traffic network built up to cover the forecasted transport demand. The value of the associations affects the prioritization of the volumes of traffic in the

[5] This changed train path may of course have a justification too, but it will not attract the same demand any longer as the prognosticated train path has moved too far in time.
[6] Adjustments are often referred to as wait times and running time supplements in this report as this is how planners refer to additional time allocated to train paths in order to create a conflict-free plan and add buffer time to enable a train to make up small delays.
[7] We will often use the term “RU” when, formally, the correct term is “Applicant” as it is not only operators that apply for train paths, e.g. regional traffic managers and large industries

capacity model. See earlier discussions in the first intermediate report (Aronsson, Broman, Odolinski 2024b).

Associations between train paths do not consume any infrastructure resources (except for vehicles on station/yards waiting for the next transport) as such and are therefore not a direct part of the partition of capacity into ATT and Rolling planning segment done in the Capacity model. However, we see a need of an association-like object that IMs can publish, informing RUs of e.g. foreseen connection times (min/max) between important passenger/cargo flows at stations/yards in the network. This “abstract association object” is similar to a bandwidth in that it states the existence of an association without expressing the actual association.

2.3.2.4 Temporary Capacity Restrictions

Temporary Capacity Restrictions (TCRs) are capacity objects where the capacity is not available for traffic. A TCR may be major or high, quite large works with large impact on traffic, and medium or minor with less impact on traffic.

An important use of the socio-economic model is then to valuate different scenarios for the configuration of TCRs, as they may interact in various ways: some may be advantageous to perform simultaneously, some should preferably be performed at different times. TCRs may be valued by their real costs, or by a generalized calculus taking note of the important cost factors for TCRs (repetition of work patterns, pre- and post-work activities, etc.). It is outside the scope of this feasibility study to form such a socio-economic calculus for TCRs.

It is however important to note that the scheduling freedom for the major and high TCRs is earlier in the previous process steps, as these TCRs are large and require much internal planning. Hence much of the configuration of the TCRs (which should be made simultaneously and which should be performed at different times) must be decided early, meaning that it is the IM’s production target that must act as traffic scenario to test against different TCR configurations, both as single TCR objects but also the combined effect of all planned TCRs. Therefore, it is important that good traffic solutions for the complete ATT can be inherited from the Capacity model to the Capacity Supply process step. A better availability to open routes through the (international) network was one of the early main goals of TTR.

2.3.3 Planning method in Advance planning

For the production target to be valid, it must be producible on the infrastructure. Thus, a planning method is needed for this early stage in planning that ensures this. For the plan to implement efficient production, a prioritization model is required so that decisions made when planning lead to efficient use of the infrastructure as well as efficient production. Thus, a valid prioritization method based on a valuation calculus is needed that prioritizes the use of the infrastructure in case of congestion, i.e. if everything cannot be produced exactly as wished.

There are various planning methods that can be used to plan railway traffic at different steps in the capacity allocation process. The time characteristics of prognosticated train paths have varying degrees of certainty and for that reason many of them are represented by other capacity objects than train paths, often including a time window.

Note that the term “resource conflict” can be interpreted differently in different process steps in the TTR process, and also be stated in different ways by different IMs. The socio-economic calculus is not dependent on the conflict resolution model, it is only dependent on that such a model exists. Specifically, it is rather the details known and available in different phases of the capacity allocation process that affect how a socio-economic calculation model can be constructed for that phase. The demonstration of the proposed socio-economic model is described in more detail in section 4.3 below.

We have in the first intermediate report outlined the basics of an alternative planning method for basic allocation of line sections of the infrastructure (Aronsson, Broman. Odolinski 2024b). This method is based on the occupancy area in a Marey graph (timetable graph). The advantage of this method is that it does not explicitly resolve resource conflicts[8] as a conflict-free schedule of train paths. Instead, the method is a guard against overallocation of the infrastructure: the accumulative resource consumption is not allowed to break the capacity limit. If this requirement holds, there are scheduling solutions to be found later when the more detailed schedule is planned. The method does not create a final timetable; it is an "existence proof" or "argument" for that there exists conflict-free schedules later when the actual train paths replace bandwidths and other more abstract capacity objects.

An example of the results is the first example in section 4.3.2 where the areas of each priority category (represented by colours) within each one-hour period gives the size of that train type's resource consumption in a Capacity model.

But whichever planning method is used at this stage of the capacity allocation process, a valuation needs to be made of the traffic that is the basis for the volume accounting in the capacity model. We have in the study checked that our example allocation method is also able to use the socio-economic valuation calculus to prioritize one solution over another.

2.3.4 Process steps in TTR

Since uncertainty of data increases with the time distance from the start of the running timetable period there are reasons to utilize generalized and more abstract procedures in the Advance planning of TTR, for example the planning method mentioned previously in section 2.3.3. Such a simplification could be to initially classify the transports in only the main train types such as freight, long distance passenger traffic and regional traffic. Later, as more information emerges, these main classes and their transportation tasks are gradually refined. A good rule of thumb is to not plan with more details than are available. Having too many details too early will lead to more replanning and rescheduling which generates more planning time in man months and calendar time, as well as lost overview of the assumptions the plan relies on, such as internal dependencies in the plan. One of the great advantages with TTR is to let the process steps of the Advance planning guide the level of details in the planning, thereby increasing the overview and making decisions on the right level of detail.

2.3.4.1 The Capacity Strategy

It is an advantage if the first version of the prognosticated traffic is available in the Capacity strategy (CS) as major and high TCRs are planned and incur rerouting and delays/prolongation as well as shortening of future train paths. The content of the production target is limited to volumes of traffic (in case there is no Framework agreements), and "tools" to adjust the traffic could be rerouting, thinning of regular traffic patterns[9] etc. The TCRs leads to increased generalized costs for traffic. Capacity strategy mainly focuses on volumes of traffic and principal decisions about rules for later planning and scheduling, e.g., alternative routes through the network. The traffic volumes are more or less single entities in the sense that individual paths within the volumes are not handled separately.

The main result from Capacity strategy is how traffic volumes are being prioritized, routed, and restrictions on their scheduling in later steps, i.e. how the capacity allocation strategy shall be performed.

[8] Which for single-task assignment on resources means order all train paths in time on all line segments.
[9] See appendices A and B.

2.3.4.2 The Capacity Model

The aim of this process step for the traffic is "… to show, harmonize and discuss more in detail the expected volumes of capacity consumed by each commercial market segment"[10, 11]. The Capacity Model (CM) reports the intended use of the capacity and refines the Capacity strategy result. CM start at X-36 and ends at X-18. The IM is not obliged to report which traffic line (Origin-Destination or other descriptive specification) the partitioned capacity in the capacity model per line segment is to be used, only how much capacity is reserved for each product segment. This partition into product segments is the main result of the capacity model regarding what is communicated to RUs and others.

The CM reports an intended resource use plan showing the traffic volumes per time frame on each line section for a typical day, usually one-hour periods. The traffic volume should be partitioned at least into passenger traffic, freight traffic, other traffic and TCRs. Information is collected from CNA (Capacity Needs Announcement, a process step event in Capacity planning), previous years' known stable traffic, estimation and IMs' own hypothesis of future market developments, multi-annual Rolling planning requests, framework agreements etc.

Different trade-offs and partitions are formed when creating the CM, where traffic is partitioned into different segments and layers, see (RailNetEurope 2022c). The production target plays an important role in making a well-balanced partition in the CM. It is the production target that is the argument for how the partitioning of the capacity is performed on the line sections. The result of the CM is a prioritized use of the available capacity, expressed in the capacity partitioning into capacity products and given in different layers.[12, 13]

In the production target associations can be introduced and verified to hold between the prognosticated train paths (depending on the planning and scheduling method the IM has chosen). Associations are also uncertain if they hold or not as all prognosticated train paths' timings are uncertain (except possibly inherited Rolling planning train paths from previous years).

Essentially, it is the line capacity and its use that is described in TTR's handbooks and documents, issued within the framework of TTR. How resources such as operational locations, stations, railway yards, and platforms should be used are not described in the same detail. It is not uncommon for these resource types to limit the efficiency of traffic and productivity of the infrastructure.

There may be alternative scenarios/production targets where different options have different probabilities. If so, the reported capacity model needs to take these alternatives into account as well as their respective probabilities of being realised (by RUs applying for the capacity). The capacity model does not need to specify *how* different parts of the capacity model will be used later in the process. Any suitable train path may use the capacity model "slot" as long as it fits the published product types and layer descriptions, e.g. any high-speed train that fits into a high-speed train path slot may be selectable later in the process, although the IM may have made the model based on another particular scenario (or several where the merged properties from the different scenarios showed that there ought to be a high-speed slot there).

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[10] We interpret "commercial" as traffic with a traffic task, i.e. also subsidized traffic.
[11] RNE, Procedures for capacity model, version 3.
[12] There are 5 different layers: layer 1 - train type: passenger, freight, service trains, TCR (mandatory), layer 2 - national/international traffic (mandatory), layer 3 – Basic train categories, layer 4 – basic parameters for the trains (depending on passenger or freight) and layer 5 – "product" 8i.e. ATT request, RP request etc).
[13] (RailNetEurope 2022c), page 18.

As a result of the capacity model, those prognosticated train paths with high probability and stable temporal location, i.e. with small time windows, should in the capacity model be partitioned to the ATT segment as preplanned catalogue paths, while other traffic is placed either in the residual capacity for allocation during either ATTP or in RTT, or as other capacity objects for later allocation during the running timetable period. It is this partition into the ATT segment, the Rolling Planning and AD Hoc segments and the TCR segment that is the result of the CM process.

Capacity Needs Announcement, CNA

Capacity Needs Announcement, CNA, is an CM-internal process step taking place between X-24 and X-18. The applicants can indicate their capacity needs to the IMs before X-24. The IMs analyse the needs and at X-21 the IMs may contact RUs for consultancy, particularly for capacity needs where capacity is scarce. This consultancy phase is due at X-18. From X-18 to X-11 IMs designs the capacity partition of the available capacity into the product segments ATT segment and Rolling Planning segment and TCRs capacity allocation.

CNA is an important event where RUs and IMs exchange information about predicted capacity needs and intended use of available capacity.

Associations in the Capacity Model

Currently there is not a generalized association object stating generally the minimum/maximum association time in e.g. passenger flow or resource association (vehicle/personnel). There is however such data available on an authority level, e.g. regional traffic often has general rules for larger flows of passenger between trains and/or other modes of transport. We therefore see a need for a generalised “association object” on the same level as bandwidths to state that associations implementing flows are requested from later process steps in the capacity model. We also see a need for that in the CNA.

We also see a need for an association-like object to state the importance of flows emerging/leaving the railway traffic. These associations would typically be used to state important dependencies to other transport modes (ferries, busses etc.), terminals (open/closed hours etc.), passenger termination (i.e. amount of departing persons/arriving persons at cities) etc. These association objects are particularly important when submitting CNAs but also states, e.g., the importance of trains having commercial stops at stations. These association-like objects also play an important role when publishing the CM in order for RUs to know what they may count on when performing their planning tasks and submitting applications later in the process.

2.3.4.3 The Capacity Supply

The aim of the Capacity supply is usable capacity for each purpose (passenger or freight)”[14]. The Capacity supply is the last step of Advance planning of the TTR process before RUs apply for capacity. The capacity of the different capacity objects is visualized for the complete timetable period:

- preplanned catalogue train paths;
- capacity for tailormade train paths;
- bandwidths (RP paths, both inherited from previous year and safeguarded reserved capacity); and
- capacity for framework agreements.

[14]RailNetEurope, TTR fact sheets - Complementary information document of the Timetabling and Capacity Redesign project, version 2.0, https://rne.eu/wp-content/uploads/2022/10/ttr_fact_sheets_v2.pd

All major, high, and medium TCRs as well as TCR windows shall be included in this process step.

In Capacity supply, the uncertainties have decreased. Preplanned paths are to be conflict regulated and must also be provided with suitable small adjustment possibilities in order for them to be scheduled efficiently together with bandwidths and the tailor-made train paths during both the ATTP and possibly also during RTT. These adjustments include shifted/rearranged wait times and runtime supplements, running time prolongation as well as changed displacements.

The Capacity supply builds further on the CM. The CM is given for a typical non-TCR day (as a minimum) while Capacity supply is given for the complete timetable period (each day) and with details regarding the orders of the trains, available residual capacity as well as bandwidths.

Although preparations for TCRs have begun already in the Capacity strategy, it is in the Capacity supply their effects will finally be described and the effects communicated.

There might still exist more generalized capacity objects such as bandwidths for Rolling Planning capacity reservations and Residual capacity for tailormade train paths in ATT, RTT and in the Ad Hoc process. The planning and scheduling method during Capacity supply must be able to handle all these different capacity objects and safeguard the Rolling Planning capacity objects.

2.3.4.4 Annual timetable allocation

The process step Annual allocation of capacity (ATTP, annual timetable) starts at X-8,5 with the Applicants requesting capacity in the form of catalogue trains paths or Residual capacity in the ATT part of the available capacity (i.e. not in the Rolling Planning or Ad Hoc Capacity segments) described in the Capacity supply. The ATT process and methods should safeguard the reserved Rolling Planning and AD Hoc capacity.

The result of the ATT process step is train paths scheduled conflict free together with the safeguarded Rolling Planning and Ad Hoc capacity (products).

2.3.4.5 Rolling planning allocation

Train paths in the Rolling Planning (RP) segment are allocated during the running timetable period in a rolling planning fashion. Within the RTT, train paths are allocated to the RP segment which was safeguarded through the Capacity supply and ATT process steps. The earliest time a RP request can be made is M-4, i.e. four months ahead of first day of operation. RP allocation to RUs may be performed up to 36 months into the future, meaning that RP capacity allocation and the RTT process can affect future timetable periods.

It is as a result from Capacity supply that actual pre-planned catalogue train paths are communicated to RU in the supply. These need to be conflict regulated with each other, but also contain some adjustment time with respect to the bandwidths that represent the reserved capacity in the Rolling Planning segment and as well as Ad Hoc.

It is one of the intentions of TTR's RP products to accomplish that train paths are applied and allocated when the facts for them have stabilized. Therefore, it is important to get the incentives right. According to the TTR documentation (ForumTrainEurope/RailNetEurope 2021), RP requests are allocated according to the first come first served principle. We have concluded that this principle is not sufficient for a socio-economic model to work properly. More information on this is provided in section 3.4.5.

Capacity for RP products can be represented in different ways:

1) As whole train paths in cases where there is a high probability that such requests will be made. It is important to note the difference between high probability for the existence of such a train path and it is timing probabilities. In principle this would be a rare case, since if the certainty of the path has reached such a limit that a complete train path can be constructed, then it should already be part of the annual timetable in the supply since the certainty about the path is so high that RUs should probably apply for this path already in the ATT.
2) As parts of a future train path, a capacity object / path “channel”, i.e. capacity reservations, through e.g. congested areas. These capacity objects are used during the running timetable period to facilitate creation of a complete RP (or an Ad Hoc) train path. All reserved capacity needs to be valued in order to be compared with the capacity allocated in the annual working timetable, otherwise it is difficult to evaluate the utilisation afterwards and ensure that the reservation was justified against the annually allocated capacity. Thus, a basis (foundation) must exist in the (underlying) production target that confirms that the capacity object should be reserved, as this will most certainly come to a cost for the annually allocated traffic
3) As bandwidths for the prognosticated train path, i.e. from origin to destination. Two sub-cases arise: a) with determined route or b) without determined route. The capacity consumption of these bandwidths must be able to be planned together with pre-planned train paths, i.e. the planning method chosen must be able to handle both types of capacity consuming objects. This requires that the bandwidths can be valued according to the same principles as preplanned train paths.
4) As bandwidths in areas where the capacity is scarce, similar to path “channel” case in 2) above.
5) As reserved and safeguarded RP capacity from earlier RP capacity allocation. The framework of RP products allows for multi-annual allocation of capacity, i.e. reserving capacity in future train timetable periods where the application that takes place under the current timetable period. The multi-annual application then competes with the next year's annual allocation which is not yet made but still must be socio-economically valuated in order for the right decision to be made.

It is one of the intentions of TTR's Rolling Planning product category and the RTT to accomplish that train paths are applied and allocated when the facts for them have stabilized. Therefore, it is important to get the incentives right.

2.3.4.6 Path alteration

Path alteration is the process of changing and replanning train paths that have already been committed and allocated to an RU (IM is initiator of a path alteration, while it is called path cancellation when RU withdraws its intention to run a train in an allocated train path). This is a form of breach of contract with the RU who possessed the train path. The amount of path alterations and the extent of it should therefore be minimized.

3 Development of a socio-economic model for TTR

This section considers the use of a socio-economic model for the process steps of TTR. This encompasses Advance planning as well as allocation of capacity once train path applications have been made by the RUs. For the latter, there are socio-economic priority calculations that are used today (see, e.g., SPC). For Advance planning, the model needs to consider traffic that are not yet applied for, but which is prognosticated by e.g. the IM, RUs and other parties. This means there is also the task of judging the prognosticated traffic’s attractiveness, which introduces an additional complexity regarding uncertainty.

The different entities of the socio-economic model and the different methods used to value infrastructure use must be adapted to the different process steps of TTR. Not all facts and details are known in the early process steps, and the plans are on a more abstract level. For that reason, both the available capacity and the demand for capacity must be expressed differently, reflecting uncertainties and the level of available facts and details – more general and abstract to begin with and adding more and more details as the process continues. In TTR, this means volumes of traffic early in the process, which are transformed into bandwidths and train paths as more and more details are known towards actual allocation of paths to RUs. These different capacity objects such as bandwidths, preplanned paths, and already allocated Rolling Planning train paths, as well as their volumes, are all present at the same time in the plans and schedules since the maturity and certainty of the underlying demands differ. This means that the valuation of different capacity objects must be comparable between themselves and with each other at any time in the process, as they will be present at the same time. Hence, the conflict resolution methods need to take the co-existence of these different capacity objects into consideration, and the socio-economic valuation of the added waiting times and displacement times as well as exclusions of traffic of the capacity objects must be measured fair and equal according to the underlying socio-economic models and data.

The abovementioned aspects are, among other things, considered in sections 3.3, 3.4, 3.5 and 3.6, which are partly built on the RNE report “European Framework for Allocation Principles for Capacity Shortages” (ForumTrainEurope/RailNetEurope2022a). To simplify the discussion somewhat in those sections, we assume that the traffic demand identified at X-60 is stable through the process in volume and time requirements, i.e. we focus on the process of gradually creating the planning solution that meets this stable traffic demand.[15]

Prior to sections 3.3–3.6, we consider standard unit values in section 3.1 which are important input to a socio-economic model for TTR. In addition, such a model also needs to consider cross-border traffic which raises a set of issues which are considered in section 3.2.

3.1 Standard unit values

One aim with the feasibility study is to analyse how socio-economic priority criteria may be used on a European scale. Standard unit values are required for what is being transported (number and type of passengers, the freight trains’ cargo), how passengers and shippers value changes in travel time, i.e., the VTTS, and operating costs for both time and distance in order to consider vehicle (capital) and personnel costs, as well as traction costs. This data is needed for each country that the priority criteria apply to.

The proposed main source of information for a European solution is the Commission’s Vademecum on economic appraisal (European Commission, 2021). The report presents guidance for years 2021–2027 based on results gathered by the Commission and JASPERS during 2014–2020.

Regarding the VTTS for passengers, the European Commission (2021), as well as the European Investment Bank (2023) recommends that VTTS should be set at the national level based on stated and/or revealed preference surveys. An alternative approach recommended by the Commission is to first set the VTTS for business travel using official Eurostat data on average hourly labour costs, including overheads. Then the VTTS for commuting trips is set to around 25–40 per cent of the business VTTS, whilst the corresponding percentage is 20–35 per cent for other or leisure trips. However, as stated by the European Investment Bank (2023),

[15] In reality, the traffic demand changes over time and TTR stretches over 6 years including the running timetable period (actually up to almost 9 years with the allocation principles of Rolling Planning). The model needs to "compliantly" follow the change in demand.

there is an extensive literature showing that that the VTTS is influenced by many other factors than wages, and again that the best approach is to conduct empirical research, based on stated preference or revealed preference data, to estimate the VTTS.

Given that a European solution is requested, and that harmonised values are required for all countries the socio-economic criteria will apply to, this feasibility study follow the statement by Shires and De Jong (2009) that values from a meta-analysis can be used whilst waiting for proper national studies. A meta-analysis is a statistical analysis of analyses that can be used for predicting values for countries where VTTS studies (and proper segmentation of the VTTS by travel purpose) are lacking. The meta-analysis on passengers' VTTS by Wardman et al. (2012) was commissioned by the European Investment Bank and its valuations of non-in-vehicle-time attributes are reported by the European Commission (2021). The VTTS for passengers presented by Wardman et al. (2012), and used by our feasibility study, comprise values for 36 European countries, with VTTS for business trips, commuter trips, and other trips. The values are in euros per hour in 2010 incomes and prices. For each country and trip motivation, the values vary depending on the distance bands 5, 25, 100 and 250 km, where the value (per hour) is increasing with distance.

Wait time is another time element that is required for the socio-economic priority criteria. The European Commission (2021) refers to a set of weights (produced by Wardman et al., 2012) that can be applied to the VTTS to calculate the value of this (and other) time element(s) of the trip.[16] The wait time element for trains presented in Wardman et al. (2012) is used in the spreadsheet model submitted together with this report.

Regarding the uprating of VTTS over time to real income (GDP per capita), it can be noted that the change of VTTS over time depends on how all the parameters within the VTTS models change over time, i.e. the models used to estimate VTTS for non-work and business trips (Arup and ITS, 2017). Further, the Vademecum by the Commission (European Commission, 2021) states that the uprating elasticities to be used should be consistent with the method of setting the unit values in the specific VTTS study. For example, the meta-analysis by Wardman et al. (2012), which is the source of the values used within this feasibility study, implied a real income elasticity between VTTS and GDP per capita at around 0.8 and 0.7 for businesses trips and other trips, respectively.

Regarding *passenger train operation costs*, the authors of this feasibility study has not been able to find a comprehensive dataset of European-wide values such as those reported by JASPERS (2017) for freight trains. For example, the report by Steer Davies Gleave (2015), commissioned by the European Commission, presents operating costs per train kilometre for each member state in 2012 (with a range between 20-40 euros per train kilometre), yet the reported values do not discriminate between different passenger train types, freight train types, and not even between passenger and freight trains. The calculation examples provided in the spreadsheet model (Excel-file submitted together with the present report) use passenger train operating costs provided by the Swedish appraisal guidelines (ASEK), which are scaled to other countries using their GDP per capita. This is also the suggested short-term solution, i.e., in lack of a comprehensive study with values from all or a representative set of European countries.

[16] There are also values of time for public transport headway (average time interval between services), which (at least to some extent) comprise information on the value of changing the service frequency for passenger trains. The European Commission (2021) presents results from the VTTS literature (e.g. Wardman et al. 2012), where there is a weight for public transport headway that can be applied to the in-vehicle VTTS.

The number and type of passengers on the trains is important information for the socio-economic calculations. The authors of this feasibility study have not found European-wide information on this, other than the passenger load factors per country (passenger-km per train-km for 31 countries in Europe) presented in the IRG market monitoring report (IRG, 2024), and the occupancy rates for short-distance and long-distance trains per country provided by Railisa UIC statistics. The current approach in the spreadsheet model is the use of (currently arbitrary) upper and lower limits of passenger load factors for different train types. Weights are applied to these load factors to calculate the number of passenger types on each of the train types and for each distance band. Essentially, this information is required to discriminate between train types that carry different number and types of passengers.

For consistent *freight transport* values, the European Commission (2021) refers to the report by JASPERS (2017) (and, as noted above, the commission refers to Wardman et al., 2012 for passenger VTTS). First it can be noted that the report by JASPERS presents transport time costs which include:

- staff cost, comprising the cost of train crew and operational overhead cost;
- vehicle costs, comprising costs for depreciation, insurance, and maintenance; and
- cost of cargo being transported, which mainly is caused by capital lock-up and loss of (or risk to) cargo value during transport.

Distance-related operational costs of transport are also provided in JASPERS (2017).

The transport time costs can be separated into two categories:

1) the time value of transport (staff time and vehicle time), and
2) the time value of cargo.

The time value of cargo (euro per tonne of cargo per hour) recommended in JASPERS and used in the spreadsheet model submitted for the present report, is based on research in France (CGSP, 2013). JASPERS (2017) considers these values to be representative for the EU-15 countries, whilst this time value is corrected for the “JASPERS countries” using the ratio of staff and vehicle time costs (see p. 23, JASPERS, 2017). Here it can be noted that VTTS for freight in the Swedish EKG uses a Speed factor since otherwise freight traffic would be given virtually no priority in the calculation model. However, any such factor should be based on empirical evidence indicating what the true VTTS for cargo is.

The time value of transport (staff time and vehicle time) varies to some extent between countries and where JASPERS (2017) provide values for the EU-15 countries, and based on these, generate values for the so-called JASPERS countries.

JASPERS (2017) notes that all unit values in the report should be inflated to the base price level year using the EURO nominal inflation rate. For future years, JASPERS recommends using an elasticity of 0.15 between real cost increase and GDP growth for the transport cost component of VTTS. The basis for this recommendation is that it corresponds to the average share of crew costs in the VTTS in Europe. Further, JASPERS (2017) recommends no real increase in unit costs for the cargo component of VTTS and for the distance-based traction and infrastructure access costs. The reason is the lack of evidence that these costs increase systematically with GDP.

Finally, the freight trains’ payloads are required in the calculations. The spreadsheet model submitted together with the present reports make use of the payloads presented in JASPERS (2017).

All in all, the proposed European solution is to use the Commission’s Vademecum on economic appraisal as a basis for the calculations. There are, however, values missing such as passenger train operating costs (a suggested short-term solution is to use values from the Swedish appraisal guidelines), and load factors indicating the number of passengers with respect to different trip motivations (i.e. business trips, commuting, and other/leisure trips).

3.2 Cross-border issues

There are incentives for a country to hinder, complicate or not allow cross-border traffic to and from other countries if this type of traffic implies that domestic trains need to be cancelled or moved. Ideally, cross-border traffic would be treated in the same manner as domestic traffic, in line with the aim of creating a single European railway area (SERA) and the aims of the Trans-European Transport Network (TEN-T). That is, when applying socio-economic criteria, the train path with the highest socio-economic value should be given priority and each country needs to follow this procedure and give way to cross-border traffic when this traffic type has a higher socio-economic value than domestic trains. In this case, we have a so-called Kaldor-Hicks improvement since cross-border traffic can hypothetically compensate the domestic traffic such that we have a Pareto-improving outcome (where no one is made worse off).

If there is a risk that the abovementioned principle is not followed, one could consider a mechanism that counteracts the incentives to not allow, hinder or complicate cross-border traffic. One option is to consider a compensation scheme based on the difference in the net value of the traffic. Specifically, consider that the increase in net present value of a train path *A* for domestic trains is 5 compared to an alternative train path *a* that could accommodate the cross-border train path *B*. The corresponding increase in net present value is 6 for the cross-border train path *B* compared to *b* (note that train paths *A* and *B* are in conflict). The cross-border traffic could thus compensate national traffic for its loss and still be better off compared to using train path *b*.[17] One suggestion for how the compensation scheme could work in practice is to consider some kind of fund at the European level. The IM that, according to the priority criteria, is required to allow cross-border traffic at the expense of its domestic trains may be eligible for a compensation, e.g., in the form of funds that are earmarked for capacity investments in its rail infrastructure. Whether it is the cross-border traffic that pays this amount or not is not the main point of this compensation scheme (yet we note that it could be more cost efficient to collect these funds in some other way than from a price sensitive train operator, which is in line with short run marginal social cost pricing where investments in, and enhancements of infrastructure are excluded). The main point and basic idea behind the compensation scheme is to create stronger incentives for an efficient use of the European railway network, getting rid of incentives for a country to hinder, complicate or not allow cross-border traffic that should be prioritized according to the socio-economic priority criteria.

Another aspect that may create disincentives to allow cross-border traffic is the impact on the reliability of domestic trains. The distance covered, which is usually longer for cross-border trains, is an important influencing factor for train punctuality (see e.g., Harris, 1992, Olsson and Haugland, 2004, and Palmqvist et al., 2017). This cost therefore also needs to be considered in the allocation process and preferably, if information on this cost is available, in the compensation scheme (for example, as noted in the section 2.1, one could use the marginal external cost of congestion). Overall, the impact on reliability that a certain timetable implies, i.e. the robustness of the timetable and its impacts, should in principle be included in the allocation process. For example, IMs can require a certain buffer time in the timetable to improve the robustness of the timetable.

[17] We consider this compensation scheme to be in the spirit of Article 47(4) 2012/34/EC, which states "The priority criteria shall take account of the importance of a service to society relative to any other service which will consequently be excluded/…/Those measures and that compensation shall include taking account of the effect of this exclusion in other Member States."

One aspect is which country's (or countries') parameter values to use when determining the value of cross-border traffic, from its origin to its destination. One solution is to treat the sections of the trip that are in different countries as separate entities and hence change the parameter values at the border. [18] We argue that this approach is feasible and has no systematic bias for or against international traffic, and it is a recommended approach for passenger traffic. For international freight traffic we recommend the same solution (yet, note that the values reported in JASPERS, 2017 are the same for EU-15, whilst they vary for the other JASPERS countries).

Here it can be pointed out that, in general, the choice between national parameter values and European average parameter values seems to have small consequences for timetabling prioritizing purposes. The reason for this is that the ratio between different values, for instance the value of waiting time compared to VTTS, is similar across countries even as their absolute values vary. Specifically, priorities mainly depend on the quotient between two parameter values rather than the absolute parameter values, and these quotients are seen to be quite stable across countries. However, if it is found that these are not stable, the solution to use each country's own national parameter values for the related country-specific parts of the cross-border trip may create solutions where time adjustments will be made in one country instead of another. This could create significant effects on domestic traffic in one country.

A situation that needs specific attention is when an IM wishes to deny a capacity request for cross-border traffic completely or grant a path that is very different from what was requested. This situation differs from the more common case where the IM proposes minor changes to make for a feasible timetable, in that it is much more difficult to put a proper value on an exclusion. This is more extensively discussed in section 3.3.1.

3.3 Resources, Capacity objects and socio-economic valuation

The following sections outlines the needs and different challenges and also describes how the example model is designed and applied to the various capacity objects. Section 4.3 provides examples of its intended use, which is to help in prioritizing among competing solutions.

It is a great advantage if the socio-economic model is expressed, e.g., as linear equations as these lend themselves well to optimization implementation and thus makes it possible to build decision support software.[19]

3.3.1 Properties evaluated by the socio-economic valuation

In the following, we go through the three components that are used when evaluating a conflict-regulated annual timetable after the application for capacity, X-8,5 – X-2 (late path requests are set). These are:

a) Travelled distance.
b) Running time, which is the basis for both value-of-time for the transport buyer and time dependent operational costs for RU.
c) Displacement/shift of departure time in relation to the anchoring point, usually at the departure station of the train, which affects the attractiveness of the transport to

[18] One could also consider treating cross-border traffic as a train path that connects two services. The association over the border may have a cost (e.g., for administration) that needs to be taken into account.
[19] The spreadsheet socio-economic model developed and submitted with this report has been implemented in that way, and an optimization model with a simplified conflict resolution method has also been developed.

customers (given that RU "knows best" where the transport is most attractive for customers).

Note that the purpose of the time window for the bandwidth is to reflect the available time for this particular prognosticated train path's room for taking additional running time (running time supplements and wait times) when being scheduled to get conflict-freeness later. Thus, the time window reflects the end points when this prognosticated train path "product" is (still) valid to customers. The time window then includes both an allowance for the execution time and the displacement/shift. Displacement valuation as a generalized cost is in principle always lower than the implementation time valuation because the sacrifice for the customer is lower for passengers/goods before/after the journey compared to when the person/goods are on board the train. Thus, it is the displacement that sets the limit (or frame) for the size of the time window.

3.3.1.1 Running time

Running time can be divided into the basic running time, which is when the train travels the nominal route through the network without being regulated by other traffic[20], as well as added conflict resolution time that occurs due to congestion and/or rerouting. In the same way as for travelled distance, the increased journey/running time in case of a rerouting can be seen as known and possible to valuate.

The running time is thus at least the base time, which is a known fact for the prognosticated train path, and partly an, as yet, unknown amount of time that arises when the train path must later be scheduled with other traffic due to congestion. For passenger trains, the additional time is often small in relation to the entire running time, while for freight trains it can be longer. In a priority calculation for the capacity model dealing with bandwidths, we know that at least the base time will be in the plan and thus this can be used for valuation. How the not yet known additional times stemming from future conflict resolution should be valued is not as obvious. Several options are available.

1) Not at all. One starts from the base time because this is the only known execution time (the floor).
2) Statistical added wait time and runtime supplements based on experience and/or load situation (i.e. the added wait time and runtime supplement is a function of the congested areas the train path passes). There are more sub-options here (which can be combined):
    i. Measure how bad the congestion is in this area in the production target that the IM has defined. The size of the additional time to pass the congested area is determined by assessed/calculated congestion (i.e. probability of being delayed).
    ii. Train type and probability that an instance of a certain train type will receive a surcharge.
    iii. Line segments with known problems leading to specific time delays passing this area.

    Note that the socio-economic valuation of the forecasted train path and its additional time is made for the entire train journey and not locally.

[20] The nominal duration is calculated as if the train was alone on the infrastructure.

3) The entire time window is used in the valuation, as it is the available space for subsequent scheduling (the running time ceiling of this prognosticated train path product).

Of these options, option 3 is probably not preferable. The general cost of taking the maximum time window into use will most likely be too high in relation to what it will later be after scheduling and determination.

There is also a distinction between the requested/predicted traffic's base case, i.e. if it "was alone on the infrastructure", and the final compromise with all other traffic at the running day, also including possible rerouting. The socio-economic valuation gives a valuation of the additional costs imposed by the plan that, e.g., a transport buyer (passenger or goods) will get in the different scenarios investigated. For the early process steps of the Advance planning rerouting costs are more dominant while in the later stages, notably ATT and RTT, the prolongation and displacement costs are more common.

3.3.1.2 Displacement

Displacement or shift is the measured time from the desired departure from an anchor point, usually the origin of the train path[21]. The size of the shift is more uncertain in Advance planning than after RUs have applied for train paths at X-8,5. This is especially true for the capacity planned to be allocated to Rolling Planning requests and Ad Hoc use. It can be difficult to predict what the shifting time may be. However, it is possible to carry out the same reasoning as for added time due to congestion. For example, the probability of displacement of the forecasted train path increases if the forecasted train path passes through several narrow sectors.

3.3.1.3 Distance travelled

The *travelled distance* is a pure function of the chosen path, or possibly of the alternative paths through the network (when e.g. TCRs apply) which can be relatively known at an early stage e.g. the Capacity strategy provides information on how the infrastructure should be used in terms of "allocation or routing rules". Thus, the socio-economic valuation components that stem from the route and its distance are in principle the same as for valuation in annual timetabling where the nominal distance constitutes the preferred path through the network. Hence travelled distance can be valued in the Advance planning process steps.

3.3.1.4 Exclusion

There is a need to develop the model regarding how to properly handle exclusions (denials of capacity requests), including changes compared to the original request that are so large that the departure is scheduled outside of the time-window specified for that type of traffic. This may be especially important for international services as IMs in transit countries have incentives to prioritize domestic services over services that generate little economic value to the local economy. Theoretically, the cost of an exclusion depends on what the second-best alternative is, including externalities, and this value can vary widely. While some passenger traffic, for instance some regional services, can be exchanged for buses with little travel time loss, in other cases a change to road or air would incur much extra travel time, cost or hassle for passengers. Similarly for freight traffic, there are some cases where the second-best option, often lorry, works well, and others where rail is the only feasible mode of transport.

[21] It is possible to introduce different costs for shifting earlier compared to shifting later compared to the anchor point

There is a fundamental difference between a train path not being able to defend its place in the production target during Advance planning and not being able to defend its place in the timetable during the ATT and RTT processes. To remove an applied train path during ATT and RTT may be termed ‘exclusion’ as the RU’s request is excluded from the timetable, while during the Advance planning it is the IM that removes a potential future train path from the production target. The term ‘exclusion’ may therefore be misleading during the Advance planning as there is no application given yet. Instead, it is a ‘removal’ of a (potential attractive) future train path from the production target. The socio-economic calculation would still be the same in both phases, although probabilities on the future realisation of the train path may apply during advance planning. The socio-economic model tries to measure the utility to society and does not care about who is performing the service.

Instead of using a specific method, the exclusion of a train service is treated in the Swedish EKG as a standardized limitation on the total socio-economic cost calculated with the basic running time and distance. But especially for freight services this can be a poor estimate of the true costs. Exclusions are fairly rare, which may explain why the current methods for valuating them have been allowed to remain. But the proper valuation of exclusions may become more important as more international freight transport is prognosticated to be done using train services. To improve on the current situation, we propose both a simplified method that can be implemented fairly quickly, and a development line for a more thorough method for exclusion values of a socio-economic calculation.

The IM should have a transparent methodology to judge to what extent it is possible to replace a requested service with an alternative mode of transport. Based on this judgment they decide on a factor, an *exclusion cost factor*, which is a number between 0 and 1, where for freight services 0 means that the shipment can be made on an alternative mode at no additional cost, and 1 means that it is not possible by any means to transport the goods if the request for capacity on the rail network is denied, meaning that the complete value of the transport is lost. The factor is multiplied by the goods value according to templates in e.g. JASPERS (2017). For passenger services this is done in a similar fashion: using the basic transport time to get VTTS, operational costs (i.e. the running time without considering wait times), and externalities. The exclusion cost can be calculated for passenger services by multiplying the exclusion factor with the generalized cost based on basic running time of the passenger service[22].

In the proposed development line, the exclusion cost is determined in one of two possible procedures: 1) by calculating costs for the second-best alternative transportation mode, or 2) by a standardized measure of the freight value. If the IM cannot find an alternative according to 1), it must use 2). For passenger services it uses 1).

1) The costs for alternative transportation can be calculated in the following way. The IM uses a software similar to the Swedish national freight transport model, *Samgods*. This is a tool that calculates the cheapest means of transportation between two places. It is fed with parameter values that include the cost of transportation per weight and volume for different types of goods, as well as information on the infrastructure in the country. Template values are used for different goods types. Both the cost of rail transport and of the second-best option is calculated, and the difference between the two is taken as the opportunity cost, i.e. the loss of the value that is forgone. Passenger services are treated similarly, using a software similar to the Swedish national passenger transport model, *Sampers*. Externalities are included in both cases.

[22] There is already such a method described in the Swedish EKG.

2) Freight values are calculated using standardized values for the type of goods being transported. When applicable (i.e. in the ATTP and in RTT) the operator will be required to declare quantities and cargo types, otherwise in Advance Planning it is the IM that has to prognosticate the content of the freight service. The IM then treats the value of goods as the basis for the cost of an exclusion multiplied with the exclusion cost factor.

In short, costs for the alternative transportation shall be calculated when there exists a reasonable alternative to transporting the passengers/goods besides by train, such as by lorry or ship. Freight values shall be calculated when there is no reasonable alternative, and the likely outcome of an exclusion is that the goods are not being shipped at all, or not being shipped to the same intended receiver in the near future.

Note, however, that the simplified method is proposed since a working method suitable for timetabling decisions (adequate and at the same time simple to use) for the value of alternative transports is currently lacking. To overcome this problem in the short run, we propose the simplified method which should be used carefully.

3.3.1.5 Volumes transported

The generalized cost is a function of what is being transported and how large volumes is being transported. When using prioritization categories after the application for capacity there is information from RUs about these properties, which are used to calculate the generalized cost.

In Advance planning, the RUs have not yet applied for train paths which implies that some other actor must set anchor points and other properties (stop pattern etc.) for the prognosticated train path and bandwidths. This "deputy customer" may also be the same organization that formulates the production target, for example the IM.[23] CNA may be one input for IMs to base its forecasted volume. The IMs' own or other authorities' prognosis for future transports is another source to be used.

3.3.2 Train paths

Train paths can be valuated using all the properties in section 3.3.1. This is also the capacity object for which there has been prioritization criteria developed and used in some countries over more than 10 years, either when a congestion has been declared after unresolved dispute, or when the infrastructure has been declared congested before the start of the coordination period.

Preplanned or catalogue paths and their valuation in Advance planning are dependent of the certainty that they will be requested

3.3.3 Bandwidths

Bandwidths can be valuated in terms of their distance (e.g. additional distance due to rerouting) and the basic running time. The wait and supplement time cost and displacement cost have to be judged on experience or forecasted for areas of scarcity that the bandwidth is passing, information received from CNA etc.

[23] It may, however, be the case that these two tasks, making the "deputy application" and formulating the production goal, should be separate departments withing the IM so that the "deputy customer" focuses on the market needs while the IM focuses on the resource usage.

3.3.4 Train path channels and Slots

Train path corridors are pieces of future train paths, constructed and safe-guarded through the ATT process. Depending on the basis of future transports that have the need to pass e.g. the scarcity area a weighted socio-economic value of the corridor’s future passing train path can be calculated. This has certain similarities with the reservation of reserve capacity under the current directives and regulation.

3.3.5 Systems of trains

Systems of trains, i.e. trains with a regularity in the timetable, can be valuated using socio-economic valuations models. It is rather the reduction in frequency of train paths or violation of traffic patterns that can be valuated, for example going from a 15 minute pattern to a 20 minute pattern.

The generalized cost for “thinning” of the traffic can be calculated by valuating the extra time passengers have to wait for a departure (alternatively leave earlier than intended). Thinning (and the converse, densifying traffic at the expense of other traffic) is one tool for traffic planners and should preferably be part of a socio-economic priority calculation in the early process steps of Advance planning. We have outlined principles for how this is to be calculated in Appendix A.

Violating regular traffic patterns can also be calculated socio-economically by computing the extra wait time for passengers. Some passengers will wait longer, some will wait shorter times but overall, the sacrifice is larger for passengers that wait longer than those who happens to wait shorter. Therefore, violating a regular traffic pattern will always lead do a loss socio-economically, the question is just how small or large this cost is. see Appendix B for an example.

3.3.6 Residual capacity

Residual capacity is capacity declared within ATT, Rolling Planning or Ad Hoc product segments. It is used to make tailor-made train paths in case RUs does not find a preplanned path within their needs. In Advance planning these future tailor-made paths are to be predicted. The properties of the train paths using residual capacity in ATT will be settled once RUs apply for capacity.

To determine the amount of residual capacity demands good knowledge about the possible or potential future train paths being requested. The socio-economic valuation model together with probabilities may be used to valuate future potential train paths in Advance planning, the crucial point is to get the probabilities right. A number of prognosticated train paths, all with uncertainties, will then together motivate residual capacity. This is part of the production target development and management.

Also note that with a high probability of a train path being requested as an ATT path, then it is created, planned and published as a catalogue path. Therefore it is train paths with less probability that are to be requested from residual capacity.

The residual capacity declared in the supply may be motivated by bandwidths in the IM’s underlying production target. The reason to not publish the bandwidths as such is that even the bandwidths and their prognosticated train paths are uncertain, meaning that the IM rather publishes “free space” than offers bandwidths (possibly train paths) with probabilities that are not runnable together.

3.3.7 Associations

Associations also need to be valued when prioritizing between different planning solutions, especially if scheduling of train paths breaks the association. Hence they are part of the socio-economic valuation of a train path schedule.

Being able to assess how well an association is fulfilled, or whether it is broken in the Advance planning is more uncertain than train paths and bandwidths. There is both the association between train paths that can be stated once the two trains paths are available as planning capacity objects. See section 3.5.7.

Associations are in principle valued in the same manner as train paths. For passenger and freight, it is the volume in the association together with the type of passenger/cargo that gives the value of the association. For vehicle association it is the cost of the vehicles (investment costs etc.) that forms the basis of the valuation. See section 2.2 for details.

3.4 Process steps in TTR and their socio-economic valuation

In the following subsections the gradually evolving generalized cost is described for each process step of the TTR process.

Note that in Advance Planning the socio-economic valuation plays an important role as “proxy” for the society’s needs on which, e.g., RUs define their services. It is therefore natural to assume that the socio-economic valuation plays a significant role for IM in the process of deciding segments, preplanned paths, bandwidths etc. In the ATTP the RUs have applied for capacity, and the main focus is to negotiate a solution for the ATT product segment that everybody can accept. During this process the RP product segment must be safeguarded.

It is always part of a planning task to cope with uncertainties, that is part of the “planning craftmanship” which can be better performed if adequate models, methods and tools are available so that scenarios can be constructed, evaluated and well-founded decisions be made. For Advance planning it is important to note that uncertainty, at this stage, is “naturally” present, and cannot be disregarded or overlooked. This uncertainty has to be reflected in the model, conflict resolution method(s) as well as in representation of the capacity objects. Planning is not designing the future; it is a preparation for the future, and the plan that inherently includes options to adapt to changes in the “real world” is better than a rigid plan made on “speculative decisions”.

At the start of the Advance Planning there may exist a prognosticated demand for capacity based on previous years (what is usually transported on railway) in terms of volumes of traffic. There may also exit long term prognosis of transport volumes. This may form a basis for the production target.

The production target has a basic generalized cost valuation which acts as a generalized cost floor, see section 3.3.1. The final schedule cannot have a generalized cost that is less than this floor, since every conflict resolution step during the process will make something (some or several “capacity objects) more expensive in terms of increased generalized cost. This set of non-conflict-regulated traffic and its valuation can be called the *original valuation*. From that point and onwards, the generalized cost will increase as compromises and conflict resolutions are made. The task of the capacity allocation process is to form the best daily running plan schedule at each running day, where “best” in this sense is interpreted as the least added socio-economically generalized cost compared to the original valuation. Hence, the sum of all generalized cost factors for the scheduled solution alternatives orders the alternatives where the one with the lowest value is the preferred one.

3.4.1 The capacity strategy and socio-economic valuation

The Capacity strategy is mainly concerned with declaring the available capacity: additional capacity foreseen to be available in the running timetable period, capacity not being available because of major and/or high TCRs. On basis of this IMs give rules for how the available capacity is to be used in later process steps.

Some relations between large traffic flows, not between individual train paths, may be valuated. For example, some PSO traffic with highly stable traffic patterns and their regular associations may be valuated, especially if they are broken by TCRs. Another example is rerouting of traffic volumes where lost traffic at certain stations may lead to lost relations with other traffic. The basis for such analyses is mainly statistics based on historic data. Vehicle associations can in the same manner be investigated in a more general way for example when the traffic volume is shortened, and the traffic starts (stops) at another station than what is usually the case. These investigation concerns large such changes such as reinvestments at larger yards, stations and main lines.

The following are decision tasks in Capacity Strategy where the socio-economic prioritization categories may play a role:

- Reroute and prioritize volumes of traffic around a large TCR. Includes also change of transportation modes for (part of) the journey.
- Weigh different maintenance methods at hand for the major and high TCRs and the availability of (expensive) maintenance resources (which are limited), contrast this with the socio-economic effects on the traffic.
- Test whether one traffic demand flow can be implemented/split into two or more “sub-flows” (e.g. part of the traffic takes one route, part of the traffic takes another route) to enable the efficient implementation of TCRs

As the maturity of underlying data may not be enough to do a good socio-economic valuation in the Capacity strategy, the above list of examples is also valid in the Capacity Model, depending on when planning is performed, and decisions being made on the TCRs. It is however important to investigate large TCR’s placement, duration and their joint impact together before locking the TCR’s placement in calendar time. One of the cornerstones of TTR is better TCR planning, specifically international coordination, to improve transport availability. It is also hard to change the TCR schemes after e.g. start of procurement of entrepreneurs. The expensive mistakes often tend to be made early in the process, in our case expensive costs in terms of socio-economy costs.

3.4.2 The capacity model and socio-economic valuation

The Capacity Model shows the expected utilisation of capacity. Mainly it is line capacity and its utilisation that is described in the handbooks and documents issued within the framework of TTR (ForumTrainEurope/RailNetEurope 2021, RailNetEurope 2022c). Points of operation, stations, platforms, etc. are not described in the capacity model documentation and proposed visualisation. Nevertheless, it is not uncommon for these to impose constraints on the efficiency of the service and affect the capacity of the line.

In order to configure TCRs with respect to their placement in time and their combined impact on traffic, IMs have to find good solutions both in their own network but also together over borders. This is one of the fundamental areas of improvement that TTR was built on. It is important to valuate the traffic loss for different TCR scenarios as it will be hard to replan major and high TCRs later in the process if the traffic impact turns out to be high. Better joint planning of TCRs was one of TTRs initial main goals.

Transport times and distances for main traffic volume flows are often quite certain at a macro level. Their basic running parameters are quite well known, as approximate volume figures, and thereby also the socio-economic parameters. It therefore makes sense to use socio-economic valuation of the main traffic impacts of the major and high TCRs when performing TCR analysis and choosing a layout of the TCRs in calendar time to study their combined impact as a whole. One could test e.g. denser traffic of a certain line while shortening others[24], or use thinning of regular traffic. Such scenarios may be calculated and prioritized by socio-economic models in the Capacity model.

The socio-economic model should help IMs to decide on infrastructure usage that improves the utility to society of the infrastructure. In the CM process step the socio-economic valuation helps IMs to do the partitioning of capacity into segments: TCR, ATT Capacity, RP capacity and unplanned capacity (rest capacity). It is important that the planning method used by the IM to valuate the production target (planned TCRs and traffic) is able to handle the different capacity objects used, see 2.3.2.

When performing socio-economic valuation in the CM process step, it is the production target that can have a socio-economic value, a utility to society, not the stated usage of the line sections. The production target should also include the volumes for already allocated train paths in the Rolling Planning segment inherited from previous year(s) as well as Framework Agreement capacity for which there already exists an RU and a contractual agreement.

The valuation of the RP product segment is especially important in the CM step. It is in this process step that the amount of RP capacity is reserved and starts to be safeguarded to be available in RTT when RP requests are being made. To judge if capacity is to be reserved for RP use, there must exist good reasons for the IM to motivate the reservation, i.e. the probability for valuable traffic applying in RTT for RP products. The socio-economic valuation is such an argument.

The planning and valuation tasks given in the Capacity strategy are still important in the CM process step, as the TCR plans evolve over time. In addition to the ones mention for Capacity Strategy 3.4.1 the following planning tasks are examples where socio-economic valuation in the CM process step may play an important role:

- Investigate how much a speed limit over a line segment "cost" the nominal (statistically known) traffic volume. This also includes a situation where single- track traffic is implemented on a double track line due to maintenance work, where the single-track traffic is approximated with schematically prolonged running times.
- Combining/planning large TCRs so that the combined impact on the traffic is minimized (according to the socio-economic model). Contrast this with the cost of the TCRs' scheduled costs.
- For a specific line segment/stretch of infrastructure, how should the capacity be partitioned into product segments (based on the prognosticated traffic)?
- For RP capacity, are there enough evidence that motivates reservation of capacity for later use in the RP segment and allocation?
- Test different scenarios and decide important aspects of the upcoming supply, e.g. test regular 15 minutes traffic and regular 20 minutes traffic against other traffic requirements (i.e. making systematic tests). Particularly on basis of the TCR plans.

[24] This method was used when making a large re-investment at the southern line into/out of the centre of Stockholm. Passengers had to take commuter trains out of the centre and switch to long-range trains outside the city. This was to decrease the number of train through the area with track works.

- In case of TCRs, valuate the impact for different types of traffic, e.g. scenario analysis of the best rerouting possibilities, wait times, runtime supplements etc.

Associations between train paths can be evaluated in the production target during the CM process step. For example, some PSO traffic with highly stable traffic patterns and their regular associations can be valuated. Another example is rerouted traffic volumes where lost traffic at certain stations may lead to lost relations with other traffic, compared to historic data. Vehicle associations as well as important personnel associations can in the same manner be investigated in a more general way, for example when traffic is shortened and starts (stops) at another station than what is usually the case.

Note that it is not just a question about socio-economic valuation but also a question of representation of associations between bandwidths and prognosticated train paths in the early process steps, where a suitable “object” to model an abstract demand for associations is needed.[25] To break such a generalized association later is a kind of exclusion of a flow of passengers, cargo, vehicles or personnel, to be compared with exclusion of a train path, as the impact is similar for the customers, see section 4.

In section 4.3 we give examples where the planning method described in section 2.3.3 have been used to calculate a socio-economically valuated capacity model whose result has been used for the detailed schedules for an annual timetable.

3.4.3 The capacity supply and socio-economic valuation

In the CM process step there will be a mix of train paths, bandwidths, residual capacity as well as associations to valuate against each other. There is also the task of safeguarding the RP capacity products. This places demands on the planning method used and likewise on the valuation metho to prioritize with the ATT products as well as safeguarding the RP product segment. Train paths can be valuated using all three valuated properties including wait times and supplements for conflict resolution: running time, distance travelled and displacement from the anchoring point.

Bandwidths can be valuated using the basic time and travelled distance, but as these are not fully instantiated yet the displacement cost may have to be forecasted, as is also the case for the amount of adjustments to make the future train path conflict free. Probabilities apply if the future application of the bandwidth is uncertain.

Residual capacity may be valuated using bandwidths with probabilities. By accumulating the bandwidth’s socio-economic value scaled with the probability that it will be realized by an application later, IMs can get a value of the residual capacity.

Tasks where the socio-economic prioritization categories may be used in the Capacity Supply process step:

- Prioritizing all train paths and bandwidths together to find the minimum global generalized cost increase (essentially what the Swedish prioritization model was developed to do for train paths).
- Safeguard the Rolling Planning segment while planning and scheduling the traffic in the published yearly supply.
- Find the threshold where it is feasible to make a preplanned path rather than keeping the bandwidth with its time window around the prognosticated train path (in residual ATT capacity).

[25] This generalized association object can be seen as a tool to transform demands on traffic flows to a network of trains and associations.

- For preplanned paths, decide the amount of still available room for adjustments during the annual allocation process step. There has to be room for adjustments, both to fit different rolling stock of the RUs as well as make small adjustments to facilitate tailor made applications in the Residual capacity. The adjustments include both running time prolongation as well as limited displacement possibilities.
- Last possibility to test different scenarios, particularly regarding TCRs and their impact on traffic, and decide important aspects of the supply based on the TCR plans, e.g. test regular 15 minutes traffic and regular 20 minutes traffic against other traffic requirements (i.e. making systematic tests).
- Valuate, where appropriate, traffic flows and resulting associations
- Valuate, where appropriate, critical business demands from the RUs, such as vehicle rotations, personnel rostering etc.

3.4.4 Annual timetabling and socio-economic valuation

It is in the annual timetabling process that the socio-economic valuation is used today on a national level in some countries, see (IRG 2019). In TTR two major challenges are added: international traffic and their harmonization using socio-economic valuations (see section 3.2) and safeguarding the reserved capacity for RP services as well as Ad Hoc.

Safeguarding of RP capacity and Ad Hoc capacity is facilitated by the socio-economic categories by “freezing” the valuation (generalized cost) of the RP and Ad Hoc reserved capacity. The reserved capacity objects could be of different kinds, depending on the situation, see section 2.3.2.

Tasks in the annual timetable allocation process step where the socio-economic valuation may be used are the following.

- Conflict resolution and prioritization of different planning/scheduling solution proposals/scenarios against each other within the ATT product segment including residual capacity for RU requests for tailormade train paths. This includes traffic and associations. This is where it is used today.
- Safeguard the RP segment while constructing the annual timetable requests in residual capacity for annual capacity.

Associations are relations between train paths in ATT and are socio-economically valuated. It is unclear how an association to a possible future train path in e.g. the RP segment could be valuated. It is a kind of “dangling pointer” as there is not a train path or RU to which the RP capacity is allocated yet. It is however possible to make and valuate associations to RP train paths from previous year’s RTT.

If there are more than one applicant to a preplanned catalogue path, then this must be solved either by negotiations during the consultation phase or ultimately by a suitable arbitration method. In negotiations, one of the applicants may be offered and accept some other train path, for example an available preplanned path or a new tailormade train path in the ATT unplanned capacity segment. If no applicant is willing to withdraw the application for the preplanned catalogue path then the competition must be solved with a suitable other arbitration method as the socio-economic categories and prioritization criteria value the utility for society to have the plan executed, not who runs the services. Therefore, there must exist a method outside the socio-economic prioritization criteria to solve the competition in case no one of the competitors steps back and the preplanned train path can be allocated to an RU. That arbitration method should preferably also take into consideration if there are other preplanned paths that are also dependent on this particular path (i.e. vehicle rotations etc). This arbitration method could be based on auctions, least ticket price or other comparable entities. We have not in this study further investigated such an arbitration method.

3.4.5 Rolling planning and socio-economic valuation

In this study, and in previous investigation and research (Aronsson, Kjellin 2022) we have concluded that the first come first served principle is not a principle that gets the incentives right with respect to socio-economic valuation and do not lead to a socio-economic correct allocation of capacity. We therefore in this report argue for another principle than using the first come first served principle but also to use a threshold value to compare the requested RP application against.

The catch is that the costs of the reserved RP capacity inflicted on the ATT train paths does not get reflected in the allocation of RP capacity with only the first come first served scheme. It has to be complemented with a reservation value that the applicant’s train path generalized cost value “beats” in order for this attractive capacity not to be abused. Thus, bandwidths for RP products must also be assigned a value so that they can defend their place during the ATT process, and this value is also used as the reservation value. Therefore, the application for RP capacity later in the running timetable period must also be verified to reach the value the RP capacity got in the ATT process. Only then does the reservation and valuation "fit together" between ATT and RTT.

It might also be the case that no request is made for the RP reserved capacity that fulfils the requirement to have higher valuation than the limit set during the ATT process. In this case, the IM either lowers the limit and/or removes the limit when the day of operation approaches. Such “discounts” should affect the future size and/or placement of RP reserved capacity, as it turned out to be wrong to reserve such valuable capacity as an RP product.

This means that IMs must decide whether the threshold still holds or not when an RU is applying for RP capacity somewhere in time. If the probability now is less for a valuable traffic to apply for the RP capacity, a transport with lower valuation may be allocated the RP capacity. If, on the other hand, the IM still has reason to believe in an application with a higher expected value (based on the probability of the more valuable transport), then the RP capacity should not be allocated to traffic with lower valuation than the threshold (given it has a lower expected value). This is not to be confused with “sunk costs” as there is nothing lost as the timetable period starts. On the contrary, there are values in the reserved RP capacity that should be managed with care.

The rationale behind having socio-economic values and the costs the ATT traffic took as a limit is that it is on the running day that the plan’s socio-economic value is realised, meaning that it is sub-optimal if each previous process step only optimized the plan based on the available facts. Therefore, RP capacity is to be reserved based on the prognosticated utility for the later allocated RP train path. But, as the IM decides upon reserving RP capacity, the IM also decides the threshold for the utility of the future RP train path. If the threshold is met, then it was correct to reserve and safeguard the RP capacity through the annual timetabling process, while on the other hand if the threshold value is not met, then the RP capacity should not have been reserved when publishing the Capacity model, at least not assign the RP capacity to the application that had too low value.

Observe that due to the timings of the process steps the follow-up of one year’s RP applications and allocation can influence a timetable three years ahead. The CM and the partitioning into segments is due X-18, and the last day of operation of a timetable period is X+12, so there is at least 30 months between the follow up result and the next timetable period it may influence.

This principle has been investigated earlier (Aronsson and Kjellin, 2022) where the principles for when it is feasible to reserve capacity for later use and when it is not. In that report a capacity reservation object was proposed, called a “capacity reservation” which is a piece of a future train path through, e.g., an area with scarcity. It is identical to the channel capacity object, see section 3.3.4, and are defined with the most important properties such as performance, axle load etc. Attached is also the threshold value to indicate the possible train paths that might come in question to “book” this capacity reservation object/channel.

Capacity for RP requests can be represented in different ways and at different process steps (see last section in section 2.3.4 for a list of alternatives):

1) As complete train paths, in cases where the probability is high for such applications. It is important to note the difference between high probability for the existence of such a train path later, and when its probable in time. Such RP products can be valuated using the proposed socio-economic valuation.
2) As parts of a future train paths, a capacity object / train path channel i.e. a capacity reservation through e.g. high traffic areas. These are justified by the weighted valuation of the likely RP products that can conceivably use this channel. As is the case for other RP reservation an RP application to use such a channel must have a valuation higher than the threshold set for this RP product during the ATT process.
3) As bandwidths when there is uncertainty about the anchoring point, the train's performance and/or other characteristics. These bandwidths can be valued according to the same principles as bandwidths in ATT to get the threshold value.
4) As reserved and safeguarded RP capacity from earlier RP allocation in previous RTT. In this case there is already a train path with possibilities to adjust the timings of it (RNE, 2021). The socio-economical valuation should be straight forward using the timing properties of the already existing train path data.

It could also be discussed whether RP and Ad Hoc reserved capacity may value some properties higher and other lower compared to the annually allocated capacity. VTTS can e.g. be lower for the RP services while the exclusion cost may be higher. Different characteristics could simply be of different importance to the product segments. Currently there are no studies on this matter, and thus no evidence for this, but in the future there is reason to investigate if such a difference between the socio-economic valuation exists.

3.4.5.1 A note on the segment Rolling Planning

A reflection is that RTT has some similarities with, but is not identical to, dynamic pricing of e.g. airplane seats, hotel rooms etc. where a certain part of the seats (capacity) is reserved for business class. These seats require a higher price and will remain late in the sales process for the customer group that arrives late and is not as price sensitive. If they are sold at the higher price, the airline has done the right thing by reserving them at a higher price, and the profit will be higher. The risk is also higher that the seats are not sold as they are presumably sold late, so if they are not sold the price of them will drop and relative to economy class, the airline will not profit from the split, maybe even get a reduced profit.

The similarity lies in the fact that the IM sets aside (reserves) attractive capacity for later in the process (implementation period) in order to maximize the benefit to society as transports being planned late can also be very profitable for society. Not least as the timings of the transport may not be known until late in the process. In the event that the probability is high for a transport to be applied for, but the location of it is uncertain during the annual application for capacity (X-8.5), the idea is that the railway company should wait with the application until more is known about the location of the transport. This was one main idea of TTR in the beginning, that is, to get rid of “speculative” application in the ATT before all facts about certain train paths were known, which in turn leads to replanning and fragmentation of the available capacity.

In order for the railway company to dare to wait, there must be attractive capacity left (reserved) through annual timetable allocation. But in order for this attractive capacity not to be abused, it is required that the applicant can "prove his place" in the timetable (for the flight seat in the example earlier this is done through willingness to pay), by the valuation for the requested RP train path being sufficiently high (with only first come first served then anyone can be allocated the reserved capacity which has probably incurred annual allocated traffic costs in terms of delay times etc). Thus, bandwidths for Rolling Planning capacity must also be assigned a value so that they can defend their place in annual allocation, and the later applications for Rolling Planning products are valued against this reservation value, based on the same principles as in annual allocation. Only then does the reservation and valuation "fit together" between ATT capacity and RP capacity.

3.4.6 Path alteration and socio-economic valuation

Compared to the previous process steps, there is the complicating fact that the train paths have already been allocated, and RUs may have based further resource planning on the allocated train path’s properties. By withdrawal of the train paths in path alteration, resource plans and business agreements that the RU may have to third parties may in turn be breached, leading to penalties for the RU. This is not the case in Advance planning, ATT or later steps in RTT as there is no contractual relationship yet between the IM and RU regarding the train path there. This makes the path alteration much more complicated to handle.

When path alteration is performed, it is important to minimize the consequences for both RUs regarding their (monetary) costs and also, when possible, the loss of utility for the society regarding less availability to transports. This makes two different objectives to achieve.

There are presumably several relationships between the RU and third parties (freight customers, passengers may have bought tickets, etc). Different solutions to the path alteration may cost very differently for the RUs as well for the IM. In addition, different RUs may also be affected, raising the question about fairness. To get the actual costs cannot be done as the IMs does not have knowledge about the RU’s costs and there is no guarantee that the RUs will leave such data to the IM.

All this means there is a need for much more information to make a correct socio-economic valuation of the situation. At the same time, the available time to find a good solution is shorter the later in the process we are. Therefore, socio-economic valuation in the Path alteration process may be too cumbersome to perform if it is going to be correct. Thus, coordination between the parties to find a compromise is very important in path alteration.

At the same time, there has to be an arbitration method to resolve conflicts if a compromise agreement cannot be reached between the parties. This method could be based on simplified socio-economic models and compensations paid by the IM (in case this is stated in the allocation agreement between the IM and RU)[26], or some other deterministic methods as a last resort to find a new conflict-free solution. If it is to be based on socio-economic models, it should be in line with the socio-economic models used in the earlier process steps., i.e. minimize the damage to society.

[26] By introducing penalties, the IM will have the opportunity to pay to breach the allocation agreement, and therefore the IM will “be in power” of the situation compared to when there are no penalties involved, in which case the IM must have other means to prioritize and balance the new disadvantages of the involved traffic.

3.4.7 Concluding remarks

The model is manageable in all the TTR phases. In Advance planning, train-paths and bandwidths devised by the IM are compared whereas in the annual timetable, the input to the model is the Capacity Supply and Rolling Planning reservations together with capacity requests of the train operators. During the running timetable period the model still plays a role in that Rolling Planning requests should be prioritized with the model's valuation so that the same principles apply regardless of when and where in the process the prioritization is being performed (see the first part of section 3.5.4 for a discussion on this). The model's structure and its parameter values should be calibrated to find the allocation that is most efficient in socio-economic terms, which means that in theory it is also the most attractive offer to end-users of the train services given the restrictions of e.g. limited capacity.

3.5 Uncertainties in advance planning

The earlier in the process the valuation is made, the more uncertain is the classification of the transport as well as the number of passengers / amount of goods that can be predicted to use the transport. This is equivalent to do sales forecasts in other sectors, and RUs most certainly do such activities today. With TTR it follows that IMs have to a greater extent acquire models and tools to be able to understand the attractiveness of the transport and set the correct transport class and volume of accompanying passengers / cargo. IM should also take into account the best usage of the infrastructure investments according to the society needs. IMs will therefore have to handle the uncertainties and risks associated with the expected demand of *customers* of train services in the Advance Planning which can be compared to the current model in which train operators request train paths based on *their* knowledge of the expected demand and IMs tries to fulfil RUs expectation once they get them. Market uncertainties are one of the new "components" or aspects of the Advance planning process steps that IMs will handle and share with RUs.

3.5.1 The IM's production target

The production target (see section 2.3.1) describes the services that are predicted to be produced during the timetable period. This underlying 'plan' acts as IMs "proxy" for what is going to be produced on the infrastructure.

However, there may be alternative scenarios/production targets leading to other resource usage plans as the traffic prognosis information for example given by RUs in CNA may be uncertain.

Therefore, the socio-economic valuation is important when forming production target, that is, to valuate the available possibilities and not only go for the best plan but rather get rid of the ones that does not use the infrastructure in an efficient way. In this sense the socio-economic valuation's role in the early phases is not to choose a specific plan that is the current best, as assumption behind that decision will change, but rather to "prune"[27] plans with low efficiency from the set of future possible plans. One may see this as an optimization process that, given the available capacity, leads to a best match of capacity and the traffic on the running day.

So the production target's role is to continuously during the process act as a proxy for the foreseen traffic situation at the running period. In the early process step this means to prune "bad" resource usage plans away while close to execution it is to optimize the production plans i.e. chose the best plan according to the socio-economic cost function.

[27] The term "prune" is here borrowed from the field of optimization and so called Constraint programming. These systems work by gradually remove values from the domains of the variables in the problem, thereby shrinking the solution space and ultimately find an optimal assignment for the problem variables that maximizes the objective function.

3.5.2 Train path uncertainties

In Advance planning, the train path's origin and/or destination may be uncertain, i.e. it may be the case that the initial part and/or finishing part of the train path may not be implemented by the RU when applying for the train path. This uncertainty can be handled by splitting the prognosticated train path into "legs" (in some scheduling software for timetable planning called "change en Route"), where the initial/finishing train path parts have probability factors for the generalized cost. The complete train path proposed by the IM then has the value of all used legs added together, i.e. it is optional to implement all legs. In fact, the legs can be seen as individual trains with "hard" associations between them. It will then be part of the socio-economic calculus (seen as an optimization problem) to see in e.g. scenario analysis if all the legs should be in e.g. a catalogue path or be optionally offered, or not at all offered.

With probabilities set on the prognosticated train paths and bandwidths, the predicted overall resource consumption over time on line sections can be assessed. This plays an important role in determining e.g. residual capacity, i.e. many less probable train paths "add up" to reserve capacity for residual capacity and tailormade train paths. The probable train paths should, according to the TTR model, end up as catalogue paths, maybe with less probable start/endings, see previous paragraph.

Challenges also arise regarding where in time and space RP capacity will be requested and with what certainty, and how to represent this capacity as an amount and as a performance will be uncertain.

3.5.3 Planning methods in Advance planning

There are different planning methods that can be used during Advance planning. Most certainly the method should be different in the early phases as the uncertainty about the facts behind the production target is higher. We have in the first intermediate report outlined an alternative method (Aronsson, Broman, Odolinski 2024b) compared to ordinary train path scheduling to show that the socio-economic valuation works also with this alternative method. This alternative method, which can be called *the Area method* since it is based on the occupancy area of a future train path in a Marey graph, has the advantage that it checks for the availability of later scheduling solutions, rather than actually pick one of them. This means that a family of later schedules is still available later while the resource usage is checked for overbooking. In this sense this method prunes the solution space but removes as little as possible of possible optional future plans. The important message in this report is that the proposed socio-economic model can be used as the objective function in that method, and thus the result from applying this method strives towards the same goal as when the proposed socio-economic model is used in "ordinary" conflict resolution.

Whatever planning method is used at this stage of the capacity allocation process, the valuation method is needed to determine the volume of each train service type in the capacity model.

3.5.4 The Capacity model and uncertainties

There are several kinds of uncertainties involved when forming the capacity model and the partition into ATT and RP segments. When the CM starts, it inherits the results from the Capacity strategy process step. This consists mainly of high-level resource usage "rules" for how volumes of traffic are to be implemented on the infrastructure. It is the CM process step that the production target is really formed in terms of various capacity objects and capacity products. As this is the process steps where these objects are "born" there are uncertainties involved in their later realization, and it is one of the main achievements of the CM process step to lessen these uncertainties and to shrink the number of options and variants of future traffic being investigated. The Capacity Needs Announcement is a process step where IMs and

RUs can exchange information regarding capacity needs, which is important to prune away scenarios that does not attract the market.

The capacity model does not need to specify how different parts of the capacity model will be used later in the process. This makes it possible to postpone detailed scheduling decisions. Any suitable train path may use the capacity model “slot”, e.g. any high-speed train that fits into a high-speed train path slot may be selectable later in the process, although the IM may have made the model based on a particular scenario, or several scenarios where the merged properties from the different scenarios showed that there ought to be a high-speed slot there. It is therefore an advantage if IMs have methods for assessing many optional scenarios and “fit” as many of the probable production target scenarios into the capacity model.

3.5.4.1 Capacity Needs Announcement

The CNAs may or may not be good forecast of the traffic that will eventually be applied for. This can be due to a failure of the RUs to correctly predict what capacity they will need but can also potentially be due to incentives for RUs to purposely overestimate their capacity needs in some situations. IMs have to value the information received in the CNAs as forecasts of future traffic and have to apply their judgement in assessing the CNAs’ forecasting value.

An uncertainty is that RUs may send CNAs that reflect what they believe will be granted rather than their most-preferred traffic. This already happens in some countries regarding capacity requests in the yearly timetabling process, especially for freight traffic, and the consequence is that IMs cannot be certain that they achieve the best outcome by following CNAs. There is a need for IMs to perform market research as well.

Different traffic types have different planning horizons. RUs that are able to plan ahead and submit detailed CNAs may receive an unproportionally large influence over the timetable. As an example, regional train operators typically know what timetable they prefer several years in advance, and they tend to favour fixed intervals between departures. But freight train operators often plan much closer to departure, and because their trains are more unregularly specified and may have different speed and stopping patterns, they sometimes need gaps in the regional train operators’ traffic. This is a conflict of interests in the prevailing pattern of the timetable, where there can be advantageous to have early influence.

An uncertainty is that RUs may send CNAs that reflect what they believe will be granted rather than their most-preferred traffic. This already happens in capacity requests in the yearly timetabling process, and the consequence is that IMs cannot be certain that they achieve the best outcome by following CNAs.

Furthermore, RUs may not submit CNAs at all or submit very little or false information in order to not disclose commercially sensitive information. This would lead IMs to have too little information for their purposes.

3.5.5 Capacity supply

It is first at the end of the Capacity supply process step that actual pre-planned train paths and bandwidths are communicated to RU in the supply. These need to be conflict regulated with each other, but also with respect to the bandwidths that represent the reserved capacity for identified Rolling Planning traffic and Ad Hoc traffic. There is a need for adjustment possibilities in these preplanned catalogue paths in order to harmonize them with e.g. tailormade applications in the residual capacity product segment. What will be requested in the residual capacity segment is still not known when IMs produce the capacity supply. Although market uncertainties should have decreased compared to previous process steps in Advance planning.

3.5.5.1 Extended supply

In Advance planning, different degrees of uncertainties exist which must be handled. One way to handle this is to postpone the decision on which train paths that should be offered in the Capacity supply and instead offer more paths than can ultimately be implemented or paths that are in conflict. During capacity allocation in ATTP and RTT, the paths in the “extended supply” are prioritized and it is decided which train paths that will be prioritized and implemented while the other ones which cannot be implemented are removed.

The rationale for this is that it is better to postpone decisions, if possible, when it is uncertain which “conflicting train path” should be chosen. This can happen if the valuation of the paths in the extended supply does not clearly show which paths are better to offer and/or the uncertainties for the paths in the extended supply are such that the chances of deciding wrongly early in the process (i.e. before RUs apply for capacity) are high.

Planning can theoretically be considered as working with either of two different representation models for train paths:

1) Scheduling of the two train paths takes place by assigning times to the two train path "objects". Depending on how the times are set, the plan will be conflict-free or not.
2) Each future allocated train path is represented by a possibly very large set of possible production train paths. The scheduling task is to select a production train path from each set of prognosticated (or applied/requested) train path where the two selected production train paths (selected elements from each set) are conflict-free. If this is not possible, one of the requested train paths will not be in the ATT.

Socio-economic models and methods still apply to the extended supply. Informally the socio-economic valuation of train paths with probabilities in an “extended supply” should add up to the final valuation of the implemented supply in the ATT. Assume that several different scenarios are possible, where different (parts of the) scenarios are removed during the planning process. Assume further that (at least) two train paths are probable in the final solution and that these cannot be realized simultaneously. It is thus a speculative decision to choose one particular scenario in the absence of knowledge about which of the two train paths that will finally be in the plan and/or if both train paths are attractive enough to be requested by RUs.

The reasoning in point 2) above can also be carried out for the "extended" supply: There may be more train paths in the offered supply than there can be in the final ATT. The point is that the probability of a train path being applied and realized is independent of its value: An improbable forecasted train path can have a high value for society if it is (later) applied as well as a highly probable train path with low value. Instead of deciding early in the process on one of the two, it is better (in theory) to keep both during pre-planning as long as possible, thereby gaining more facts as time goes by about the probabilities. It is therefore beneficial to wait with the decision as long as possible.[28]

Having both train paths in the offer means that both can be applied by RUs. If the highly valued train path is applied for, it will be allocated over the low valued one. If it is not applied for, the low-valued path will be allocated instead.

It is important for IMs to clearly state that all paths in the extended supply cannot be allocated capacity at the same time. The decision about which paths that will be in the final ATT

[28] This is an instance of the Lean methodology. By waiting, the risk of having made the wrong decision is decreased, hence also the risk of replanning. When replanning, the previous planning work is thrown away, thereby introducing waste in the planning process. Lean planning is about not having to replan.

becomes a business decision for the RUs; if they are going to apply for a path in the extended supply that may not be realizable.

Note that if alternative train paths, with (partly) the same traffic task but e.g. shifted in time, interact in such a way that if one of them is not implemented, the utility of the other train path will increase. This is especially visible in freight traffic, where e.g. two RUs can apply for train paths with the same customer’s transportation task but only one will be implemented since only one of them will be rewarded the transportation contract. Thus one of the train paths will not be implemented.

Extended supply can partly be handled with probabilities in the Capacity model, as long as the competing RUs for the same business covers the whole demand. But within the proposed framework it is difficult to handle a change in demand for travellers when e.g. two passenger RUs implement different traffic layouts over a larger network where they focus on different service segments, and the result is predicted to be that only one of them will be implemented. The Socio-economic model developed here is valid for small changes, and a stable demand is an underlying assumption for the model: if a train path is shifted a small amount of time, the demand is assumed to still be the same. The model has no tools for reflecting change in demand due to larger shifts of departure/arrival times of the train paths. For this more information is needed, e.g. alternative transport, also on other transport modes, and their socio-economic valuation.

3.5.6 Rolling Planning and uncertainties

A good capacity allocation method is one that makes the most efficient use of the infrastructure once the trains are run inside the train paths. Efficiency is here measured in the socio-economic sense. To achieve this, the allocation must be efficient within each product segment, and each segment must also be assigned the right share of overall capacity. An efficient planning method in the early phases also takes into account the uncertainties and leaves good alternative plans as options, if reality changes with time. Thus, resource planning as well as socio-economic valuations must cope with uncertainties by abstracting, generalizing and efficiently handle optional ways to implement train services.

To make efficient priorities, each capacity request and each available train path must be attributed a correct value. Since capacity is deliberately set aside from the annual timetabling process to be allocated through RTT, a train-path that is allocated on the first day of the RTT in the running timetable period has a value equal to the marginal value of a train-path with equal characteristics that is allocated in the annual timetabling process. But on the last day of the RTT running period, immediately before the would-be departure time, the value of that same train-path is zero. So, through the RTT and running timetable period the value of non-booked capacity changes and, if capacity utilization is unchanged, decreases towards zero.

Besides the uncertainties with the RP product segment as a whole, and that capacity is reserved through the ATT process, the products themselves have uncertainties attached to them. From the list in the first part of section 3.4.5 we have

1) RP capacity represented as a whole train path.
2) RP capacity represented as a part of a future train path, i.e. a channel through an area with capacity scarcity.
3) RP capacity represented as a bandwidth.
4) As reserved and safeguarded RP train path from earlier timetable periods.

For the fourth case there is not much uncertainty around the already allocated train path to an RU, properties around it are already clear and so should the socio-economic valuation be. Case 1 would be rare in reality, but uncertainty around the train path’s property would be small. The probability of the train path to be requested could be anything, but for the IM to actually represent the traffic need as a catalogue path would mean that the IM is quite certain that it will be requested. Otherwise it would have been represented by a bandwidth or as residual capacity.

Case 2) and 3) would probably be more usual as RP products. Both these objects can be motivated by more than one prognosticated train path in the production target where their total probability is high.

RP capacity is reserved by the partitioning made in the CM. It is then safeguarded through Capacity supply and the ATT process steps. It is part of these processes to manage the probabilities of the RP products in the production target.

It is common for commercial firms to face similar challenges with uncertainties about the attractiveness of offered services, i.e. that bookings are made sequentially for a time-specific service, and they wish to maximise the generated value (in their case profit). This is the case for hotel rooms, airplane tickets and, in the railway sector, passenger tickets for commercial train services. These firms typically use yield management techniques, which lets fares change continuously as the capacity utilization rate changes and the date of the service approaches. It would in principle be possible for IMs to use yield management principles, based on socio-economy, in the allocation of track capacity in sequential allocation such as Rolling planning capacity in order to achieve an efficient allocation within the segment. The prices charged – a proxy for their value – can be compared to the calculated value of train-paths allocated in the yearly timetabling process. The amount of capacity allocated through each segment can then be changed iteratively from year to year. When the value of train-paths allocated in the two segments are (near) equal, there is also an efficient allocation between the segments. See the first part of section 3.4.5 for a discussion on these matters.

3.5.7 Associations in the Advance planning

In the Advance planning there are many predicted train paths that are still only bandwidths. Also, the association is not a line capacity consuming “object”[29] and is therefore not a direct part of any resource usage diagrams of the Capacity model. But they may play an important role later in the scheduling process connecting train paths and is thus something to plan for in the production target. Such “loose” associations are more a declaration that there should be suitable interchanging durations for passengers implementing a passenger flow or that the same vehicles from one (future) train path is to be used in the returning train path.[30]

Being able to assess how well an association is fulfilled or whether it is broken can be difficult in the Advance planning of TTR. On the other hand, an association-like object can fill the need to state that a connection between two "flows" of trains should be there, i.e. specify that two future train paths must be planned so that the passenger transition or wagon transition is practically effective so that a transport flow can be achieved in the running timetable period. This association object corresponds in a sense to the bandwidth that represents a future train path, i.e. it is a generalized object which will later be converted into an association. The valuation of this association-like object would then be similar to that of bandwidths, i.e. it is the nominal value (that the association holds) that forms the basis of the association. A prognosticated adjustment can be added to the minimum association duration (base valuation)

[29] Stations and yards are not part of the Capacity model in the same way as line planning.
[30] There might be a need for a corresponding associations object that specifies a future association between a (future) train path and a set of train paths implementing a more or less regular traffic pattern. This would mean that when the train paths are scheduled and finalized there should be an association between the first train path and one of the train paths in the set.

because the association will probably not be optimally planed (e.g. longer waiting time) based on the probability of the outcome in later scheduling. However, the future characteristics of the association are more difficult to assess than for bandwidth and train paths as it relates two bandwidths where two future train paths will be scheduled. Both of these two bandwidth's train paths can "move" within their time windows, see Figure 2

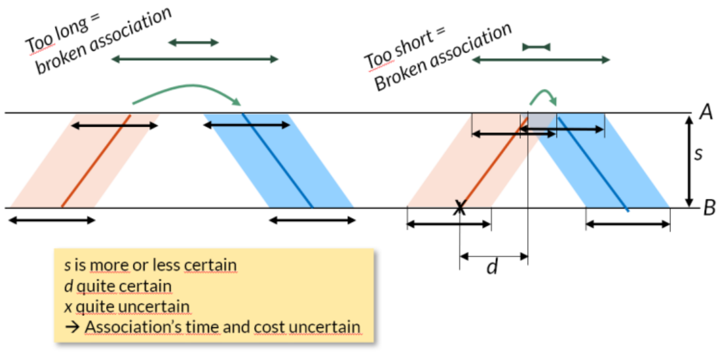

Figure 2. Broken associations.

Depending on how the two train paths will be scheduled the association duration will be determined.

In the same way, it is difficult to specify associations in ATT relating an uncertain future Rolling planning request. The other way around is instead possible, i.e. a rolling planning request relating to an already allocated train path during RTT can be fully valuated. This means that association assessment for Rolling Planning products is expected to take place late in the process when Rolling Planning capacity is translated into train paths, and so is the case for the association between a Rolling planning request and already allocated train paths.

A similar problem arises in the Capacity supply when an association between a preplanned paths and not yet planned but prognosticated train paths (possibly represented by bandwidths) occur. There is a need to represent and valuate these associations socio-economically, but as the bandwidths are not yet scheduled as train paths, it is not clear how the corresponding train path will be scheduled and therefore not the association's properties either.

We have recommended to add a generalized association type to be a complementary relation between bandwidths. The idea is that these generalized association states that there should exist association between two traffic systems, with a maximum association time, in the Capacity supply. These generalized associations are analogous to the bandwidths in that the specify the existence of an association, not the finally scheduled association between two train paths.

3.5.8 Final remarks on Advance planning and uncertainties

Uncertainties are a natural component of all planning activities: to plan is to prepare for an implementation that brings about a result. Therefore, to cope with uncertainties is a core component of the planning activity. The various risks and benefits must be assessed, decisions should be made as the plans evolve. To correctly assess the likelihood for certain things “to happen” and the probabilities for prognosticated facts to become true is essential.

In today's capacity allocation process it is mainly RUs that do market analysis with respect to which trains to run. With TTR and the Advance planning, also IMs need to do market analysis to be able to offer capacity products that are attractive to run, both for RUs but also for the transport buyers. With TTR it gets a shared task between RUs and IMs to develop the offer towards the transportation market. This also include some risk-taking in that it is to some extent uncertain what the market needs will be and that risk-taking is with TTR shared between RUs and IMs.

3.6 Previously proposed components of a socio-economic model for timetabling

This section contains factors or properties for a socio-economic valuation model that has been proposed previously. It is based on the paper "Allocation Principles for Capacity Shortages" (ForumTrainEurope/RailNetEurope 2022a), which proposes several components to possibly be include in a socio-economic valuation calculus for prioritization in conflict resolution. Table 1 contains a compilation of these components together with the possible applicability of them for each TTR process step.

The paper does not address allocation of Rolling planning capacity as it stops at ATT. For Rolling planning capacity, it is important to note that this capacity is reserved and safeguarded through the process steps Capacity Supply and Annual Capacity Allocation. This means that the question regarding the different components of a socio-economic calculation for Rolling planning capacity is (at least) the following.

- When reserving RP capacity, the reservations must defend its capacity against the annual allocated capacity, i.e. the reservations must be motivated as a globally least generalized cost.
- When allocating the RP capacity, the train path utilizing the RP capacity must have a valuation at least as high as was “paid” in the annual timetabling process to make room for the reservation. This point is not mentioned in the TTR process specification (ForumTrainEurope/RailNetEurope 2021, ForumTrainEurope/RailNetEurope 2022a, ForumTrainEurope/RailNetEurope 2022b,c) but is needed as a threshold value in order for the process to deliver a socio-economically sound result in terms of actual traffic performed.

In principle this means that all components used in a prioritization calculus in the annual timetable must also be used when allocating RP capacity during the running timetable period. See also the discussion in section 3.4.5.

During the running timetable period it is possible to apply for and get capacity allocation for up to 36 months, which means that RP train paths may be present in the coming timetable period(s). The capacity allocation is allocated to an RU, i.e. it is an agreement reached between two parties. This means that when performing the annual timetabling process step there might be RP train paths already present as a prerequisite in the schedule. Note that these are already contracted, and it can be costly to breach the contract. It is difficult to specify a cost of breaching this type of contract and include in a socio-economic evaluation. One solution is therefore to let the contract contain some adjustment possibilities to optimize the capacity allocation for coming years if the RP capacity is reserved and safeguarded for longer than in the running timetable period.

In Table 1, the components already tested in socio-economic prioritization calculus are coloured green. The components that are judged as being able to be given a socio-economic interpretation in one way or another (i.e. perhaps not directly but capturing the aim of the suggested component) are coloured yellow. For one case (framework agreements on row 9) a socio-economic valuation for prioritization is irrelevant (i.e. when framework agreements have been signed), which is coloured grey. An ‘X’ in the process step columns to the right marks that it is in the PM (ForumTrainEurope/RailNetEurope 2021) suggested to be applicable in that process step. We have added the Rolling planning process (RTT), not present in the PM, and marked with ‘RTT/Ad Hoc’.

Table 1. Various proposed components of a socio-economic valuation, with colours representing how well an interpretation of the component can be given in socio-economic terms.

	Various proposed components of a socio-economic valuation	CM	CO	ATT	RTT / Ad Hoc
1	Transport distance (paths/slots with CNAs should be counted from the origin to the destination	X	X	X	R
2	Standardised cost of excluded path/slot (per traffic type, also includes the modal shift risk and environmental impact)	X	X	X	
3	Standardised cost of displaced path/slot (per traffic type, includes also the modal shift risk and environmental impact, furthermore the technical constraints e.g., re-routing of electricity-hauled rolling stock to non-electrified line, includes also displacement due to the TCR re-routing)	X	X	X	R
4	Cost for exceeded maximum running time (paths/slots with CNA only)	X	X	X	
5	Line coefficient – multiplication of traffic type weight per specific line (e.g., specific freight lines can give higher costs to freight, high-speed lines to passenger)	X	X	X	R
6	Costs of lost association, turnover time for both rolling stock, locos and HR – (per minute for next slot and traffic type to the extent visible in Capacity Supply)[31] a. Passenger: lost connection or lost integrity and regularity of service[32] b. Passenger traffic coefficient based on the rolling stock capacity and average occupancy. c. Freight: lost feeder and or outflow	X (only a. and c.)	X (only a. and c.)	X	(R)
7	Priority bonus for international traffic (driven by higher effort and costs to organise)[33]	X	X	X	R

[31] A lost association should also consider the turnover, and association with the return journey slot. This consideration would depend on the form of the Capacity Supply.
[32] This provision shall not be an obstacle for competition on the market where allowed, but to contribute to a homogenous timetable.
[33] There are extra costs given that more parties are involved that must agree for international traffic to be carried out. One could argue that the increased cost for organising such traffic should be reflected in higher marginal costs for the traffic (when the international traffic carries its own higher planning costs). However, this in itself does not provide an argument for a priority bonus. Such a “bonus” should reflect the added socio-economic value of international traffic, when such a value exists.

8	Priority bonus for traffic type in a specific period a. Passenger: for instance, bonus for the peak hours b. Freight: for instance, bonus for off-peak hours and night period	X	X	X	R
9	Framework agreements (FA not respected by the IM, multi-annual Rolling Planning capacity)	X	X	X	
10	Thinning or condensing regular traffic, i.e. higher or lower density in regular traffic				
11	Breaking regular traffic patterns				

We go through the rows of the table one by one below.

1) **Transport distance**
Transport distance is a factor in the operational costs for train paths but does not directly affect VTTS for passengers and goods and is thus part of the socio-economic calculus.

2) **Excluded train path**
An exclusion cost arises when a train path cannot be scheduled due to scarcity of capacity and needs to be removed from the plan. The material in this note is also discussed in section 3.3.1.

The exclusion cost must be set in relation to the probability that this train path will be requested by any RU at a later stage, and whether the rail transport demand can be met with other transports and even other transport modes. Thus, the exclusion cost can be difficult to calculate, especially early in the process.

For the advance planning in the TTR's process description, there is no applied train path to anchor the train path, as RUs have not applied for train paths yet. The prognosticated train paths and their properties are identified by other methods, including the time and route they may run. This means that the exclusion cost should be based on the IMs' understanding of the attractiveness of the train paths (i.e. an understanding of the alternative transport cost), both from the RUs' and the society's point of view (passengers and freight transport buyers).

3) **Displacement, prolonged running times, rerouting and changing the path distance**
Displacement and prolonged journey time are both based on VTTS. A displacement cost arises if the train path is scheduled later or earlier than an estimated displacement point. The cost of the passenger's sacrifice differs depending on the type of waiting time (if the passenger is without the opportunity to use the time for something else or if the passenger is able to carry out alternative tasks). When considering all passengers, it is likely that some will be able to perform alternative tasks, whilst others will not. This leads to a displacement time which is valued lower than the VTTS when passengers are onboard the train – that is, a factor between 0 and 1 of VTTS and operational costs for the actual running time is applied. In the Swedish EKG model, the factor is set to 75 % of the running time cost which in turn is based on the foreseen volume and mix of passengers. Similarly, the lead time for cargo that must wait for its transport can be argued to have a displacement cost that is less than the actual VTTS

when transporting the cargo and is also set to 75 % of the VTTS and operational costs.

There is no scientific basis for that the displacement cost should be set to 75 % for all types of transports and train paths. For example, freight trains that implements a transport flow (e.g. bulk trains like iron ore trains, different block train networks etc.) do not have a displacement cost of 75 % of VTTS. Rather they do not have a displacement cost as long as they depart within a certain time window. They often depend on the other train paths in the same regular transport pattern and should have a certain period of time between them. The displacement cost and the nature of it needs to be further investigated in order to set more accurate values than just 75 % of VTTS for all type of train paths.

Any adjustment of times in the timetable stemming from conflict resolution, referred to as wait times and supplements, gives rise to changes in the schedule, i.e. prolongation of journey times, displacement of departure times compared to the given anchor point, and possibly a different route through the network (which will affect not only the distance but also the journey time and possibly also the displacement). It is the difference between the value calculated from the basic running time together with the nominal distance cost with the scheduled travel time, distance cost and displacement time which is the total increased generalized cost for society to conflict regulate the train schedule, as long as all train paths are included in the plan.

A socio-economic calculation based on VTTS without considering customer demand changes works only for small timetable changes (or for volumes of train paths for which small changes are made to the transport time of the volume or flow of trains). In case of major changes, demand will certainly also change and modal shifts need to be taken into account. It varies how hard it is to calculate the alternative cost, from simple (when there is no alternative as for the iron ore traffic in the northern part of Sweden) to very complex, many alternative possibilities including longer train journeys. See the discussion in section 3.3.1 on exclusion costs.

There are models that simulate how a (complete) rational ticket buyers and freight transport buyers will act.[34] These systems are complex both in architecture and data requirements and are used for long term forecasting. It is uncertain whether these systems can be used in actual planning of the running timetable to investigate, e.g., exclusion costs and similar. Potentially, there is a need for more abstract and generalized methods need to include costs for other transport modes as a foundation for exclusion costs.

Environmental costs and other external costs that are not internalized can be added to the calculation together with the operational costs as long as they are expressed as a function of distance, train characteristics (such as electricity or diesel) and/or from running time (the environmental cost is not currently part of the Swedish calculation). In principle, all marginal costs for the transport (costs for the society including RU costs, IM costs etc.) should be part of the cost term, not only the operational cost.

4) **Exceeding maximum running time**
The base time for a train path (prognosticated or applied) is the reference for

[34] See e.g. Trafikverket.se, https://bransch.trafikverket.se/for-dig-i-branschen/Planera-och-utreda/Samhallsekonomisk-analys-och-trafikanalys/trafikprognoser-och-trafikanalyser/prognosmodeller/ (in Swedish)

comparison. For each increase in running time, the cost increases (linearly) according to the calculation values which are essentially based on VTTS. A large cost increase can affect the demand such that it differs substantially compared to the expected demand for the originally specified train path. This can imply that the sacrifice from the intended travellers or the goods becomes too high, meaning that the utility is lost, and the train path has lost its transportation task. The new train path that has emerged may be attractive to other passengers or freight transport buyers, but this train path is not the intended train path that was identified earlier. If this train path is to be offered it should be valued as attracting other demands.

5) **Line coefficient**
For different lines and/or for different time periods, a certain type of traffic with certain performance characteristics is more common than other types of traffic. *Setup times* occur if a single train path breaks the pattern, i.e. more capacity is required to be allocated as a result of the traffic being heterogeneous. The extra capacity allocated and the cost stemming from allocating traffic with deviant performance patterns could be attributed to the train path that breaks the pattern. This is in line with Lean methodology where the amount of setup times is minimized to maximize value-adding production time.

In this way, a “balance” is obtained, not only of the generalized cost of the train paths but also for the "damage" that the violation of the traffic pattern gives rise to. If it turns out, with the setup time also attributed to the deviating train path, that it still is advantageous to have the deviating train path in the schedule, then this deviant train path has “earned” its position in the timetable. If, on the other hand, it turns out that other traffic displaces the deviating train position, then it should not be scheduled there. Thus, breaking the traffic pattern is "paid" by the deviant train path.

This is only relevant if there is capacity shortage, otherwise there should be room for the setup time as well as the deviant train path and ordinary rules apply.

The declaration of the nominal performance (speed) can be made based of previous time tables and/or based on the investment appraisal calculations made earlier, if the line segment is newly built. The distribution of the setup time costs could e.g. be performed proportionally to the number of train path types over, e.g., one hour time frame. From a socio-economic perspective, the cost of the heterogeneous traffic is then distributed over the train types involved, and the more unique a certain train path is, the more this train path has to carry the cost of making room for it.

But given that the performance of two different train types are equal there is no support to give one train type general priority over another type. It is the mix of services whose sum of socio-economic values have the highest utility that should be performed on the infrastructure. If a service is run regularly with many departures, the marginal utility of running one more of that service may also be less than running the first service of another type.

However, there might be reason to classify resources from a practical point of view. For example, on a line with 4 tracks, of which 2 are used for commuter traffic and 2 for other traffic, there might be reason to classify 2 tracks as “commuter tracks” as platforms etc. are built for that purpose, and to simplify the scheduling task (as presumably the scheduling would end up with the commuter traffic on the tracks designed for that traffic anyway). But there is no socio-economic argument that prohibits the use of a service on a particular line segment, or to give a “bonus” for a particular use and thus priority to a specific service type.

6) **Associations**
Associations are directed relationships between train paths that relate them to each other. Associations implements different relations between trains, such as passenger flows, switching of wagons and shared vehicle resources such as locomotives between train paths. They form an important element in a transport network, and thus also need to be valued when prioritizing between different planning solutions, especially if scheduling breaks the association.

The earlier in the process, the vaguer it is how an association is to be represented and if it is valid in different scenarios. For example, in the capacity model, where volumes of traffic are handled, the association is more of a requirement to be implemented later when the actual train paths are scheduled. The associations are not published in the capacity model (RailNetEurope 2022c) but is an important object in the underlying production target. The value of the associations affects the prioritization of the volumes of traffic in the capacity model. See earlier discussions in the first intermediate report (Aronsson, Broman, Odolinski 2024b).

Associations can be of different kinds: passenger flows changing trains on a station, freight wagons shifting trains (block swaps) or even relations between arriving and departing trains at marshalling yards, vehicle associations implementing reuse of vehicle resources (train sets, cargo locomotives etc), and personnel such as drivers. Each of these types have their own valuation, for passengers and goods it is part of the journey and VTTS applies, for vehicles it is the marginal cost based on the vehicle costs that forms the basis of the valuation, and for personnel it is wages etc. All of these can be calculated as key factors usable in the valuation of the association. See section 3.1 for suggestions on how these calculations can be carried out.

It is a harder problem of determining when the association is to be regarded as broken. Associations are implemented as a relation between two train paths. If one of the train paths is e.g. excluded the easy interpretation is that the association is also lost. But that may not be the case as the passenger may find another train (or transport) within a reasonable amount of time implementing the passenger’s next leg on the journey. Associations, if correctly represented, should be regarded as broken only if there does not exist any other train path or transport by another transport mode that implements the rest of the journey for the passenger in an efficient way. Currently this is not implemented, and an association is broken if a lower limit or upper limit is exceeded.

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7) **Cost for international traffic**
There is a political will to support cross-border traffic. A possibility is to compensate operators for the costs associated with the additional administration and organisation that is required of international services. Such a bonus is compatible with the proposed model in the sense that it is not hindered in any way by the introduction of a prioritization model discussed in this report or a similar system. However, the model does not give higher priority to services with high one-off costs such as costs associated with a border crossing in timetabling disputes. This differs from costs that are proportional to travel time, since such costs will show up in the calculations when different options are compared that have different travel time. It is also noted that the best option is, as far as possible, to remove obstacles associated with border-crossings rather than compensate operators for them. This topic is further discussed in section 3.2

8) **Bonus or differentiation**
Bonus is not compatible with socio-economic models which essentially is concerned with VTTS and the generalized cost. In point 5) above, we have sketched a possible socio-economic model expansion by attributing the setup times that occur in heterogeneous traffic to the train path that deviate from the normal performance pattern. This "tool" could enhance the overall efficiency where capacity is scarce by valuating and attributing all planned capacity to the train paths and not just the capacity technically needed to run the train. This will work as a tool for striving towards homogeneous traffic.

To differentiate e.g. passenger types further or differently is possible. The current differentiation is mainly performed by clustering e.g. passengers according to their purpose of travel: business travel, leisure, commuter etc., regardless of when in time the trip is being performed. It is possible to study if there are reasons to believe that travellers' VTTS differ with time of the day also or other factors. It may be the case that e.g. commuters at late evenings adapt to lower service frequences (or accept it as they are aware of that fewer persons travel at that time). Another example would perhaps be that people may value time differently with the area they live in, VTTS in densely populated may differ from sparsely populated areas. But the current available data does not support such a differentiation (as far as the authors of this report are aware). To introduce further or another differentiation demands investigation into how travellers valuate time according to the differentiation chosen.

For freight, the current differentiation by Jaspers (Jaspers 2017) of cargo values being transported is quite crude and only in the value of the cargo, not in the type of cargo. This means that e.g. time-sensitive cargo such as food may not be given a VTTS factor reflecting its time sensitiveness. To be able to give better service valuation, and also being able to approximate the exclusion cost factor (see section 3.3.1 about exclusion modelling) a better differentiation into transported cargo types is needed. For example, the Swedish EKG, based on the ASEK model (Trafikverket 2023), uses 15 cargo types.

9) **Framework agreement**
Framework agreements are signed "separately" from the various process steps in advance planning. Breaching a framework agreement may be costly. The cost of breaching a contract in this context is uncertain, and one way is therefore to make framework agreements that are fully compatible with the socio-economic model used in the capacity allocation process in order for anomalies not to arise. Specifically, it is important that the Framework agreements are signed so that the utility of the future executed traffic (the number of years the framework agreements consider) as a whole is maximized. It would therefore be natural if a socio-economic analysis is made by IMs before any Framework agreement is being signed, in order to predict the impact of the Framework agreement on the delivered services to society.

Since framework agreements are signed several years in advance, and may cover several years, it is important to not specify the traffic in terms of detailed train paths but as safeguarded reserved capacity with room for adjustments. This is beneficial for both IM and signing RU, as no one can predict the future situation. Therefore, framework agreement capacity has resemblance with bandwidths that express the existence of a train path within a certain time window, although the bandwidths within a framework agreement are already contracted through the agreement. A similar case is already assigned Rolling Planning capacity which can be valid up to 3 years.

10) **Thinning and densification**
In the event of congestion, it is common that the traffic contains traffic with regular patterns. Cancelling individual trains in such a pattern is often not relevant as this will leave large time frames without a transport. It is rather the reduction in frequency of train paths that is used to make room for other traffic, for example going from 15 minutes patterns to 20 minutes pattern. The generalized cost for this “thinning” of the traffic can be calculated by valuating the extra time passengers have to wait longer for a departure (alternatively leave earlier than intended). Thinning (and the converse, densifying traffic at the expense of other traffic) is one tool for traffic planners and should preferably be part of a socio-economic priority calculation. We have outlined principles for how this is to be calculated in Appendix A. It is probably more useful to apply this kind of calculation in the advance planning up to forming the capacity supply, as going from one regular pattern to another will have drastic changes on other traffic which is anticipated to be hard to change once the capacity supply is published.

11) **Violation of traffic patterns**
Violating regular traffic patterns can also be calculated socio-economically by computing the extra wait times passengers have to spend. Some passengers will wait longer, some will wait shorter times but overall, the sacrifice is larger for passengers that wait longer than those who happens to wait shorter, see Appendix B for an example.

The “mental” inconvenience that the regular pattern is broken, i.e. remember that a certain departure is slightly displaced compared with the usual case, cannot be valued mathematically. To get a key value of that something like a revealed preferences study or similar must be performed.

3.6.1 About valuating trains and associations rather than passenger/cargo flows

Having a model that values transportation flows rather than train paths require a lot more information. i.e. knowledge about the passenger flows for each OD pair as well as for freight flows. Valuating train paths (bandwidth and/or traffic volumes in terms of train paths) requires less data. In the former the number of onboarding and offboarding passengers and their mean distance travelled over the performed transport has to be known, while in the latter case it suffices with the occupancy rate of the train. Note that it is not the maximum capacity of the vehicles used that sets the limit, rather it is the number of onboarding passengers and their mean distance travelled which gives the end value along the y-axis, see Figure 3.

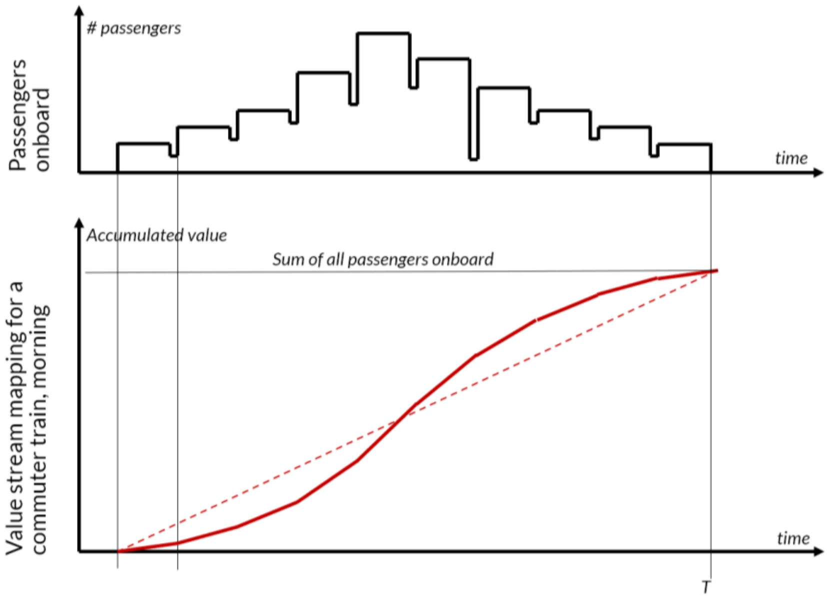

Figure 3 Number of passengers onboard as a function of time, and the corresponding value stream mapping

In Figure 3, the linearization of the curve shows the effect of approximating the actual value stream mapping with a linear model, where the exact behaviour of the on/offboarding passengers has been abstracted away. There is thus a trade-off between the simplicity of just having an occupancy rate of the train path as a whole and the (more correct) model where each individual passenger flow has to be modelled, something that requires a lot of more data.

4 A proposed model for a Socioeconomic model for TTR

The proposed model is inspired by but simplified with respect to the SPC, which is a currently used method for railway capacity allocation using prioritization criteria based on socio-economic principles. The proposal is to develop this model in a number of ways (summarized in section 5) in order to simplify usage, improve performance, adapt it to the requirements of countries where it is not currently in use, ensure that the specific requirements of international traffic are met, and ensure that it is usable throughout the phases of the TTR process.

The current section presents the proposed model through three perspectives. Subsection 4.1 introduces a spreadsheet model that is attached to the report. In 4.2, reflections on the report are presented concerning its likely performance in terms of fostering competition and prioritizing traffic that generates the most welfare to society. Subsection 4.3 comprises a few idealized examples of how the model is to be used in different situations, and of its outcomes.

4.1 The spreadsheet model

A demo version has been developed as a spreadsheet model which exemplifies how the results from WP2 can be used to form a basic pan-European socio-economic model. The demo spreadsheet model serves the purpose to show how a socio-economic model can be used for traffic prioritization, i.e. planning and scheduling compromises in order to form a feasible running timetable without resource conflicts.

The spreadsheet model of a pan-European socio-economic prioritization model includes calculations of association costs, with separate sheets for passenger trains and freight trains. Here it can be noted that the VTTS vary depending on passengers' trip length. In the cost calculations for associations, one need to consider a mix of passengers with respect to trip length. The spreadsheet model assumes different shares of passengers depending on the type of train. The user may define a completely different mix.

Like the other cost calculations in the spreadsheet model, the passenger VTTS (waiting at interchange) for the associations are collected from Wardman et al. (2012), whilst the passenger train cost (investment cost etc.) are retrieved from the SPC given the lack of standard values for Europe. Moreover, the freight VTTS and freight vehicle costs presented in JASPERS (2017) are used for the freight associations.

The issue with low VTTS for freight traffic is currently handled in the same way as in the Swedish EKG model, the so called "S-factor" ("speed factor"). This factor does not have a scientific foundation but is used in the Swedish EKG, where it is motivated by the EU directive 2012/3434: "The importance of freight services, and in particular international freight services, shall be given adequate consideration in determining priority criteria."[35] and by the Swedish regulator's ordinance and regulations[36] restating the directive text. The VTTS for freight transports was discussed in the first intermediate report of this project (Aronsson, Broman, Odolinski 2024b).

It should be noted however that the valuation of freight traffic is somewhat problematic in the EKG. The VTTS for freight is calculated from the financing cost of the goods/cargo being transported for (changes in) the duration of the trip, and this financing cost is then multiplied by the somewhat arbitrary S-factor that can be either 4, 6 or 8 depending on the segment. The motivation for the S-factor is that the VTTS would otherwise be so low as to give freight traffic virtually no priority. The underlying problem behind the low VTTS values is that the financing costs alone might not capture the full cost of delaying a freight train. There is no scientific support for the S-factors. But is there reason to believe that the VTTS for freight in EKG is too low? And is this aspect captured in the VTTS provided by JASPERS (2017)?

Here it can be noted that the financing cost of the goods/cargo in EKG – i.e., the value that the S-factor is applied to – is based on the cargo value combined with an interest rate for capital lock-up and logistical effects with respect to transport time, which is similar to the cargo value defined in JASPERS (2017). The logistical effects consider transport reliability that decrease the variation in transport times which makes it possible to decrease the stock levels. It is thus not only the value of the goods and the interest on them that make up the value of freight transport, but also transport time reliability. Still, even if the VTTS in EKG (or in other countries) seem to include all the cost components, there is reason to investigate whether the values are too low when freight traffic is given virtually no priority in the calculation model.

[35] Directive 2012/34/EU, Article 47.5
[36] The Swedish regulator Transportstyrelsen, Regulation TSFS 2022:32, chapter 3, 2§: "Prioriteringskriterier i järnvägsnätsbeskrivningen ska vara utformade så att de i tillräcklig grad beaktar betydelsen av godstransporttjänster, särskilt internationella sådana."

This is also the case when applying the VTTS provided in JASPERS (2017). However, it should be highlighted that any modification of these values needs to be based on empirical evidence indicating what the true VTTS for cargo is.

The model was designed with some main principles.

- It should, as much as possible, be based on data available on a European level. The proposed model is mainly based on data/values recommended by the Commission (2021) and the European Investment bank (2023).
- It should be configurable to different situations regarding passenger/freight properties.
- It should be configurable to different train types (e.g. seats / length /weight, performance (e.g. speed) etc.

In principle it is a function from the valuation data found in a framework for socio-economic valuation. We have used the sources listed above in formulating the example model and in the examples. Input to the function is a declaration of the volume of passengers / cargo mix, and a train declaration. Output of the function is a value of running this train one hour.

The mix is declared in terms of the available data types in the underlying valuation model. In the case for passenger trains, these types are business passengers, commuter passengers and other passengers. For freight, a mix of the values transported is instead available in the underlying data.

For freight transport the operational costs can be calculated using data from JASPERS (2017).

The lack of studies on operational costs for passenger traffic has been handled in the spreadsheet model by taking the values from the Swedish transport appraisal guidelines (ASEK) as a basis and scale it according to GDP per capita to get a pan-European operational costs. The use of values from ASEK should be seen as a feasibility check of the model (but can also be a short-term solution).

The model does not implement exclusions of trains. We have in 3.3.1 discussed how this may be addressed in the long term as well given a suggestion on how to solve exclusions in an Ad Hoc manner in the short run.

The example model implementation calculates the VTTS in a few steps.

1) Calculate a general mix of passenger types, in terms of percentages, getting a normalized passenger for this category.
2) As the underlying data classified the travellers in the number of kilometres they travelled, a mix of these distance classes is also calculated getting a normalized passenger and distance travelled value for the mix chosen.
3) Lastly, the occupancy rate is applied to the value of the typical passenger (mix and distance travelled)
4) The shift cost is calculated, in the example model it is set to 75 % of the VTTS value. This is the same as in the Swedish EKG model.

The value could easily be changed, as more research has been made. The argument for having a lower value for displacement of e.g. departure is that the passenger may use this time to other tasks while waiting.

For passenger trains, the exclusion value should ultimately be calculated as the alternative transport available to passengers (train or other transport mode) and its VOT value. Lacking this, we propose a short-term solution (while this is researched for a viable solution) to set a percentage to the VTTS value of the basic transport. We have not implemented this in the example model, but the Swedish EKG and the Swedish Network statement declares how this can be done.

For freight trains, the underlying data is given as a price per tonne depending on the values transported. This classification is quite crude in the underlying data: < 6000 €/tonne, 6000-35000 € / tonne and > 35000 € / tonne.

1) A typical tonne transported goods is calculated using a percentage of the three cargo value classes.
2) A displacement cost is calculated in the same way as for passenger trains, i.e. 75 % of the cargo mix / tonne of the VTTS value.
3) The volume of the train class is applied to the cargo mix's value, giving the total value of this prioritization category.

In our example model we have also calculated the value on board. These values are part of the exclusion costs, depending on the alternative transport available (train or other transport mode). As proposed in section 3.3.1, the short term solution could be an exclusion cost consisting of a percentage applied to the transported value. The reason for this is that some transports, if not performed on railway, will simply not happen (i.e. 100 % loss) down to just a fraction of the transported value (e.g. 10 % or less), depending on the content.

For associations it is similar calculations, but depending on the association the cost per hour for the association is based on the vehicle costs (vehicle associations) or passenger/cargo volume and mix.

The spreadsheet model is attached to this report and is used to calculate various test cases to see the relative comparison of different combinations of passenger and freight trains. The following aspects are important to note when using the model.

- It is the sum of the relative increase of the generalized cost that is to be measured and compared between different scenarios, not the total values. This means that, e.g., a long and short distance train within the same category may have the same increase in generalized cost.
- It is the total value of the scenario with all trains (a conflict-free schedule) that should be compared with other (conflict-free) schedules in other scenarios. The intended use is not to solve train by train conflicts.

A small scheduling example showing the intended use of the model is presented in Appendix C.

4.2 Reflections on the proposed model

The model allows for free market-entry and does not prevent competition. There is for instance no advantage of incumbency or size in the allocation of train paths, and nothing that makes monopoly pricing more likely than in current practices. However, the model does not remove opportunities that IMs currently have to use market-distortionary policies. There are also exceptions to the main conclusion, albeit in unusual situations, where market-entry is problematic under the rules of the model.

A potential problem could be if train services with more passengers were valued higher in conflict resolution. On the face of it, this would not be unreasonable: A change in e.g. travel time has a larger effect on socio-economic outcomes if it affects more travellers, all else being equal. But since new entrants on a market typically start out with fewer passengers than incumbents, this could cause barriers-to-entry in practice. As it is, the EKG does not use the passenger numbers of individual train services, but instead uses template values for classes of services. Because of this, incumbents and new entrants are treated equally in this regard.

However, there is a paragraph in the Swedish Network Statement that describes how new entries to the market should be treated, see appendix 4B, section 4.4 “Identification of priority categories when commencing new traffic”. The model proposed in this report implemented in a spreadsheet example file makes it easier to adapt the number and mix of passengers (similar for volume and type goods) to the service being classified. For example, it is easier for both the RU and the IM to declare and use own categories as well as check that the declared properties are feasible, e.g. that number of passengers on board the service matches the train type and vehicles used for the transport.

Monopoly pricing, and high prices that are possible because of strong market positions short of monopoly, is damaging to welfare and should be avoided. In particular, a good capacity allocation method should not favour monopolies (or near-monopolies). The proposed model does not favour monopoly. For instance, it does not automatically prioritise train services higher if they can raise prices.

However, the proposed model does not address various market-distorting behaviours. It remains possible for IMs to give higher priority to services with good connections, which risks favouring incumbents that tend to have larger networks. Railway markets typically have few competitors, both on open-access markets and on public tenders, which means that oligopolistic behaviour is a recurring problem; this situation does not fundamentally change with the proposed model. Incumbents sometimes have better access to trip-planning tools used by travellers, and similar advantages, which is something the proposed model does not address.

Examples can be found where, in unusual situations, the EKG is a hindrance to perfect competition. In one case, two train-paths were available for fast long-distance passenger trains just after one another in the morning rush hour. The incumbent asked for both train-paths while the market entrant, with its smaller capacity, asked for one of the train-paths. In this case the IM found that the track capacity would be more efficiently used if both train-paths were used with trainsets that had the same top-speed and braking and accelerating characteristics, and it therefor handed both train-paths to the incumbent. This is clearly an example of incumbency advantage.

The CM does not generate problems regarding competition within segments, as no train paths are yet published. There is however competition between segments. As such, the socio-economic model should be the guarantor of a fair and efficient distribution of the available capacity between segments.

For the supply, the preplanned train paths must contain certain adjustment possibilities so that several different vehicle types can be used. Also, they should state “room for X stops” rather than “stop at A, B, C “. This may be in conflict with the commission’s proposal in article 8 “connectivity and accessibility”, as the operator may be the final one to make a decision.

For the annual timetable (ATT) and residual capacity, the “normal” procedure applies – that is, competition for capacity occurs in the application for capacity. The pre-planned paths must be stable through ATT, i.e. when applied for, they must be implemented.

4.3 Experiments

For the first (and simple) set of scheduling examples, we assume a small network as shown in Figure 4. More extensive examples are given in section 4.3.2.

In all examples we have used optimization software to calculate the solutions, where the socio-economic valuation has been used as the objective function.

For the scheduling examples the model for conflict freeness is somewhat simplified compared to the ones used by IMs. It handles stations with meeting possibilities expressed as the number of simultaneous trains at the station[37], single resource allocation is performed for all line segments, i.e. they behave as signal blocks with only one train at a time. Single track lines handle both oncoming traffic as well as speed heterogeneity. Double track lines are seen as two single track lines with one-way traffic on each line. No additional durations for acceleration or deceleration have been added to the simplified conflict resolution model[38]. This is sufficient to test the socio-economic model although in reality more requirements of the schedule are required to achieve conflict-freeness.

4.3.1 A small prioritization example

The first example is a small one, the aim being to introduce the workings of the model. The small network used is shown in Figure 4.

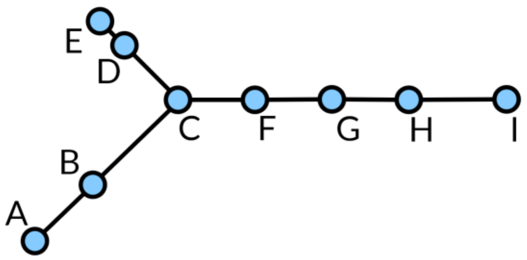

Figure 4. Small network used in the example scenarios below.

The distances for the line sections, A to E is 48 units, and from station E to station I the distance is 96 units. The distances are used to calculate the operational costs but, in this example, they will not affect the solutions as there is no change in routes for the example trains. The values used to calculate the socio-economic valuation of the scenarios are the ones in the spreadsheet model.

Two scenarios are constructed and compared. The basic data is shown below in Table 2 and Table 3.

Scenario 1 in Table 2 shows 6 trains to be scheduled on the small network in Figure 4 with their basic properties and, in particular, their prioritization categories, where WLFT and IMFT are freight train types while RSPT and RCPT are different regional train types (see also list of abbreviations presented earlier in the report). Running times (the lower row in the second column that also show the route) are given in minutes while other time values are in hours. The occupancy column ('Occ') states the occupancy rate onboard compared to the nominal weight/number of seats given in the model.

Table 2. Scenario one, showed with dashed lines in the figures.

ID	Path & running time duration	Dep min	Arr max	Anchor	Prio	Occ
1	`A-    -B-     -C-     -D-    -E` `9.7    17.0    12.1    2.4`	0.0403	1.0083	0.2017	WLFT	100 %
2	`A-    -B-    -C-    -D-    -E` `4.8    7.3    4.8    2.4`	0.2017	1.0083	0.4833	BTFT	100 %

[37] The capacity for all stations is two simultaneous trains, except for station D which has capacity of one train. The idea is that D is a point in the network to, e.g., a terminal just before arriving at station E.
[38] This was a simplification that made the mathematical optimization model much simpler and do not change much of the intended use, which is to exemplify scenario calculation with, e.g., differences in the prioritization categories for the trains.

3	E- -D- -C- -B- -A 2.4 4.8 7.3 4.8	0.2017	0.8067	0.3630	IMFT	75 %
4	E- -D- -C- -F- -G- -H- -I 2.4 4.8 7.3 4.8 4.8 4.8	0.0807	1.0083	0.3227	IMFT	75 %
5	E- -D- -C- -F- -G- -H- -I 2.4 4.8 7.3 4.8 4.8 4.8	0.0807	1.2102	0.4033	RSPT	50 %
6	I- -H- -G- -F- -C- -D- -E 4.8 4.8 4.8 7.3 4.8 2.4	0.0807	1.2102	0.4033	RSPT	25 %

In the two last rows, train 5 and train 6, have prioritization category RSPT. These values are the ones that change in scenario 2 compared to scenario 1, no other data is changed, scenario 2 is given in Table 3. The coloured cells show the difference between the two scenarios.

Table 3. Scenario 2 showed with solid lines in the figures.

ID	Path & running time duration	Dep min	Arr max	Anchor	Prio	Occ
1	A- -B- -C- -D- -E 9.7 17.0 12.1 2.4	0.0403	1.0083	0.2017	WLFT	100 %
2	A- -B- -C- -D- -E 4.8 7.3 4.8 2.4	0.2017	1.0083	0.4833	BTFT	100 %
3	E- -D- -C- -B- -A 2.4 4.8 7.3 4.8	0.2017	0.8067	0.3630	IMFT	75 %
4	E- -D- -C- -F- -G- -H- -I 2.4 4.8 7.3 4.8 4.8 4.8	0.0807	1.0083	0.3227	IMFT	75 %
5	E- -D- -C- -F- -G- -H- -I 2.4 4.8 7.3 4.8 4.8 4.8	0.0807	1.2102	0.4033	RCPT	50 %
6	I- -H- -G- -F- -C- -D- -E 4.8 4.8 4.8 7.3 4.8 2.4	0.0807	1.2102	0.4033	RCPT	25 %

The optimal solution to the first scenario is shown in Figure 5 with a value (cost) of 6193. The two timetable graphs share the section C-E; hence all trains are drawn in both graphs. The anchor points and time windows are shown at the bottom of the graph. We have not implemented any exclusion values in this model. No trains are thus excluded in the calculations which means that if the underlying optimization model would not have been able to schedule the train paths it would have given the result "unsatisfiable". Since this did not happen, the schedules given by the optimization model are correct (as long as the exclusion values are higher than the increased generalized cost, for all train paths in the example).

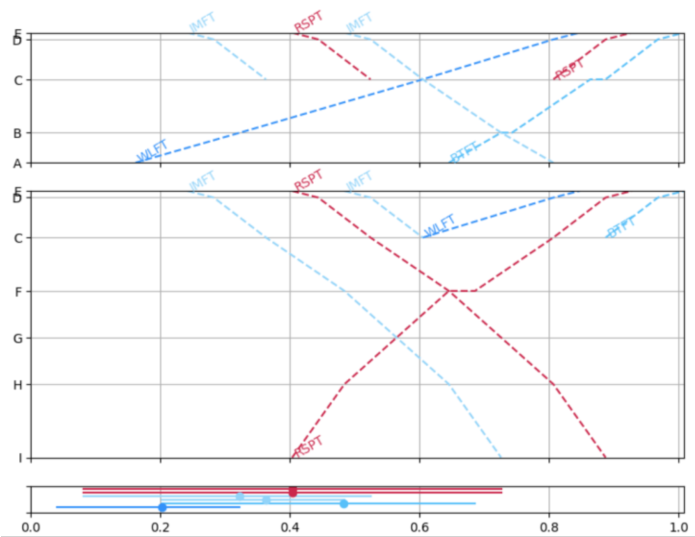

Figure 5. Schedule for scenario 1.

For scenario 2, the prioritization category for train paths 5 and 6 are changed.[39] Just retaining the old schedule will imply a cost of 19 569 which is higher than in scenario 1 due to the change of prioritization category for train 5 and train 6. A new schedule is generated when using the new categories' cost coefficients, as shown in Figure 6.

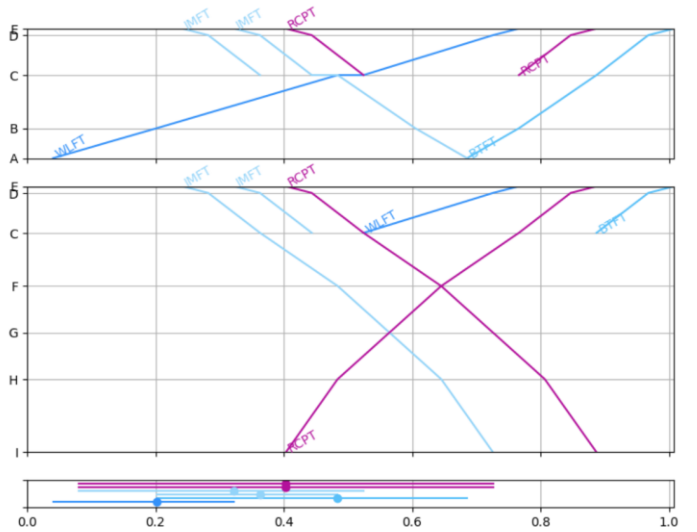

Figure 6. Schedule for scenario 2.

This new schedule has the optimal value 19 246, a decreased cost of 323. As can be seen no regional trains (RCPT) waits at the station F in Scenario 2, while the other trains from scenario 1 have changed schedules which is more visible in Figure *7*, where the two optimal solutions are compared against each other.

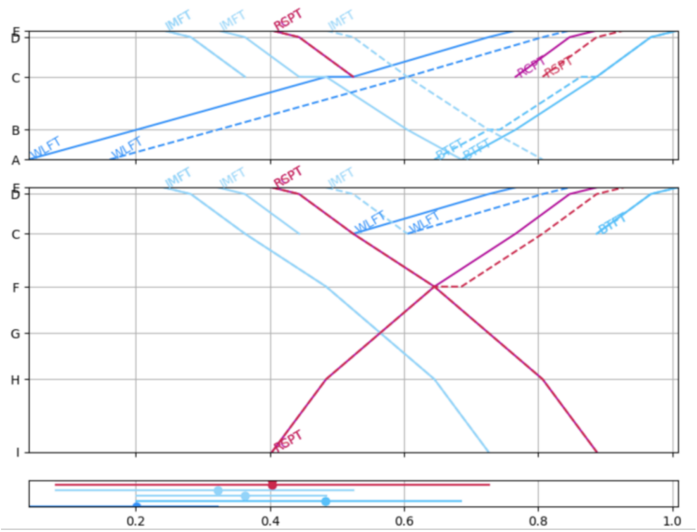

Figure 7. Plotting the two schedules in the same graph.

It is not the absolute values of the schedules that should be compared or analysed, it is the scheduling improvements with respect to the objective function (the generalized cost) that is the key result when applying the socio-economic model to scheduling.

[39] For example, higher demand due to changed interregional traffic patterns which could in turn stem from factors outside the railway traffic system.

4.3.2 Larger examples

In this section four larger examples are given. For the capacity model examples we have used the area measurement model to measure the capacity usage, see 4.3.2.2. “Conflict freeness” is checked whenever a bandwidth starts on a line section by adding all overlapping bandwidths’ heights (resource consumption). The result is accumulative diagrams, showed in figures in the examples. The requirement is that nowhere should the resource consumption exceed 1.0 of the normalized available capacity on the line section.

The execution times on an ordinary laptop are less than a couple of seconds. But one should bear in mind that job-shop scheduling problems are in a complexity-class called NP-hard, meaning that complexity increases exponentially with problem size. That does not mean that one may find good solutions to large problems, but the execution time to find one can be hard to predict. This is a general property for job-shop scheduling problems and not specific to the particular problem of scheduling train paths to be conflict free.

4.3.2.1 Network

In the next set of scheduling examples, we make use of the slightly more complex example network illustrated in Figure 8. The nodes A3 – A6 represents a narrower area, with regional traffic implemented together with commercial trains starting/ending at A4 and passing A3. Freight volumes starts/ends in A6. A1 represents a terminal or similar infrastructure situated somewhere in the countryside and cargo flows to/from A1 to A6 and P1. P1 is a harbour terminal or similar. X1-X2 represents a small town with commuter traffic. The commercial passenger traffic starts/ends in X2. X3 is not part of the test network, it only indicates that that the network is extendible, and that there might be additional traffic in Country X (to facilitate discussions about scenarios tested in the study).

For the first three examples the geographical network in Figure 8 is used. In the last example a slightly changed version is used.

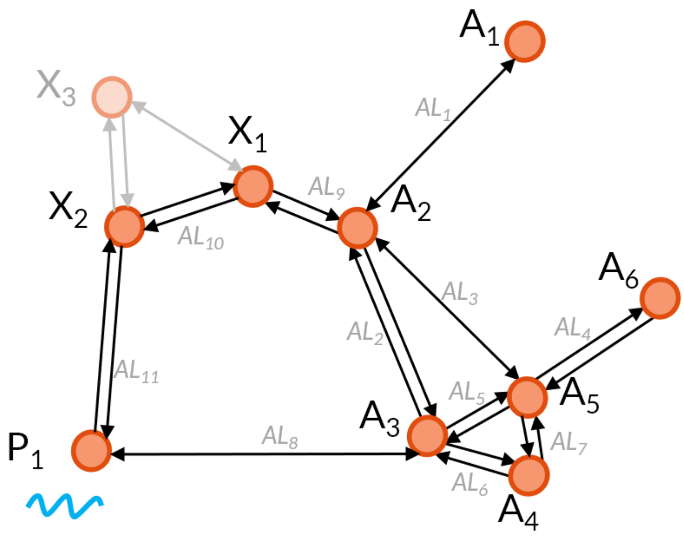

Figure 8. Network used in the first three examples.

The line segments have the following data

ID	Node	Node	Distance	Track speed Average over distance
AL1	A1	A2	250	160

AL2	A2	A3	140	200
AL3	A2	A5	150	100
AL4	A5	A6	25	70
AL5	A3	A5	25	80
AL6	A3	A4	23	80
AL7	A4	A5	15	70
AL8	A3	P1	115	140
AL9	A2	X1	52	120
AL10	X1	X2	35	90
AL11	X2	P1	150	200

These line section also contains stations or operational points, which are visible in the detailed schedule diagrams below named “dp” and a consecutive number. Between these operational places we have not implemented any signalling blocks, an allocated train path occupies the whole stretch between the operational points. All trains can use all line section.

Each line section has a maximum speed, which is not dependent on the train type. Each prioritization category has a maximum speed (inherited by the train path). The minimum value of the line section’s speed and the prioritization category’s speed is chosen to calculate the running time duration.

There is commuter traffic (pink in the graphs), commercial passenger trains (green in the graphs) and two types of freight trains, (two blue colours in the graphs). The commercial passenger trains go between nodes X2 and A4, with a commercial stop at A2. Commuter traffic go between X1 and X2, and between A3 and A6 passing A5. Freight trains have more varying origin-destination pairs, A6 to A1, A1 to P1, and P1 to A6. There are 130 regional trains, 22 commercial trains and 18 freight trains making a total of 170 trains in the examples.

4.3.2.2 Planning method for the Capacity model

For the capacity model we use a capacity measure based on the area occupied by the prognosticated train path. This area is transformed into a bandwidth with a width corresponding to the time window in which the service is valid. When the occupied area in the graph is divided with the duration of the time window, a resource occupation height is calculated, see Figure 9.

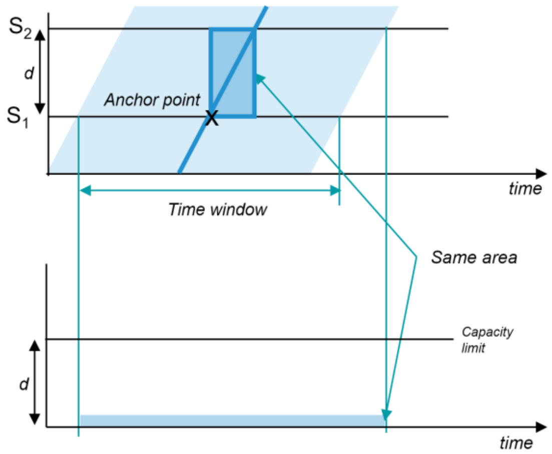

Figure 9. The relation between a prognosticated train path and a transportation path (bandwidth).

With this measure it is possible to calculate the general resource usage over time, aggregated into segment types, without scheduling the prognosticated train paths. As all bandwidths for a prognosticated traffic are accumulated over time for a line segment, we get something very closely related to a capacity model. As the area is equal to the occupancy of the prognosticated train path (and, if the prognosis is correct, a later constructed "real" train path), the socio-economic value of the bandwidth can be calculated.

There are a number of benefits with this capacity measure, as well as some drawbacks. The largest advantage is that the resource usage plan formed by the accumulated bandwidths over time does not determine the train orders and the detailed schedule while still being able to reflect the congestion situation over time. By aggregating the areas of the same product segment type we get the volume rather than the individual bandwidths, thus showing the resource use of the different product types while not displaying the underlying individual transports. It has also the advantage to capture some kinds of uncertainty, e.g. two train paths within the same segment, each of them having a probability of 50%, will sum up to one "slot" in the capacity model[40], as the different segment types are added together within a time frame.

In subsequent sections a couple of examples based on the network and traffic are described.

4.3.2.3 Example 1: From CM to supply and scheduled traffic

This first example shows the process steps Capacity model and Capacity supply/Annual Timetabling with use of socio-economic valuation. We have used the more abstract model for resource planning, presented in the first intermediate report, as a proxy method for resource planning in the capacity model. As the objective function to optimize on, we have used the socio-economic valuation for the basic case of the prognosticated train path, i.e. the train path scheduled with no wait times as if it is undisturbed on the network (case 1 in section 3.3.1). The uncertainty of additional wait times to find a feasible schedule in later process steps is represented as a time window around the prognosticated train path, thereby creating the capacity consumption area used to create the bandwidths in the capacity model.

In the capacity mode, the traffic may take other routes than originally specified through the network if it still passes the specified via-stations with commercial activities and if that gains the socio-economic value and the resource consumption, checked by accumulating the areas over time, is still within their limits. The result for the example traffic is shown in Figure 10.

[40] This is, from a probability point of view, an oversimplification. Two transports with a 50% likelihood will lead to 25% chance of both showing up later, 50% chance that one of them is realized and 25% chance that neither of them will show up. Nevertheless, many budget forecasts are performed this way.

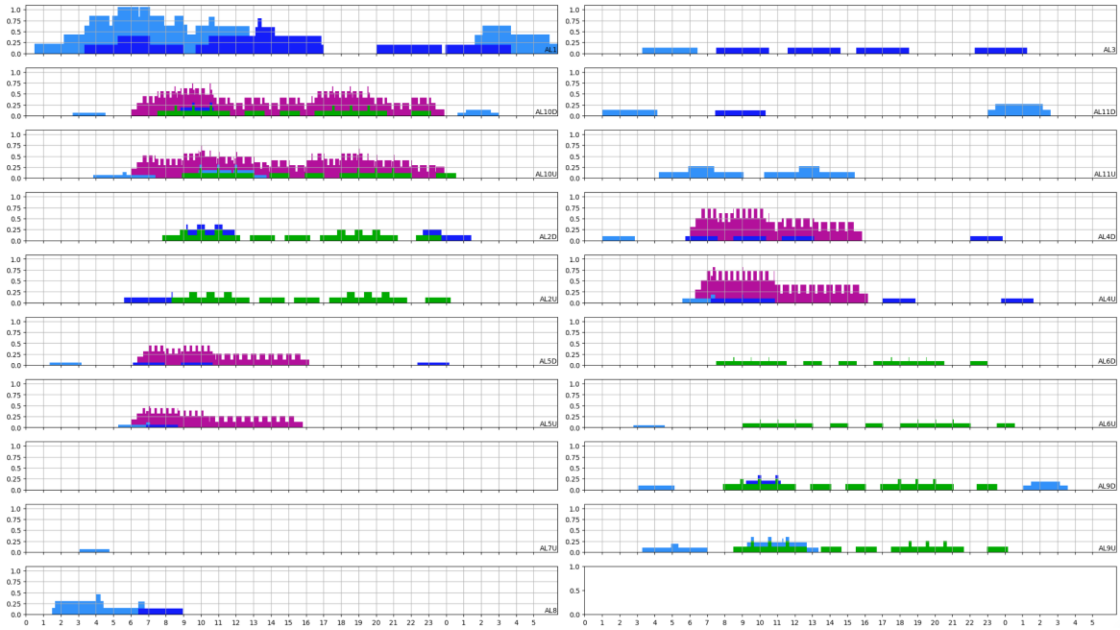

Figure 10 Capacity model computed from the Area-based capacity method. Note that double track lines are shown with two diagrams, one for each direction

The result, containing some rerouting of a couple of freight trains (shown by the optimization to be more efficient) is then used to form the specification of the more detailed scheduling problem, where train orders, meetings/overtakes etc are planned. The time windows introduced earlier forms the scheduling opportunities for each train path, visible in the graph as light-coloured areas around the actual train path. The train paths must fit in this time window in order for them to be valid catalogue paths with respect to their original specifications. The result of the scheduling process is shown in Figure 11. The objective function is the socio-economic valuation calculus presented in this study as the "spreadsheet model". In this particular case we have used the European average costs for displacement, prolonged journey time etc.

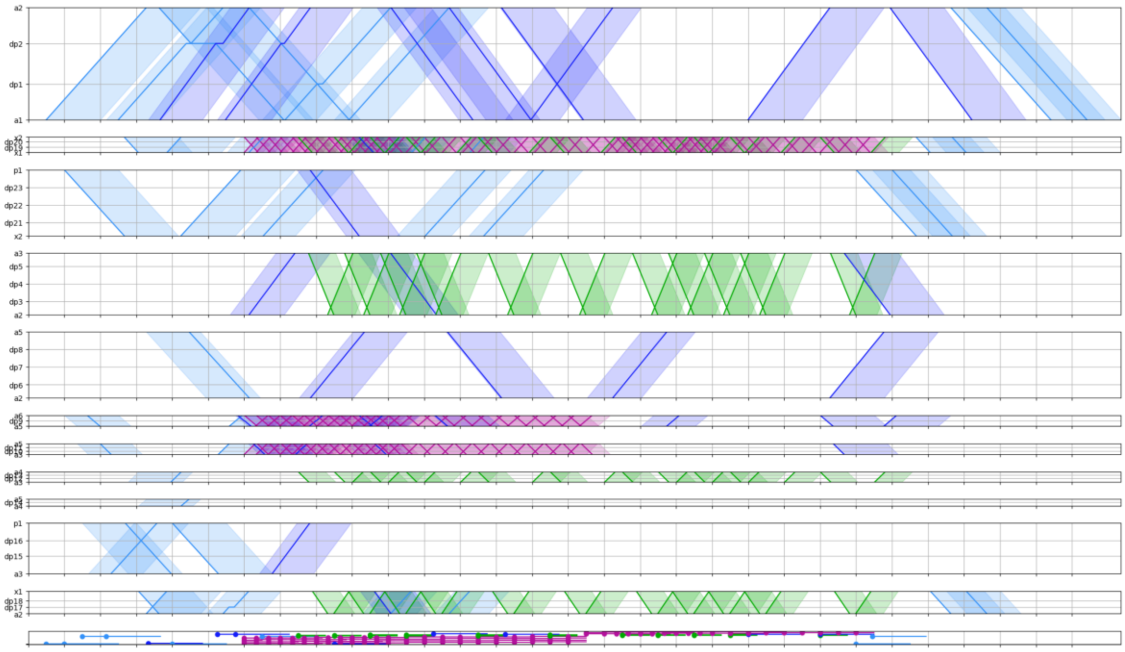

Figure 11 Schedule computed from the time windows used in the capacity model, as well as the routes used (computed) in the capacity model

This example exemplifies the basic process flow and that the use of the socio-economic valuation through the process is possible to perform.

4.3.2.4 Example 2: TCR re-routing

The next example shows an example where part of the infrastructure on the line section AL2 is closed, leading to single track operation between the nodes DP2 and DP3 where switching possibilities exists between the two tracks and also to reduced speed on the available track (due to speed restrictions caused by the track work on the other track). This affects all traffic in both directions.

First a capacity model is created where traffic may be rerouted due to capacity limit on AL2. The socio-economic valuation shows that some freight trains have the possibility to take other routes, while the commercial passenger trains rather take the original route but with some prolongation of the journey time (as these trains that starts in A4 and must pass the commercial stop in A2 it is still “cheaper” to pass the track works rather than also using AL3 or AL8 and AL11). The result is shown in Figure 12. Compare this to the nominal case shown in Figure 10.

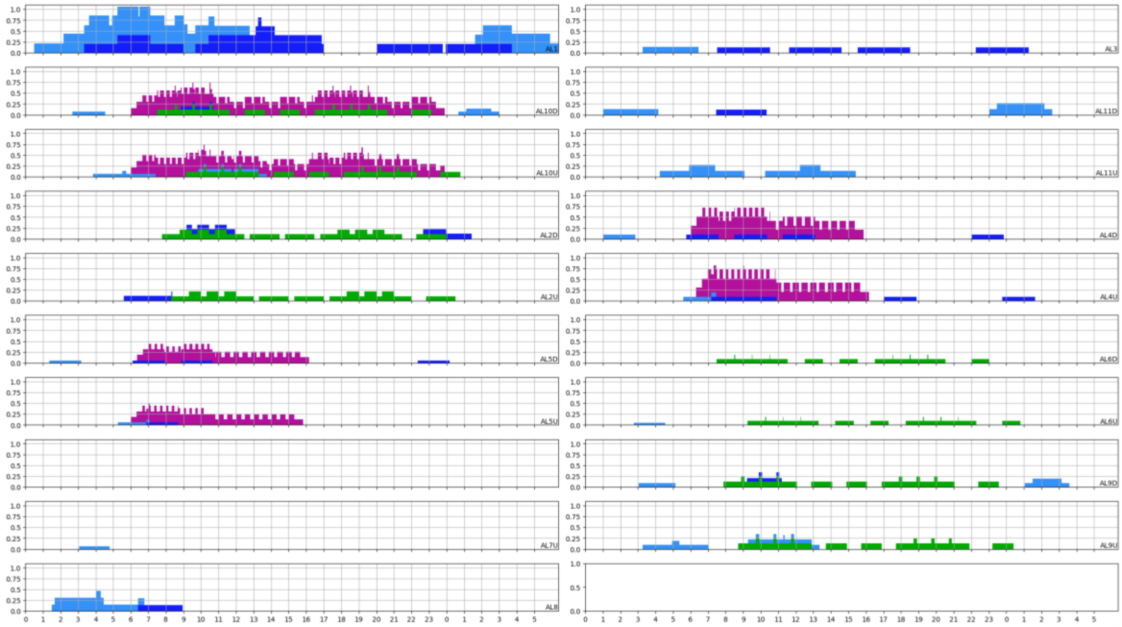

Figure 12 A capacity model when a TCR is introduced along line section AL2.

The output of the capacity model, optimized with respect to the socio-economic valuation for the prognosticated train path's basic case, is then used as input to form a detailed schedule, resembling the case going from the process step Capacity model to Capacity supply and the Annual timetable. The result of optimizing the detailed schedule based on the capacity model is shown in Figure 13. The arrow point to the tracks where the TCR is located, and the reduced speed is visible in the diagram. Compare this to Figure 11.

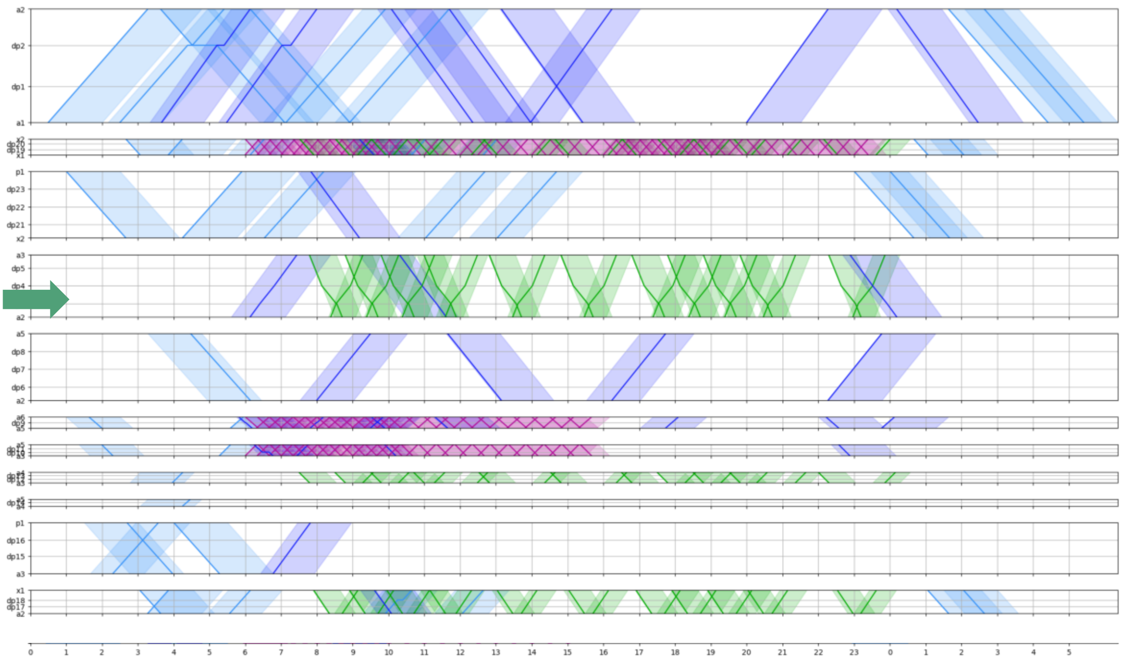

Figure 13 Detailed schedule (ATT) of a scenario with a TCR between operational points DP3 and DP4 leading to single track operation and reduced speed.

The following table shows the difference between undisturbed traffic and the TCR case

	No TCR, wait times : shifts	TCR, wait times : shifts	TCR additional cost
Regional/commuter	0 : 1.36	0 : 0.13	-8775
Commercial passenger	0 : 0.16	4.97 : 1.54	81120
Freight	2.86 : 7.90	4.29 : 7.82	1772
Total	2.86 : 9.42	9.26 : 9.49	74117

The reason why the regional traffic gains is that the TCR is on a line where the regional traffic is not present and therefore may gain by the other traffic being e.g. rerouted or more outspread. In reality the regional traffic would still go as the nominal undisturbed timetable, we have not implemented the possibility to freeze timetables for certain product segments in our example software.

4.3.2.5 Example 3: Scheduling order with respect to train types vs. cost benefit analysis

The third example compares the difference of using a fixed planning order based on train types with using socio-economic valuation as the basis for prioritization, using optimization. The fixed planning order is simulated by multiplying the regional and commuter traffic's cost with a scaling factor of 100 while freight traffic is scaled with a factor of 0.01. By this scaling we in principle get the same effect – it is very expensive to shift regional traffic while it is very cheap to move freight trains.

The result for the detailed schedule is shown in Figure 14. It is visible that the commercial trains (green lines) are moved within their time windows, as are the freight trains (blue lines). In principle, the commuter trains' schedules move the commercial train's schedule a bit, which in turn moves the freight trains even more. Compare this with the case where the socio-economic valuation calculus is used as the basis for the optimization Figure 15.

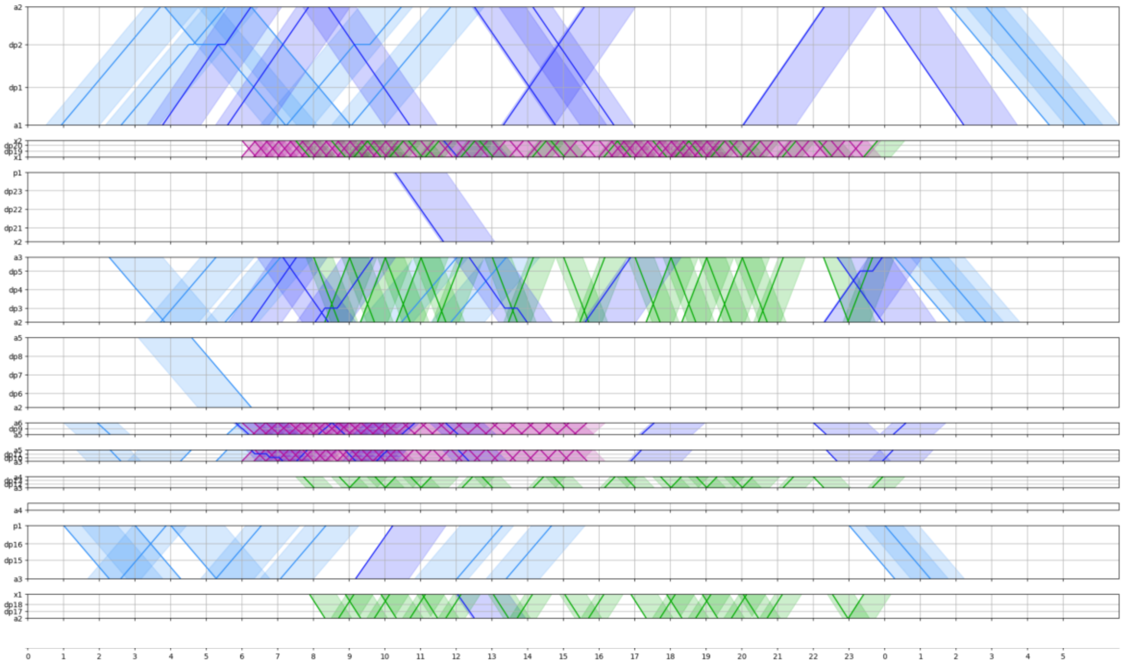

Figure 14. Scheduled according to train types: regional and commuter first, commercial passenger trains next and last freight trains.

When comparing the two schedules it is important to remember that the socio-economic calculus is used to value the additional time and distance to find a valid schedule. Using the socio-economic valuation to compare the two schedules, the first schedule is 91 % worse in added generalized cost than the schedule where the socio-economic calculus is the basis for the optimization.

- Basic cost: 1 536 468 €
  (i.e. the same as in undisturbed capacity model)
- Scheduled cost: 1 573 593 €
  Increased generalized cost due to capacity scarcity (conflict resolution): 37 125 €

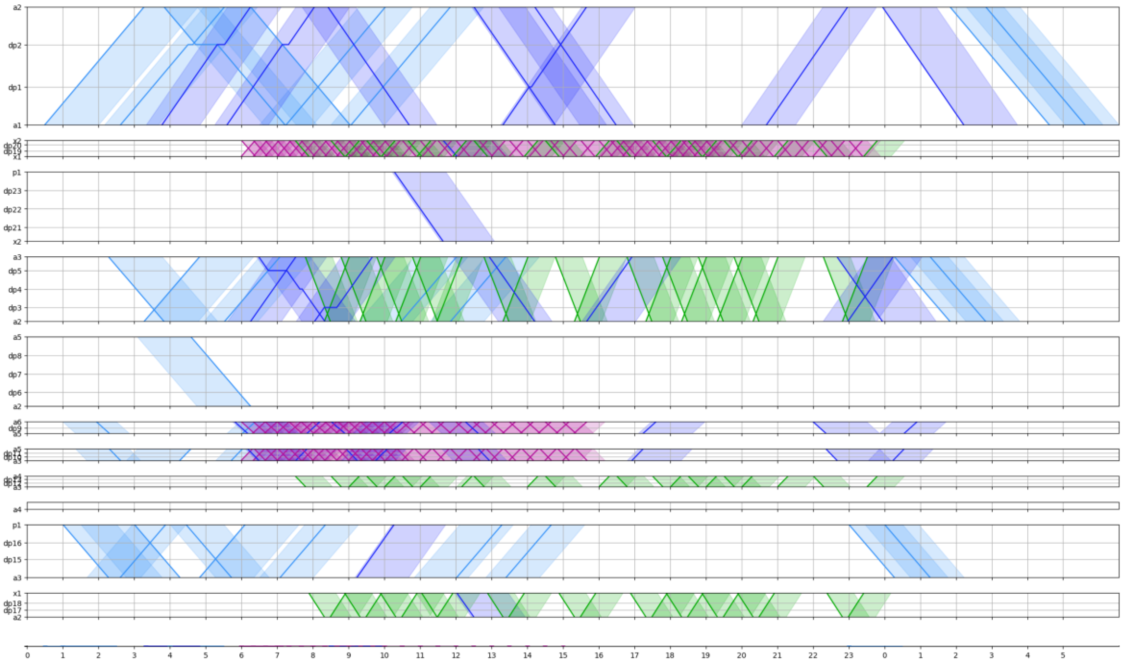

Figure 15. Scheduled according to socio-economic calculus presented in this report.

Scheduled trains from bandwidths from capacity model solution

- Basic cost: 1 536 468 €
  (i.e. the same as in undisturbed capacity model)
- Scheduled cost: 1 555 845 €
  Increased generalized cost due to capacity scarcity: 17 748 €

If the socio-economic schedule is better than the schedule created with a train type construction order ultimately depends on if we believe in the socio-economic cost parameters. But the aim must be to strive towards the best utility for the society. The calculus presented in this report is such an attempt to form one, based on the best currently available data.

4.3.2.6 Example 4: Comparing EU average values with different country values

To test the impact of using national values vs. European wide average values, a test was performed with different cost parameters where countries A, X, and P has been introduced in the example network, see Figure 16.

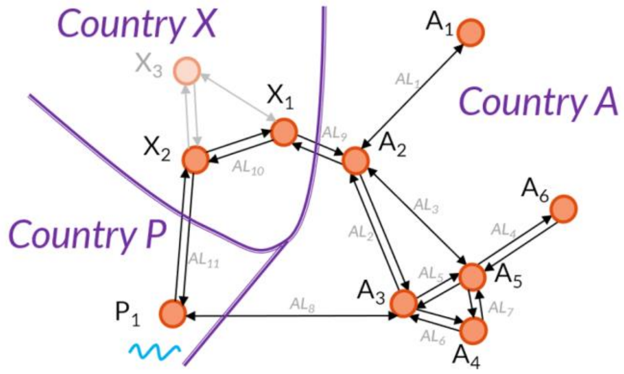

Figure 16. example network with countries and country specific cost factors

The values were chosen from real countries in the spreadsheet model but chosen so that the case could not occur in reality (to focus the discussion on the principal questions). The values were also chosen so that the difference is as large as possible between them, in order to provoke differences in schedules. Note that freight traffic always uses European average, as the underlying framework does not distinguish countries. It could be discussed whether the operational costs for freight should be national parameters, as these should follow the same pattern as for passenger trains. However, the underlying framework (JASPERS, 2017) does not distinguish between European countries.

The case with national parameters is shown in Figure 17.

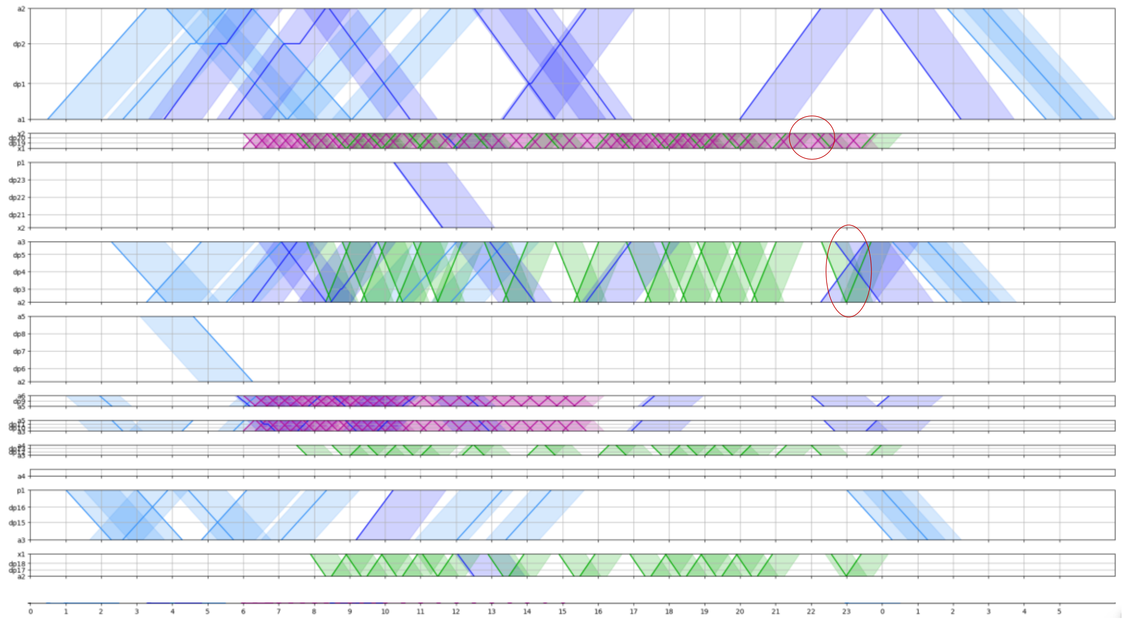

Figure 17 Schedule using the national cost parameters

In Figure 18 is the version with EU average values. There are minor differences to the commercial passenger train paths (green) that passes from country A to X leading to a minor difference in timings (marked with a red ring on the line X1 to X2). This leads to a knock-on effect in the schedule between a freight train path (blue lines) and the commercial train path marked with a larger red ring.

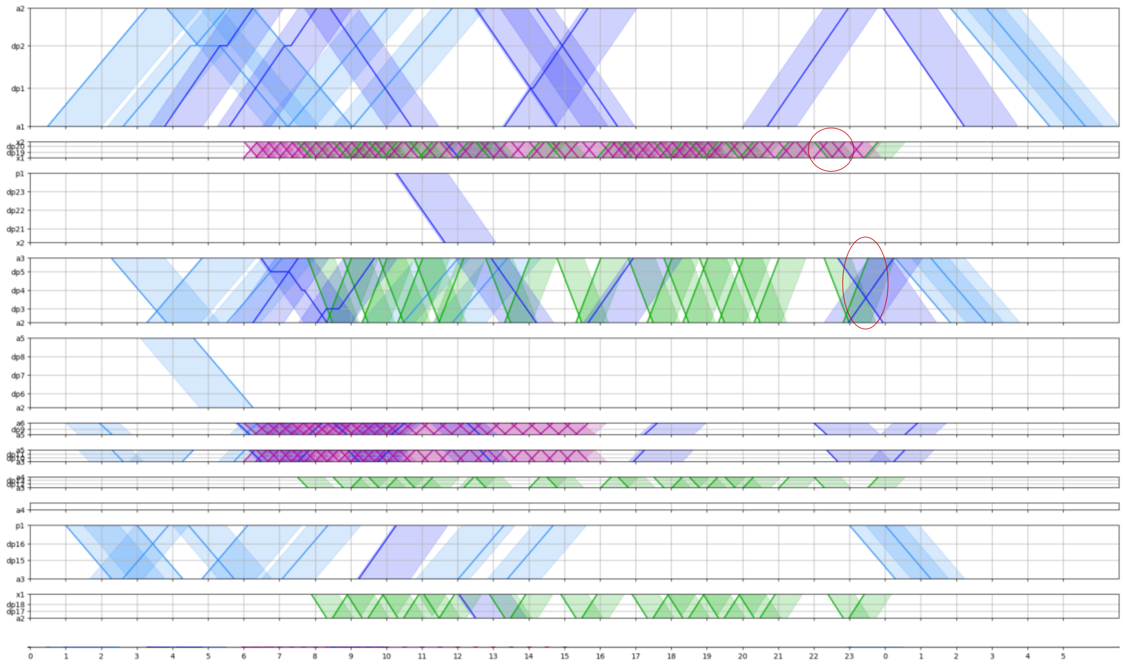

Figure 18 Schedule using European average cost parameters

This example shows that it does not matter so much if national parameters are used or a European average. This might surprise as the parameters' value sometimes differ substantially from one country to another. The reason why it does not matter so much is that it is the prolongations in time that is used in conflict resolution to create a valid schedule, and it is the relative difference in the cost parameters' values that matters inside a country where running time supplements, wait times and displacement should be placed. The effects of prolonging the running time for trains in the same country is relatively almost the same regardless of the absolute values of the parameters. The absolute values do not matter that much, see section 3.2 for a discussion on this). However, differences in schedules may appear around a country boarder, where a time adjustment may be "cheaper" to take in one country than in the other one. But in the large picture this seems to be of minor importance. Further tests and study of these "effects" are however required.

Also note that the knock-on effects may affect national traffic, and in particular freight traffic whose VTTS (Value of travel time savings) is low compared to passenger trains.

5 Conclusion

This final report has presented results from the feasibility study on using socio-economic cost criteria in case of capacity shortage. A principal model is put forward that is based on general principles for economic appraisal of investments that are recommended by the European Commission and the European Investment Bank (European Commission, 2021; European Investment Bank, 2023; JASPERS, 2017). Hence, there is a common ground for investments in infrastructure and planning traffic using the infrastructure.

The developed model is a working model for prioritization that considers volumes of trains that are affected by the decision on capacity allocation. However, a number of developmental needs and issues that require further research have been identified. First, it can be noted that the methods that are currently available value train services and only indirectly the passenger and freight flows. A first step is to use the existing methods. Direct valuation of passenger and freight flows is a possible area for development.

One set of issues concerns the prognosticated capacity products in the rolling planning (RP) segment, which should have prioritization classifications and be valued. It is imperative that capacity allocation is efficient both within and between segments. By valuing the bandwidths with socio-economic methods, these can be compared to allocations in other segments. The amount of capacity allocated through different segments should be adjusted annually with the aim that the value of allocated capacity is equal across segments. Moreover, a development work is required for prognosticating the size of and valuing the wait times and runtime supplements that are added onto capacity products when these are turned into train paths in the ATT. The proposed valuation framework already works for basic valuation of bandwidths, but there is an uncertainty regarding the amount of wait times and runtime supplements needed.

A generalized form of association that relates to traffic flows should be introduced as a new object to be published in the capacity model. Associations are important and valuable features of service offerings which motivates their inclusion early in the timetabling process.

Development work is needed to properly handle denial of capacity requests (“exclusions” in this report). The treatment of exclusions is likely to become more important with increasing international traffic, and it is especially important that such services are not unfairly excluded. The exclusion cost should be the loss of the value that is forgone due to the exclusion. This is the opportunity cost, which is the difference between the cost of the requested rail transport and of the second-best option. A simplified method is also proposed to be used in the meantime as the above-described opportunity cost calculations are developed.

This feasibility study has considered the use of standard unit values as input to the socio-economic calculations. First, it can be noted that development work is required to ensure the availability of standard parameter values for Europe. These are currently missing for operational costs of passenger train services (but exist for operational costs of freight train services). Second, it is important that the parameter values used are consistent within countries to make comparisons possible within and between segments. This means that the same rules and parameter values should, as far as possible, be used throughout the capacity allocation process. National IMs may choose to use national parameter values if these exist, or European average values otherwise. The implications of this choice are small since priorities mostly depend on the quotient between two parameter values (e.g. the VTTS of a freight train compared to the VTTS of a passenger train) rather than the absolute parameter values. Furthermore, such quotients are seen to be quite stable across countries even as absolute values vary. Related to this, it is recommended that trains are valued using parameter values from the country where they are located in all cases. This means that the valuation of a cross-border service changes at the border. This method is deemed to produce a good approximation of true values in most cases, while also facilitating efficient administration for the IMs.

Train classifications are a vital part of the socio-economic model. Each IM should be responsible for template train classifications within their country. It should also be possible to value each requested service directly, without the use of template values according to train classes, if an IM sees such a method as more suitable. The classification does not need to be harmonized across countries.

All in all, this report has described the possibilities of introducing a track capacity allocation method that uses prioritization criteria based on socio-economic valuation across Europe. Such a method has the potential to increase efficiency and transparency, and to strengthen the possibilities to obtain attractive train paths, especially for international train services. A number of development needs have been identified to improve existing methods and adapt them for use in countries that currently use other methods, for the specific needs of cross-border traffic and for the changes to capacity allocation implied by the TTR process.

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Appendix A – Train frequencies and waiting time

The following describes how socio-economic methods may be used to calculate the increased generalized cost when thinning a regular commuter traffic from 15 minutes period to 20 minutes.

Assume that there is an equally distributed demand curve over the period studied, and that the passengers are aware of the timetable, i.e. they make an informed decision of which train that fits them best. Furthermore, in this example since we do not know the type of the passengers, they are normalized and thus the valuation of the demand is equal over time. With 15 minutes period the waiting pattern over time will be as the red curve, and also the increased generalized cost.

Now assume that there is a 20-minute period between the trains. This means that some passengers, compared to the previous scenario, will have a suitable train longer from their most wanted departure time. The tipping point is 10 minutes in the latter scenario, while it is 7.5 minutes in the former scenario. The increased cost with 20 minutes period is the difference between the areas under the two curves.

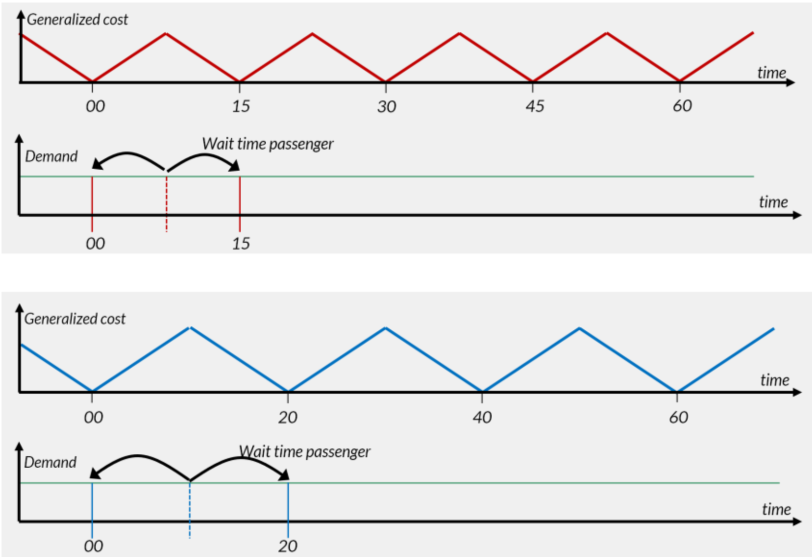

Figure 19. Waiting time for planned arrival at station.

Instead, if we assume that the travellers just come to the station at a steady rate, i.e. they are not aware of the timetable, we get other curves as shown in Figure 20. In principle, the waiting times for the ones just missing the train will now be 5 minutes longer. Again, the increase in generalized cost is the difference between the area under the curves.

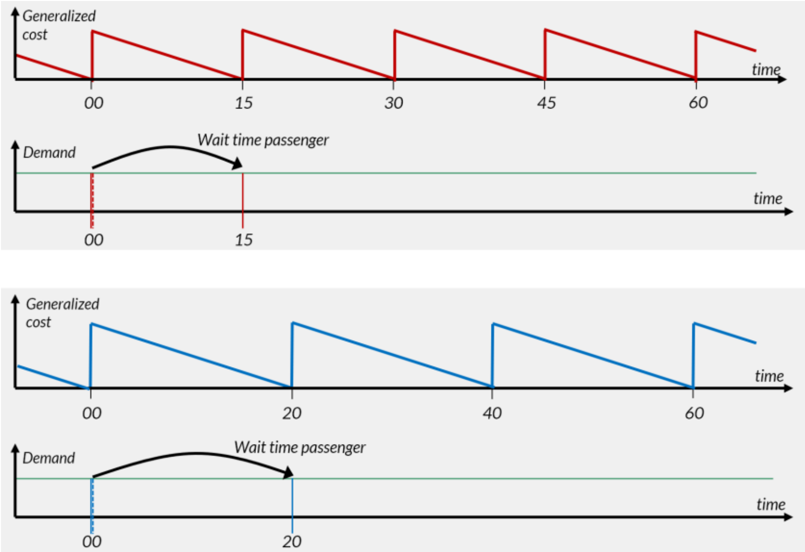

Figure 20. Waiting time for unplanned arrival at station.

Presumably the truth is somewhere between the two scenarios, i.e. some passengers are aware of the timetable, others just drops down to the station, as long as the traffic is still dense enough.

Appendix B – Displacement of trains and impact on generalized cost

Figure 21 depicts a situation with regular traffic and equal time periods between departures. The period between each train departure is 3 units of time, and the generalized cost is showed on the y-axis. It is assumed that passengers arrive at the station at a steady rate, equally distributed over time.

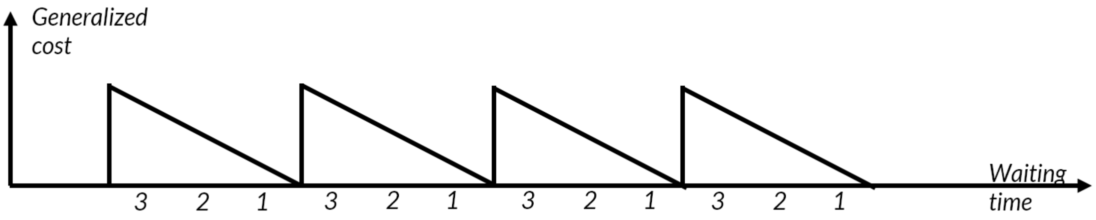

Figure 21. Regular traffic with equal time periods between departures.

Then consider a situation where one of the train paths is displaced and thus has a later departure (one unit), which is showed in Figure 22.

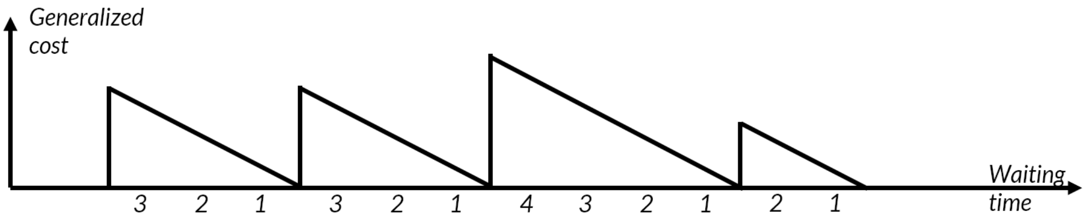

Figure 22. Unregular traffic.

The area under the generalized cost function over time in Figure 21 is
4 ×(3+2+1)×#passengers = 24×#passengers, while the cost is
(2×(3+2+1))+(4+3+2+1)+(2+1)×#passengers = 25×#passengers in Figure *22*.

If the train is even more displaced, the situation gets worse, as shown in Figure 23. The area under the generalized cost function is then (2×(3+2+1)+(5+4+3+2+1)+1)×#passengers = 28×#passengers.

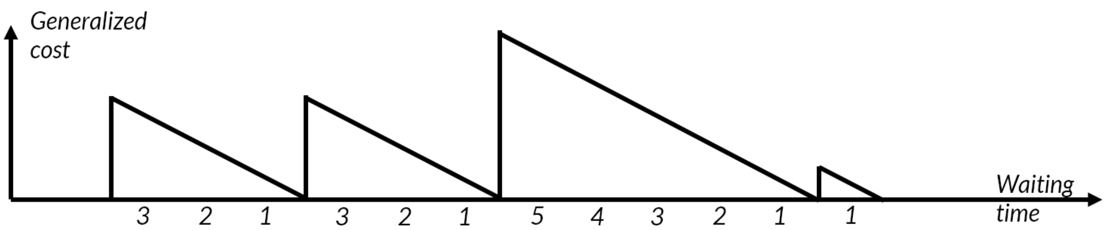

Figure 23. Even more unregular traffic.

The increase in generalized cost can thus be calculated given the number of passengers, the period length and the displacement.

Appendix C – Spreadsheet model, calculation examples

The example sheets comprise the following.

- One major example (two sheets) showing the calculation of individual train paths matching, e.g., capacity supply calculation of preplanned paths.
- One major example (two sheets) showing comparison of volumes of traffic in two different scenarios.

In the latter example the idea is that two different cases are valuated and compared. The background information is that there is scarce capacity due to a TCR being performed on a double track section of the rail infrastructure. The TCR's duration is 60 days. Two different scenarios are constructed and compared, one where the freight train volumes (10 each day) are rerouted and one in which they are not rerouted. The former scenario implies a lower impact on the passenger trains, whilst the freight trains get a longer distance, leading to a prolonged journey time.

The calculation for passenger trains without the TCR in the plan is showed in Figure 24. The grey cells are input chosen by the user. The passenger service is performed every Monday to Friday except for 2 summer months (220 days). The occupancy rate is 75 % meaning that 75 % of the seats are occupied. This is a regular service, so there are 20 trains run each day. Distance and speed are determined from the timetable so if this was linked to the timetabling system, these values would have been collected from there.

To the right of the black column line is the prognosticated prolongation and displacement of the service (all trains in the regular service). To the left is the basic case, i.e. without wait times and displacement (as if the train was alone on the infrastructure)

BASE CASE					
Example Calculation	***RSPT***		**Volume 1**	**Calculation**	
Country	EU+UK+CH+NO				
VOT €/pax	6,08 €	6,08 €		6,08 €	
Occupancy rate, average		*75%*	*75%*	75%	
Capacity	500	*L*	*L*	500,00	
Distance, km		*475*	*475*	475	
Speed, average, km/h		*160*	*160*	160	
Basic Duration, hours		02:58:07		02:58:07	
VOT		6 765 €		**6 765 €**	
Operational cost duration	355,32 €	1 055 €		**1 055 €**	
Variable cost duration	0,94 €	1 043 €		**1 043 €**	
Operational cost distance	1,90 €	900 €		**900 €**	
Variable cost distance	0,01 €	1 700 €		**1 700 €**	
Basic cost		**11 464 €**		**11 464 €**	
Number of train paths / day		*20*	*20*	20	
Number of days		*220*	*220*	220	
BASIC COST VOLUME		**50 439 797 €**		**50 439 797 €**	
Displacement cost, duration	4,56 €				
VOT Prolongation, prognosis			*00:10:00*	379,80 €	
Displacement , prognosis			*00:10:00*	284,85 €	
Prolongation operational cost				117,79 €	
Total value/day				**12 246 €**	
TOTAL COST VOLUME		**50 439 797 kr**		**53 882 546 €**	**3 442 749 €**
			Marginal cost	3 442 749 €	

Figure 24. Base case for a demonstration passenger train, as declared in the spreadsheet demo for a pan-European socio-economic prioritization model.

The corresponding calculation for the freight train basic situation (without TCR) is shown in Figure 25. Analogous to the passenger service, key data is given in the grey cells.

BASE CASE					
Example Calculation	***WLFT***	**Bsic case**	**Volume 1**	**Calculation**	
Country	***EU15***	EU15			
VOT €/tonne	0,16 €			0,16 €	
Occupancy rate		*75%*	*75%*	0,75	
Capacity, net tonnes	1143	*1200*	*1200*	1200	
Distance, km		*475*	*475*	475	
Speed, nominal, km/h		*60*	*60*	60	
Basic minimum Duration, hours		07:55:00		07:55:00	
Speed importance factor		*4*	*4*	4	
VOT		4 645,50 €		4 645,50 €	
operational cost / hour	500,60 €	3 963,08 €		3 963,08 €	
operational cost/km	3,43 €	1 630,20 €		1 630,20 €	
variable cost distance					
Basic cost		**10 239 €**		**10 239 €**	
Number of paths per day	10	10		10	
Number of days	220	220		220	
BASIC COST YEAR		**22 525 306 €**		**22 525 306 €**	
Displacement cost, duration				0,12 €	
Prolongation, prognosis			*00:15:00*	271,85 €	
Displacement, prognosis			*00:05:00*	36,68 €	
Additional operational costs					
Total value/day				**10 547 €**	
TOTAL COST YEAR		**22 525 306 kr**		**23 204 060 €**	**678 754 €**
			Marginal cost	**678 754 €**	

Figure 25. Base case for a demonstration freight train.

The TCR affects the trains 60 days. In the first scenario the freight train is rerouted. The scenario case is the two columns added to the right (to be compared with the nominal case in the middle). As there is single track operation when passing the work area of the TCR, the regional traffic gets a 5 additional minutes wait time and lower speed passing the TCR. For the passenger train volume is shown in Figure 26 in the two columns to the right. The total marginal cost increase for the traffic volume is given in the green cells at the bottom to the right, 3 741 304 €.

SCENARIO 1							
Example Calculation	***RSPT***	**Basic case**	**Volume 1**	**Calculation**	**Volume 2**	**Calculation**	
Country	EU+UK+CH	EU+UK+CH+NO					
VOT €/pax	6,08 €	6,08 €		6,08 €		6,08 €	
Occupancy rate, average		*75%*	*75%*	75%	*75%*	75%	
Capacity	500	*L*	*L*	500,00	*L*	500,00	
Distance, km		*475*	*475*	475	*475*	475	
Speed, average, km/h		*160*	*160*	160	*160*	160	
Basic Duration, hours		02:58:07		02:58:07		02:58:07	
VOT		6 765 €		**6 765 €**		**6 765 €**	
Operational cost duration	355,32 €	1 055 €		**1 055 €**		**1 055 €**	
Variable cost duration	0,94 €	1 043 €		**1 043 €**		**1 043 €**	
Operational cost distance	1,90 €	900 €		**900 €**		**900 €**	
Variable cost distance	0,01 €	1 700 €		**1 700 €**		**1 700 €**	
Basic cost		**11 464 €**		**11 464 €**		**11 464 €**	
Number of train paths / day		*20*	*20*	20	*20*	20	
Number of days		*220*	*160*	160	*60*	60	
BASIC COST VOLUME		**50 439 797 €**		**36 683 488 €**		**13 756 308 €**	
Displacement cost, duration	4,56 €						
VOT Prolongation, prognosis			*00:10:00*	379,80 €	*00:15:00*	569,70 €	
Displacement , prognosis			*00:10:00*	284,85 €	*00:10:00*	284,85 €	
Prolongation operational cost				117,79 €		176,68 €	
Total value/day				**12 246 €**		**12 495 €**	
TOTAL COST VOLUME		**50 439 797 kr**		**39 187 306 €**		**14 993 794 €**	**3 741 304 €**
			Marginal cost	**2 503 818 €**	**Marginal cost**	**1 237 486 €**	

Figure 26. A simple use case for socio-economic calculation of volumes of traffic, scenario 1.

For the freight trains, the corresponding sheet is shown in Figure 27. The freight trains gets longer travel time as the rerouting distance is longer, and the additional generalized cost is 2 295 403 €.

SCENARIO 1							
Example Calculation	***WLFT***	**Bsic case**	**Volume 1**	**Calculation**	**Volume 2**	**Calculation**	
Country	***EU15***	EU15					
VOT €/tonne	0,16 €			0,16 €		0,16 €	
Occupancy rate		***75%***	***75%***	75%	***75%***	75%	
Capacity, net tonnes	1143	***1200***	***1200***	1200	***1200***	1200	
Distance, km		***475***	***475***	475	***600***	600	
Speed, nominal, km/h		***60***	***60***	60	***60***	60	
Basic minimum Duration, hours		07:55:00		07:55:00		10:00:00	
Speed importance factor		***4***	***4***	4	***4***	4	
VOT		4 645,50 €		4 645,50 €		5 868,00 €	
operational cost / hour	500,60 €	3 963,08 €		3 963,08 €		5 005,99 €	
operational cost/km	3,43 €	1 630,20 €		1 630,20 €		2 059,20 €	
variable cost distance							
Basic cost		**10 239 €**		**10 239 €**		**12 933 €**	
Number of paths per day	10	10	10	10	10	10	
Number of days	220	220	160	160	60	60	
BASIC COST YEAR		**22 525 306 €**		**16 382 041 €**		**7 759 914 €**	
Displacement cost, duration	0,12 €						
Prolongation, prognosis			***00:15:00***	271,85 €	***00:15:00***	271,85 €	
Displacement, prognosis			***00:05:00***	36,68 €	***00:05:00***	36,68 €	
Additional operational costs							
Total value/day				**10 547 €**		**13 242 €**	
TOTAL COST YEAR		**22 525 306 kr**		**16 875 680 €**		**7 945 029 €**	**2 295 403 €**
			Marginal cost	**493 640 €**	**Marginal cost**	**185 115 €**	

Figure 27. Use case for volumes of traffic, scenario 1, freight traffic calculation.

The total generalized cost increase for scenario 1 is 6 036 707 €.

Scenario 2 has the same kind of sheets, given in Figure 28 and Figure 29. Similarly, the green cells at the bottom right for scenario 2 should be added together. The difference for the passenger trains in scenario 2 is that the running time prolongation is longer, 15 minutes, due to the freight trains not being rerouted.

SCENARIO 2

Example Calculation	***RSPT***	**Basic case**	**Volume 1**	**Calculation**	**Volume 2**	**Calculation**	
Country	NIPT	NIPT					
VOT €/pax	6,08 €	6,08 €		6,08 €		6,08 €	
Occupancy rate, average		*75%*	*75%*	75%	*75%*	75%	
Capacity	500	*L*	*L*	500,00	*L*	500,00	
Distance, km		*475*	*475*	475	*475*	475	
Speed, average, km/h		*160*	*160*	160	*160*	160	
Basic Duration, hours		02:58:07		02:58:07		02:58:07	
VOT		6 765 €		**6 765 €**		**6 765 €**	
Operational cost duration	355,32 €	1 055 €		**1 055 €**		**1 055 €**	
Variable cost duration	0,94 €	1 043 €		**1 043 €**		**1 043 €**	
Operational cost distance	1,90 €	900 €		**900 €**		**900 €**	
Variable cost distance	0,01 €	1 700 €		**1 700 €**		**1 700 €**	
Basic cost		**11 464 €**		**11 464 €**		**11 464 €**	
Number of train paths / day		*20*	*20*	20	*20*	20	
Number of days		*220*	*160*	160	*60*	60	
BASIC COST VOLUME		**50 439 797 €**		**36 683 488 €**		**13 756 308 €**	
Displacement cost, duration	4,56 €						
VOT Prolongation, prognosis			*00:10:00*	379,80 €	*00:25:00*	949,51 €	
Displacement , prognosis			*00:10:00*	284,85 €	*00:10:00*	284,85 €	
Prolongation operational cost				117,79 €		294,47 €	
Total value/day				**12 246 €**		**12 992 €**	
TOTAL COST VOLUME		**50 439 797 kr**		**39 187 306 €**		**15 590 903 €**	**4 338 413 €**
			Marginal cost	**2 503 818 €**	**Marginal cos**	**1 834 595 €**	

Figure 28. Scenario 2, volumes of passenger traffic.

The freight trains in scenario 2 are not rerouted but gets longer running times (the estimation shows 30 minutes more, in average, compared to non-disturbed schedule). The freight traffic is still better off than in scenario 1.

SCENARIO 2

Example Calculation	***WLFT***	**Bsic case**	**Volume 1**	**Calculation**	**Volume 2**	**Calculation**	
Country	***EU15***	EU15					
VOT €/tonne	0,16 €			0,16 €		0,16 €	
Occupancy rate		*75%*	*75%*	75%	*75%*	0,75	
Capacity, net tonnes	1143	*1200*	*1200*	1200	*1200*	1200	
Distance, km		*475*	*475*	475	*475*	475	
Speed, nominal, km/h		*60*	*60*	60	*60*	60	
Basic minimum Duration, hours		07:55:00		07:55:00		07:55:00	
Speed importance factor		*4*	*4*	4	*4*	4	
VOT		4 645,50 €		4 645,50 €		4 645,50 €	
operational cost / hour	500,60 €	3 963,08 €		3 963,08 €		3 963,08 €	
operational cost/km	3,43 €	1 630,20 €		1 630,20 €		1 630,20 €	
variable cost distance							
Basic cost		**10 239 €**		**10 239 €**		**10 239 €**	
Number of paths per day	10	10	10	10	10	10	
Number of days	220	220	160	160	60	60	
BASIC COST YEAR		**22 525 306 €**		**16 382 041 €**		**6 143 265 €**	
Displacement cost, duration	0,12 €						
Prolongation, prognosis			*00:15:00*	271,85 €	*00:45:00*	815,55 €	
Displacement, prognosis			*00:05:00*	36,68 €	*00:05:00*	36,68 €	
Additional operational costs							
Total value/day				**10 547 €**		**11 091 €**	
TOTAL COST YEAR		**22 525 306 kr**		**16 875 680 €**		**6 654 600 €**	**1 004 974 €**
			Marginal cost	**493 640 €**	**Marginal cost**	**511 335 €**	

Figure 29. Scenario 2, volumes of freight traffic.

Adding the additional generalized costs for scenario 2 gives 5 343 387 €. This generalized cost increase should be compared with scenario 1's increase in generalized costs (6 036 707 €) which implies that scenario 2 is the better alternative, i.e. not to reroute the freight train. Globally, in this case, it is a better alternative to let the passenger traffic be delayed on average 15 minutes compared to rerouting the freight trains.