Study of Travel times in public transport on selected nodes in Sweden, Finland, Estonia and Latvia

Author: Kassaw Bediru Seid, Albin Dahl, Daniel Knutsen, Sophie Persson, Fredrik Widegren , WSP

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Figure 1: Travel times in Public Transportation

European Union

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Introduction

Region Örebro is a partner in the EU-funded Baltic Loop project, which consists of regions along the corridor The Northern Growth Zone (Örebro – Stockholm – Helsinki / Riga / Tallinn – St. Petersburg). The purpose of the project is to identify bottlenecks in the transport system and develop solutions to minimize travel and freight times for passengers and goods, and contribute to reducing emissions.

During the spring of 2021, WSP, on behalf of Region Örebro, mapped and analyzed various digital and automated working methods that could contribute to shorter travel times in public transport. A number of different nodes, both along the railway and with other public transport, in Sweden, Finland, Estonia and Latvia have been analyzed from a travel time perspective. Current train planning processes and railway operations in the four countries have been analyzed to get an idea of how much extra time is applied in timetable construction, and whether this time could be removed by applying one or several of the digital and automated working methods that have been mapped.

Studied nodes

In the study, the following nodes have been studied

Primary nodes:

- Oslo - Örebro - Stockholm (Sweden)
- Helsinki - Salo – Turku (Finland)
- Tallinn - Narva (Estonia)
- Tukums - Riga (Latvia)

Secondary nodes:

- Kopparberg - Lindesberg - Örebro (Sweden)

- Katrineholm - Eskilstuna - Västerås (Sweden)
- Helsinki - Tampere (Finland)
- Riga – Cesis (Latvia)

Tertiary nodes:

- Örebro – Askersund (Sweden)
- Örebro – Hällefors (Sweden)
- Turku – Pori (Finland)
- Cesis – Smiltene (Latvia)

Obstacles in the investigation

In the data collection, we have encountered some difficulties in obtaining sufficient information regarding traffic in Estonia and Latvia, as these countries do not provide as much open information as Sweden and Finland.

We have also encountered some difficulties in finding information about traffic management systems, as these have in recent years been given a higher protection rating.

Conclusions in brief

The report's conclusions are briefly described here. Detailed conclusions can be found in the chapter Conclusions

- Both Sweden and Finland have regulations regarding extra redundancy in timetable construction. The supplement for redundancy is calculated differently, and is therefore difficult to compare, but based on the primary nodes in Sweden and Finland, we have been able to conclude that Finland has more redundancy than Sweden per travel minute.

- There are a number of driver support systems on the market that could reduce travel time in public transport, as traffic can be planned more frequently through more detailed driving information for train drivers.
- In the case of timetable construction, a simulator could possibly be used to find efficiency possibilities in travel time.
- It would also be possible to reduce travel time through a number of measures that do not require digital aids - however, these measures come with certain consequences that need to be taken into account - see Conclusions.
- The purpose of most of the redundancy in the timetable is to compensate for quality deficiencies in the railway system. By reducing margins without investing in the railway system, there is a risk of increased disturbance sensitivity.

Train planning process and Traffic management systems in Sweden, Finland, Estonia and Latvia

This section describes the train planning process and traffic management systems in the four countries Sweden, Finland, Estonia and Latvia. The train planning process describes, among other things, allocation of capacity, prioritization rules, guidelines regarding timetable construction and practice in timetable construction. Current traffic management systems describe how the technical systems for traffic management work and may affect capacity.

As Sweden and Finland provide more open data than Estonia and Latvia, the descriptions of Sweden's and Finland's railway network are more detailed than the descriptions of Estonia's and Latvia's railway network.

Sweden

The Swedish Transport Administration's allocation process

Allocation of capacity on the state tracks in Sweden is made by the Swedish Transport Administration. At the beginning of each year, the railway companies apply for their desired capacity in the coming timetable. The Swedish Transport Administration's traffic planner combines the various wishes and creates a draft timetable based on the railway companies' wishes, in combination with current guidelines.

In the event of conflicts in the timetable making, the railway companies are urged to coordinate a solution together. If the railway companies themselves cannot agree on a solution, a new attempt is made for consultation together with the Swedish Transport Administration. If the timetable conflict still cannot be resolved, the Swedish Transport Administration declares the line congested. This gives the Swedish Transport

Administration the opportunity to prioritize the transport that has the greatest societal benefit.

The train schedule will be determined at the end of September, and in December the new timetable will come into force (Swedish Transport Administration, 2021c).

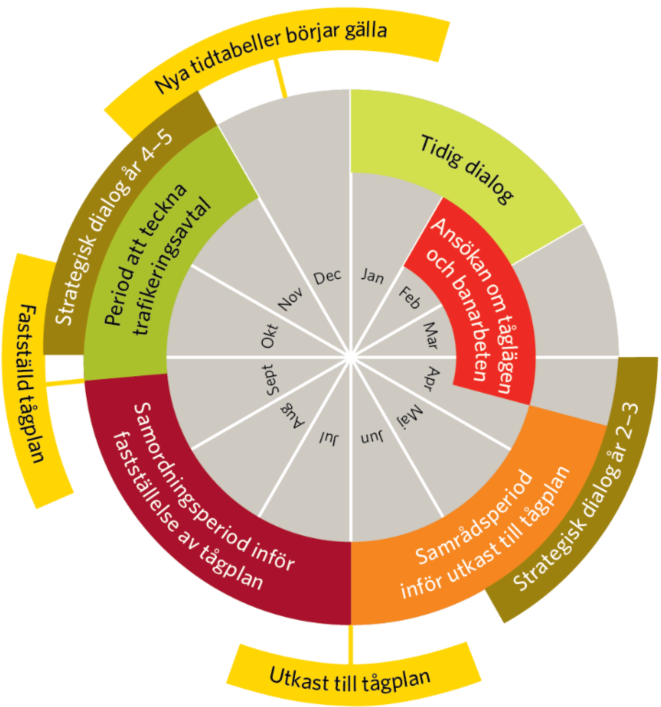


Figure 2 The Swedish Transport Administration's process description of the allocation process.

Timetable construction

When the Swedish Transport Administration's traffic planners construct timetables, they have a number of different aspects to take into account. The running time is calculated to determine the time the train needs from its departure station to its final station. When planning, traffic planners also take other trains on the line into account by ensuring that the train schedule follows the Swedish Transport Administration's guidelines for tightness between trains (Swedish Transport Administration, 2020a).

Running times

When calculating the running time, the traffic planner takes into account the aspects in the table below.

Addition	Description
Base time	Running time calculated on the train and track performance.
Track work supplement	A supplement that allows extra running time due to speed reduction that is not calculated in the basic running time.
Congestion surcharge	A congestion supplement provides extra running time as other traffic activities prevent the train from being driven according to the train's performance.
Node extension	A node addition provides increased redundancy in the timetable so that a train can keep its timetable even if the train is run on a different track than planned (for example, right-hand tracks or deviating main tracks).
Retardation supplement	A supplement of 90 seconds will be added for freight trains at the starting point, at the change of driver and after a break for uncoupling and coupling of wagons.
Supplement for deviating main tracks	Trains that are planned on deviating main tracks are provided with a time supplement that compensates for this.

Rounding	When constructing a timetable, the time is given in minutes and seconds. The Swedish Transport Administration's traffic planning system Trainplan rounds the time down to a full minute in the published timetable.

Table 1 Addition Running times in Sweden (Swedish Transport Administration, 2020a)

The node extension

The purpose of the node addition is to create increased redundancy in the timetable and give the trains an increased opportunity to run in a minor delay, and thus not risk losing their timetable channel. Along several different tracks, a number of operating locations have been designated as nodes. This means that trains running between these nodes receive an addition to the timetable. The nodes are described in Table 2 below (Swedish Transport Administration, 2015)

Path	Nodes
Western main line	Stockholm, Hallsberg, Gothenburg
Southern main line	Stockholm, Mjölby, Alvesta, Malmö*
East coastline	Mora, Borlänge, Sala, Stockholm
Svealandsbanan	Stockholm, (Hallsberg)
Mälarbanan	Stockholm, (Hallsberg)
West coastline	Gothenburg, Förslöv / Markaryd, Malmö
Coast to coastline	Gothenburg, Alvesta, Kalmar
Skånebanan/Blekinge kustbana	Helsingborg, Hässleholm, Karlskrona
Värmlandsbanan	Charlottenberg, Karlstad, Hallsberg
Norway / Vänernbanan	Kornsjö, Gothenburg

Mittbanan	Sundsvall, Ånge, Östersund, Storlien
North main line	Gävle/Storvik, Ånge
The main line through upper Norrland	Ånge, Vännäs, Boden
Malmbanan	Boden, Gällivare, Riksgränsen
Botniabanan	Sundsvall, Örnsköldsvik, Umeå
Other courses	Departure and destination

Table 2 Nodes in Sweden
** Deviations occur for passenger traffic that passes more than two nodes.*

The size of the supplements

Traveling trains	
Vehicles with a maximum permitted speed of more than 180 km / h	4 minutes between 2 nodes
Vehicles with a maximum permitted speed below 180 km / h	3 minutes between 2 nodes
Trains shorter distance than one node	2 minutes
Arlanda express	1 minute between departure and final station
Freight trains	
Freight trains	2 minutes between 2 nodes
Freight trains shorter distance than one node	1 minute

Table 3 Size of Node Supplement
(Swedish Transport Administration, 2015)

Increased redundancy in the timetables

In recent years, the Swedish Transport Administration has carried out analyzes of redundancy on various tracks with timekeeping problems.

In 2019, an analysis of punctuality on the West main line was carried out, as traffic on the line has suffered from punctuality problems for several years. During the analysis, a number of critical points were identified where the trains risk ending up in the wrong order, and thus risk ending up so far outside their channel that they do not have the opportunity to recover before the final station. Critical points arise, for example, where trains turn, for example in Gnesta where the commuter train crosses the tracks on the main line when the train turns, and places where trains enter the main line from connecting lines.

In connection with this analysis, new construction rules for timetables have been introduced on the western main line. The new design rules mean, among other things, that the node extensions are moved to the critical points along the main line, and that the headway time[1] is extended at critical points. This means that the trains are spread out more during the day, as they can no longer run as tightly. Theoretically, the new construction rules should not mean longer running times for the trains, but in practice the running times can still be longer as the new construction rules more clearly regulate breaks that in practice take longer than planned (Swedish Transport Administration, 2019).

In 2016, new construction rules were introduced on Värmlandsbanan. It was then decided that the timetables at, for example, train meetings must reflect the time required in reality. The result of the new construction rules was that punctuality on

[1] Tightness between trains

Värmlandsbanan increased for all train types between the timetable year 2016 and 2017 (Swedish Transport Administration, 2017).

Guidelines for tightness between trains

Guidelines for the minimum time between trains are calculated by the Swedish Transport Administration with a headway analysis in the simulation tool Railsys. Quality time is added for disturbances according to normal train operation, and additional quality time may be relevant at critical nodes where crossing train paths occur frequently.

The guidelines ensure that the time distance between two trains is long enough so that the trains behind do not have to start braking before signals stop (Swedish Transport Administration, 2020a).

Path	Minimum distance between trains
Stockholm Central – Stockholm S	2 minutes
Stockholm S – Flemingsberg (ytterspår)	3 minutes
Flemingsberg – Järna	3 minutes
Järna – Flen	4 minutes*
Flen – Hallsberg	4 minutes
Hallsberg – Laxå	3 minutes
Path	**Minimum distance when passing**
Järna - Gothenburg	4 minutes

Table 4 Distance between trains
** At least 5 minutes after freight train*

Traffic management system in Sweden

Until the summer of 2020, the traffic management system EBICOS TMS from Bombardier was used at a number of operating locations along the Western Main Line. Today, only the EBICOS 900 traffic management system is used on the state railway network. In recent years, the traffic management system has received a higher protection rating.

The sections Charlottenberg – Stockholm, Kopparberg – Lindesberg – Örebro, and Katrineholm – Eskilstuna – Västerås are also remotely monitored in system H, which means that the trains short-circuit the tracks as they pass and that their positions can be followed by a train dispatcher on a traffic screen.

In connection with the introduction of NTL (National Train Management System), there are intentions to switch to Alstom's traffic management system ICONIS.

Automatic

Integrated in the traffic management system EBICOS 900 is the TLS function, which partially automates traffic management. In TLS, the trains 'routes are programmed using the trains' train numbers. When a train number approaches a signal, TLS can detect which train is coming and prepare the train path. This means that when the trains run according to schedule, TLS can ensure that the train always has driving signals far enough to not receive restrictive driving instructions in ATC[2], but without the train path becoming so long that other trains can be hindered. When the trains depart from the timetable, however, this may mean that the TLS releases the trains in

[2] Automatic Train Control

the wrong order, and therefore it is required that the Traffic Manager constantly monitors the TLS and ensures that all trains run according to the timetable.

Finland

The Finnish railway market in change process

Train traffic in Finland is mainly operated by the state-owned VR Group. At the moment VR's passenger services is the only operator that offers public transport services in long-distance and commuter traffic on rail. VR Transpoint is a logistics provider both on rail and road and VR FleetCare offers rail fleet maintenance and lifecycle services.

Rail traffic has for long been based on the monopoly position of one operator, VR Group, and therefore the planning and coordination and prioritization of capacity have been carried out mainly on the basis of the operator's internal planning principles. In recent years, the situation has partly changed, as company called Fenniarail has also started to engage in freight transport and HSL has started to seek capacity for its own traffic and take on a more controlling role in its planning in the Helsinki metropolitan area. In addition to VR Group and Fenniarail, also Ratarahti Ltd and Aurorarail Ltd operate with shift work at the railway yards. Operail Finland got licence and safety certificate in June 2020 to act as an operator.

The Finnish railway market is currently changing. A concession agreement between the Ministry of Transport and Communications and VR is valid in domestic passenger traffic until 2024. Based on the agreement VR has the exclusive right to domestic passenger traffic outside the HSL area[3] on those line sections in which VR currently operates. In future all railway companies with acceptable qualification to get infrastructure capacity

[3] Helsinki-area Traffic

will be secured to have equal access to get the capacity for operating domestic passenger traffic and for the use of railway network.

Later, due to the deregulation, there can be more operators on the network and their needs for the use of track capacity may be in conflict with each other. The operating environment of several railway undertakings requires new integrated working methods for the planning and management of track capacity in order to ensure the quality of traffic and a level playing field.

At present, there are few guidelines for rail traffic planning and the guidelines in use are general. In practice the applicants for the track capacity have mostly determined the planning principles they use and decided for themselves how they fit the trains of their own traffic into a coherent whole when scheduling (Väylävirasto, 2020c).

Infrastructure capacity and train planning

The timetables are intended to be planned for the passenger transport as a one whole so that different routes can form a working network of interchanges. The planning rules are based mainly in the Railway Instructions for requesting infrastructure capacity but in practice the expertise and the views of the planners have had a strong role in making planning solutions.

Timetable planning of the freight transport has been based on the customers' transportation needs and therefore the market situation of industry and trading and changes of demand have largely affected to the timetable planning. The customer needs of the freight transport are estimated to come in a shorter period of time in the future and therefore the process of requesting the infrastructure capacity should be developed to become more flexible (Väylävirasto, 2020b).

Allocation of infrastructure capacity

In Finland the Transport Infrastructure Agency Väylävirasto allocates infrastructure capacity to operators operating on the state rail network. Transport Infrastructure Agency publishes the Network Statement of Finland's state-owned railway network for each timetable period for applicants requesting for infrastructure capacity.

The requests for infrastructure capacity must be applied yearly latest eight months ahead of the beginning of new timetable period. New infrastructure capacity or changes in the capacity for the regular train services can be requested also during the timetable period but the changes must not affect any changes to the infrastructure capacity already allocated to other capacity applicants. The need of request for the ad hoc capacity is important specially for the freight traffic.

The infrastructure of the rail network defines the constraints for the capacity that can be applied. The infrastructure capacity in Finland is restricted by the mainly single-track rail network. On the single-track network the meetings of the trains must be located in the railway yards or in the meeting points.

In the allocation of infrastructure capacity takes into account, in particular, the needs of passenger and freight traffic and track maintenance, as well as the efficient use of the track network. In principle, all requests of infrastructure capacity will be met. In case the allocation of infrastructure capacity can not be made in a way that meets the needs of all applicants must the infrastructure manager announce certain part of the train path congested (Väylävirasto, 2020b).

Current planning guidelines and practices

In Finland, the timetable planning guidelines are based both on the operators' own guidelines and the instructions for requesting infrastructure capacity. The applicants of infrastructure capacity have to use feature data of the railway network for the basis of their timetable planning. The data is available for the applicants in track information extranet websites.

The things to be taken into account according to the instructions for requesting infrastructure capacity are:

- Leeway, the extra time to be added to driving time and the distances between the trains must be considered according to the instructions.
    - In the current situation, it is recommended to use a 10 percent margin for driving time planning, which means that the timetable is at least ten percent slower compared to the theoretical maximum speed. For the freight trains it is recommended to use even larger clearance. Commuter tracks can use smaller margins, for example five percent leeway to make the use of capacity more efficient.
    - When the section blocking system is frequent, the trains can have four-minute margins and the commuter trains even three-minute margins.
    - The importance of careful planning of train encounters and passing faster trains is emphasized in the design guide. The amounts of required minutes for arriving early enough, waiting and departing are given very strict.
- The instructions of using the tracks in the traffic operating points
    - The use of tracks is planned in connection with the change times of the timetable period.
    - The planning of the process of track using is under update to meet the needs of the multi-operator environment.
- The rolling stock used may also have features that affect timetable planning.

Although the majority of issues related to timetable planning are described in the network statement or in the track data extranet, many details related to infrastructure utilization are known only to experienced planners. This which means that all planners have no access to the tacit information (Väylävirasto, 2020b).

Estonia

Traffic Management System

The Estonian railway network is a mostly single-rail network managed by two state-owned companies. The railways from Tallinn directly to the south all the way to Pärnu and Viljandi are manged by Edelaraudtee (*eng. Southern railways*), while the rest of the network is managed by Estonian Railways (*Eesti Raudtee*). The only double-track section in the country is an East-West line from the western suburbs of Tallin to Tapa, where the lines to St. Petersburg and Tartu/Latvia diverge.

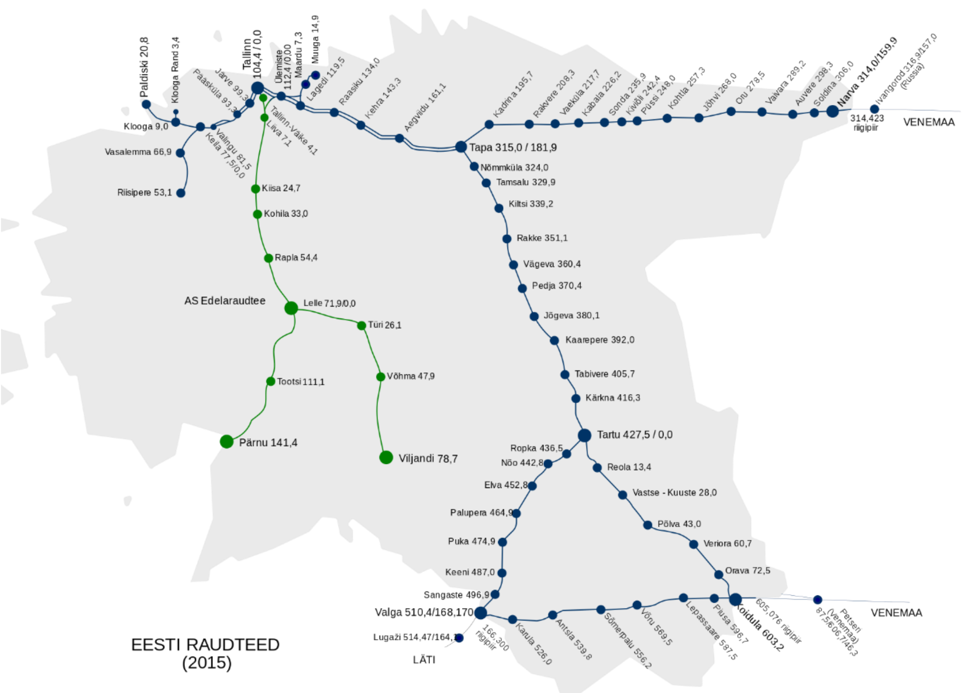


Figure 3 Map of the Estonian railway network with blue lines indicating lines owned and managed by Estonian Railways (Eesti Raudtee) and green indicating the lines of Edelaraudtee (Southern Railways).

The management of train traffic on the infrastructure of Estonian Railways occurs through train dispatchers, which are organized for four areas:

- Tallin-Tapa,
- Tapa-Narva,
- Tapa-Koidula and
- Tartu-Valka & Tallin-Paldiski.

The signaling system used by Estonian Railways is automatic for most of the network, including Tallin-Narva. Some tracks use a semi-automatic signaling system. The train control system in Estonia resembles other countries formerly under soviet rule, which is ALSN. Most of the technical traffic management systems of Estonian railways are vastly outdated (dating from sixties, seventies and eighties), and require renewal in the near future (Eesti Raudtee, 2020).

Train Planning Process

Railway capacity on the Estonian railway network is allocated by the infrastructure managers: Estonian Railways and Edelaraudtee. The following description is based only on the planning process of Estonian Railways. The timetable is planned yearly, and the first deadline for applicants to apply for railway capacity is 9 months before the next timetable period. The timetables change every December. The draft decision of capacity allocation is made 7 months before the implementation of the next timetable.

If the train planning process cannot yield timetables which would be possible to fulfill and meet the requests of the applicants, Estonian Railways will organize a coordination process to develop the requests of the applicants so that all train paths could be provided. If the process cannot produce results that satisfy all applicants, Estonian Railways will declare the rail line in question congested and continue to prioritize traffic according to a set of priorities. If there are still conflicts after the priorities have been sorted, the remaining train paths will be settled with an auction among the applicants. The capacity will be given to the applicant with the highest bid.

The planning process of Estonian Railways is subject to the Railways Act of Estonia, which sets out the priorities Estonian Railways must follow. According to the law, priority is given to passenger trains with a direct international connection. The secondary priority is then given to domestic passenger trains.

Estonian Railways coordinated their timetable planning process with their counterparts in Latvia and Russia, to ensure that train paths continue through the borders of countries (Eesti Raudtee, 2020).

Latvia

Traffic Management System

The railways of Latvia are mostly managed by an interlocking system and automatic locking system with dispatcher centralization. In Latvia there are two centralized traffic control centers in Riga and Daugavpils. A handful of rail sections around the capital region are equipped with an automatic locking system, as well as some sections with a semi-automatic locking system. The train control system used in Latvia is ALSN (*Continuous Automatic Train Signaling),* which is used widely on the main lines of the ex-Soviet states.

Only a minor portion of the infrastructure is electrified. The maximum permitted speed for passenger trains is 120 km/h and up to 90 km/h for freight trains. These speed limits are based on the limitations of the traffic control systems (Latvijas dzelzceļš, 2020).

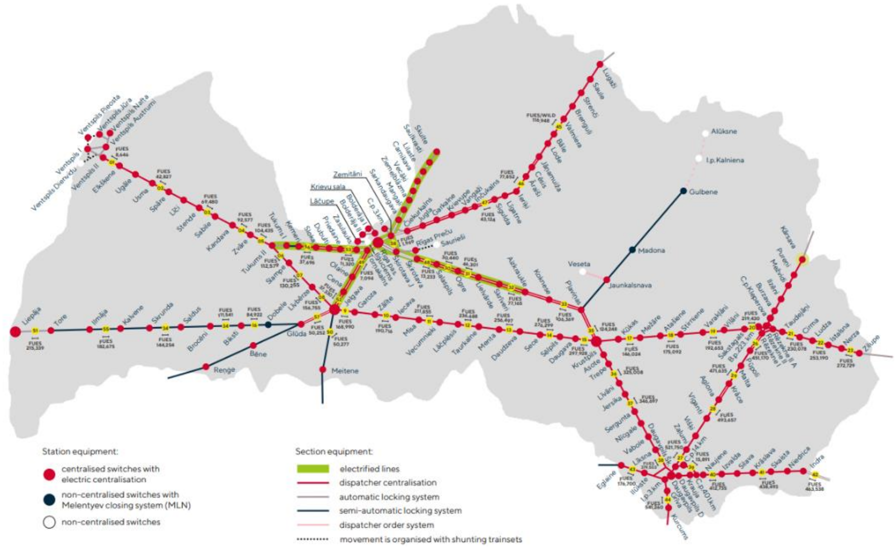


Figure 4 Infrastructure equipment of railways in Latvia.

Train Planning Process

Capacity of public railways in Latvia is allocated by LatRailNet (LRN), which is a subsidiary of the state-owned company Latvian Railways (Latvijas dzelzceļš, LDz). LDz is the manager of public railway infrastructure in Latvia, and the subsidiary LRN assumes many of these tasks: decision making on capacity allocation and train path assignment, including both the determination and assessment of accessibility and the allocation of individual train paths and decision-making on infrastructure charging, including the determination and collection of the charges.

LRN allocated railway capacity with a yearly timetable starting from the second Sunday of December. The timetable is build based on the requests of different operators during the previous year. The initial applications of different carries are to be submitted to LRN by May 15th of each year, after which LRN makes the decision on infrastructure capacity allocation and approves the infrastructure capacity allocation plan for the next capacity allocation period by July 15th. LRN produces a draft schedule by October 15th. During the scheduling applicants can modify their applications or submit late ones, but they can only be fulfilled to the extent that they do not burden other applications.

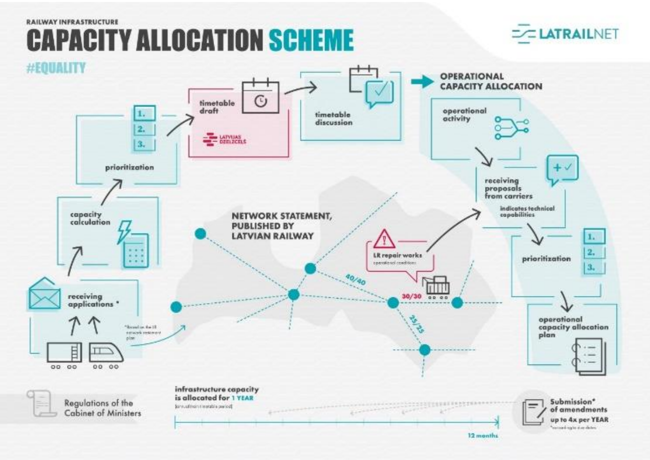


Figure 5 The railway capacity allocation scheme of Latvia.

In the timetable planning process LRN aims to allow all capacity applications by resolving conflicts with coordinating the applications to not interfere with one another. If this is not possible and infrastructure capacity is exceeded, LRN offer applicants different train paths or ask the applicants to modify their applications accordingly. If applicants do not agree to modify their infrastructure capacity applications, then the dispute settlement procedure can be applied. In this case, the relevant part of railway infrastructure is declared congested.

The planning process of LRN is subject to the Railway Act of Latvia, which sets out the priorities LRN must follow. According to the law, priority shall be given to

- those railway transport services which are provided on the basis of a state or local government railway transport contract,
- railway transport supporting foreign or national armed forces,

- services which are provided in full or in part, using the state public railway infrastructure intended or built for special purposes (high-speed, freight and similar transport).

(LatRailNet, 2020)

Data-driven and automated methods in operation

Driver Advisory Systems

There are today several developed Driver Advisory Systems (DAS) on the railway market, where several of them have been put into operation to various levels, both in Sweden and internationally. A DAS-system's main task, in a broader sense, is to optimize the driving by giving the driver advice on optimal speed and acceleration at any given time during operation. By optimizing these, the system can give positive effects regarding, for example:

- Reduced energy consumption
- Increased efficiency
- Reduced maintenance / wear
- Increased comfort
- Strengthened train guidance / capacity
- Increased flexibility (as real-time traffic planning takes place)

There are three different variants of DAS:

1) Standalone Driver Advisory System (S-DAS)
2) Connected Driver Advisory System (C-DAS)
3) Automatic Train Operation (ATO)

The most basic level is Standalone Driver Advisory System (S-DAS) as it does not have or only have one-way communication with e.g. a traffic management system. With the more advanced D-DAS, the traffic management is instead connected to the driver in a transponder system, which can be compared to that used for aviation traffic information systems (Swedish Transport Administration, 2020c). As C-DAS continuously communicates with the traffic management system, different recommendations are given to the driver depending on other traffic in the system. In reality, this means that the long-distance train dispatcher exchanges his paper graph[4] for a digital graph in the STEG system (in Sweden), where the traffic is planned as usual, but the decisions made by the train dispatcher are sent digitally to the driver's screen. In this way, the information between the train dispatcher and the driver becomes immediately available to those who need it, e.g. if train meetings are added, cancelled or rescheduled at the same time as the driver will have recommended speeds to relate to in order for traffic to flow smoothly, punctually and according to the timetable re-designed in real time.

The last step, ATO, is a system for automatic running of trains, but from a driver support system perspective, the difference between ATO and C-DAS can be very small. Driver support systems should not be confused with supplementary safety systems and do not have a dependency on them as systems such as Automatic Train Control (ATC), Automatic Train Protection (ATP) and ERTMS handle these.

Driver support systems can have different levels of integration in the vehicles, where above all either the app in smart phones / tablets, screen in the driver's desk or communication with the TCMS system or stand-alone are the most common. All DAS systems use their own servers in one way or another and rely on data from different data sources. Table 5 illustrates examples of such sources.

[4] Graph - A graphical timetable used by traffic managers when planning. Available in paper format or digitally.

Data source	Description
Ban Information System (BIS)	Database that contains information about the infrastructure, objects (such as number of switches, bridges, platforms, etc.) as well as information about slopes, speeds, etc.
Körorder	Contains information for the train driver with orders for the specific train, e.g. temporary speed reductions, changes to the track that are not entered in the line book, etc.
Linjeböcker	Contains a description of the infrastructure from a traffic safety perspective for primarily passengers.
Tågpositioneringsssystem (TPOS)	Collects train passages and planned carriageways from traffic management systems and provides the information to other systems.
UTIN	Collects and provides railway-related information from various data sources within the Swedish Transport Administration and provides this as XML files.

Table 5 Examples on different systems in Sweden that DAS-systems collects real-time data from.

In Table 6, several DAS-systems that are available on the market is presented.

System	Supplier	Installation
CATO	Transrail	Tågkompaniet (2017 –) Arlanda Express (2015-2016) Malmbanan (2012 – 2016) Helsinki metro (2018 -)

System, App and Webb	Tydal Systems	Hagalunds bangård, SJ AB, Hector Rail, Arlanda Express
Cubris Greenspeed	Cubris	DSB (Danmark), Öresundståg, Krösatågen (nord och syd), Kustpilen (2015 -)

Table 6 Several DAS-systems that are available on the market

Below is a more detailed description of each system as well as a glossary of abbreviations that will appear continuously in the text, see Table 7 below.

Förkortning	System
DAS	Driver Advisory System
S-DAS	Standalone Driver Advisory System
C-DAS	Connected Driver Advisory System
ATO	Automatic Train Operation
ATC	Automatic Train Control
ATP	Automatic Train Protection
BIS	Ban Informations System
TPOS	Train Positioning System
ICC	Intelligent Cruise Control
COB	Cato Onboard
CTS	Cato Trackside
CATO	Computer Aided Train Operation
BIS	Ban Information System

Table 7 Glossary of abbreviations for various technical systems in Sweden.

Transrail (CATO)

Computer Aided Train Operation, Cato, is a system developed by Transrail (originally together with Uppsala University and Banverket / Trafikverket) with the aim of meeting the demand for improved and more coordinated traffic control through driver support systems in trains. This is achieved through a central traffic control that adjusts the flow of the trains so that they follow a certain timekeeping and at the same time run more energy efficiently.

The system was introduced in 2014 and today covers functions such as C-DAS, Intelligent Cruise Control (ICC) and ATO. In 2018, Cato was the only C-DAS system on the Swedish market. The system offers improved performance linked to a set of factors, see Table 8 below.

Factor	Description
Punctuality	Trains on time at second level throughout the journey
Increased traffic capacity	Small impact in the event of disruptions in the daily operations, high and stable resource ultilization
Environment	Reduced energy consumption and emissions
Customer satisfaction	Good time management, improved information about the traffic, and increased awareness for the staff
Economy	Lower costs and increased revenues

Table 8 Improved performance factors that CATO is offering.

The Cato system consists of several different subsystems and functions but is based on a computer in the vehicle that communicates with a monitor, either fixed or loose (reading tablet). It is based on a mathematical model (a “Digital Twin”) that includes the train, the infrastructure (incl. Signal system), the timetable (preferably the real-time traffic plan) and the movements of other trains. The system then uses this data to make simulations of train movements that optimize the best driving profile for each individual vehicle with regard to:

- Exact timekeeping (arrival time, time restrictions while traveling)
- Restrictions on infrastructure and trains
- Lowest cost (based on a cost function that is minimized)

Cato is an IT system that enables integration with other IT systems, such as traffic management and signaling systems. Through equipment on board, Cato Onboard (COB), and at the track, Cato Trackside (CTS), communication and solutions for status monitoring and statistics between these interfaces are made possible.

In Sweden, the system is connected to the train control module STEG, which is the train dispatcher's user interface (however, it requires manual handling) and in return the system receives static infrastructure data from BIS, which, however, requires manual installation. Dynamic data is retrieved continuously via UTIN, which provides which tracks trains run on, and through TPOS, GPS or accelerometers, which provide information about where the trains are. By gathering all essential driving information in one place, driving profiles can thus be created with optional optimization criteria and which consider all restrictions (e.g. time, station, etc.).

The first tests with the system were performed in 2010 in Norrköping and Boden, but today Cato has been put into operation by the following players, among others:

- Helsinki Metro
- Vy, formerly Tågkompaniet (since 2017)
- Vy, formerly NSB - LKAB (Malmbanan, 2012-2017)
- Virgin Trains
- A-Train (Arlandabanan, 2015-2016)

In 2018, CATO was the most advanced DAS-system in Sweden and was available in three different versions with different levels of detail as well as variants of information about surrounding trains.

Tydal systems

Tydals Systems AB has developed DAS-systems since 2010 and has a portfolio of products in the categories Apps, Systems and Web. The products either enables available data or gathers a set of real-time data sources such as UTIN, BIS etc.

Below is a brief description of each product, see Table 9.

Category	Product	Customer	Description
System	Xpider	SJ AB (2019)	Xpider compiles all data from about twenty systems in one place. It covers everything from planning and operational operations to follow-up. The functionality has been expanded gradually since 2003.
	XDL	Hagalund's railway yard	Hagalund, the Nordic region's largest train depot, was delayed due to time-consuming manual handling. With XDL, Tydal Systems has computerized the process and connected all users in the system.
	Digital Körorder	SJ AB, Hector Rail, Arlanda Express	Previously, new traffic safety information had been added or if the train was to run on a different road than planned, the traffic management had to manually call each train. With the introduction of Driving Orders, this process has been digitized and

			the information is now sent electronically at the touch of a button.
App	1409.se	800+ users	1409.se is a page for travelers who want to keep track of where the trains are, arrivals and departures for different stations, and what delays are due to. The information on the page comes from Tydal Systems and the data is retrieved from the Swedish Transport Administration and Trafiklab.
	TrAppen	2000+ users	The first version of TrAppen was released already in December 2010 for SJ and is aimed at all staff in the field (train drivers, train staff, informants, etc.) who want to quickly get correct information without having to search.
	GPS/Eco-drivning	1000+ users (SJ AB)	Originally developed as the first eco-drive solution that could be run with only a standard smartphone. The app gives the driver the information he / she needs to be able to drive in the best way, where the driving profile is continuously (every second) recalculated.
Webb	Tågexperterna	50+ users	Website where a number of experts answer questions received related to the railway area.
	Vem-kör-vad	SJ AB (2019)	There was previously a challenge in finding which staff were on a particular train, where the information was in different

			folders divided according to which place the staff should be employed. This was solved by Who-runs-what where instead only the train number needed to be stated, a list of affected staff was reproduced.

Table 9 Summary of Tydal Systems products.

Cubris - GreenSpeed

GreenSpeed has its origins in Denmark since the founders Sune Edinger and Christian Hage of Cubis started the company in 2008. Already a year later, they entered into a partnership with Danish National Railways (DSB) to create and implement a resource-efficient DAS-system for them. The system was then put into operation at DSB in 2012.

During the period 2014–2018, Cubris GreenSpeed expanded by establishing its system with several railway operators around Europe, which had now been supplemented with functionalities corresponding to a C-DAS system (Cubris). In 2018, Cubris was acquired by Thales Group, where the company today is part of a separate business unit.

GreenSpeed is marketed as a complete C-DAS system consisting of both hardware and software on the vehicles and in the infrastructure, where the system continuously delivers updated data to the train from the external data center (Cubris). This means that the system is based on real-time data and can communicate with a third party within the traffic control system. Through real-time data, the system can obtain information about e.g. updated timetables and routes in the event of disruptions, which can then be converted into new driving orders.

The system can be modified based on the operator's needs and extends from making all information available on the train to only include simpler applications that do not require any installations on board the trains. Driving profiles are then developed based on typography, timetable, speed limits, train performance, etc., where a combination of the three strategies Coasting (advice to reduce energy), Powered coasting (advice to place the control unit in a certain position) and Cruising (advice to maintain speed).

When a journey begins with GreenSpeed, the on-board device (at the command of the driver) will request all the necessary data from the data center that is processed in a central server. In Sweden, this means that timetables are retrieved from UTIN, infrastructure data comes from BIS but requires manual application, information about speed reductions etc. is entered manually from the Line Book and Train Orders and recommended (lower) speeds are entered based on the drivers' experience.

The communication between the vehicle and the data center takes place continuously throughout the journey. The data center can in turn also request and receive all driver data automatically, either through an external data provider or by the driver manually entering it through their on-board management tool. This is however mainly restricted based on what data sources that are available. The entire route is logged and then transferred to the data center for storage and analysis.

GreenSpeed is currently working on the process to become an integrated solution with the ERTMS interface in Denmark to meet the requirements of the new European system standard. The system has been used in Sweden since 2015 by, among others, Transdev on the Öresund trains, Krösa South and North and Kustpilen (KAJT, 2018).

Additional DAS-systems in Europe

In addition to the above Driver Support Systems, there are several additional products on the market, which to some extent are summarized in Table 10 below.

Supplier	Product name
Bombardier	EBI Drive 50 / DSM

DB Kommunikationstechnik GmbH	FASSI
DB Systel GmbH	ESF-EBuLa
Iavet GmbH / ETC Gauff Mobility Solutions	Smarttrains.DAS
Interautomation Deutschland GmbH / TU Dresden / Inavet GmbH	InLineMobile.FAS
Knorr-Bremse AG	LEADER
SBB AG / CSC	RCS-ADL
Siemens AG	ECO Cruise
TU Dresden	COSEL
Voith GmbH und Co. KGaA	EcoScout

Table 10 Additional suppliers and their products for automated systems in Europe.

Support in the train planning process

While driver support systems have a positive impact on operational operations, many countries today, including Sweden and Finland, have access to well-developed simulators.

Today, the simulators are used primarily for educational purposes - including the training of new traffic managers. By developing the use of simulators to also be an aid in timetable construction, the quality of the timetables can be improved by allowing the train schedule to be tested and any errors or improvements in the train schedule can be detected already in the planning stage. By testing the train schedule, it is, among other things, possible to detect

- where train meetings can be made more efficient,
- how faults in the infrastructure could affect the timetable,
- what happens to surrounding trains if a train runs too slow against its timetable,
- how traffic flows at stations with many tracks.

Travel Time Analysis

Project Objectives

The main project goals and objectives for this part have been:

- Develop possible solutions to minimize travel times for both passenger and freight trains

Approach

Railway planning process whether it is upgrading of the existing infrastructure or planning new lines, requires rigorous planning, modelling and simulations, operations and evaluations efforts that usually extend decades.

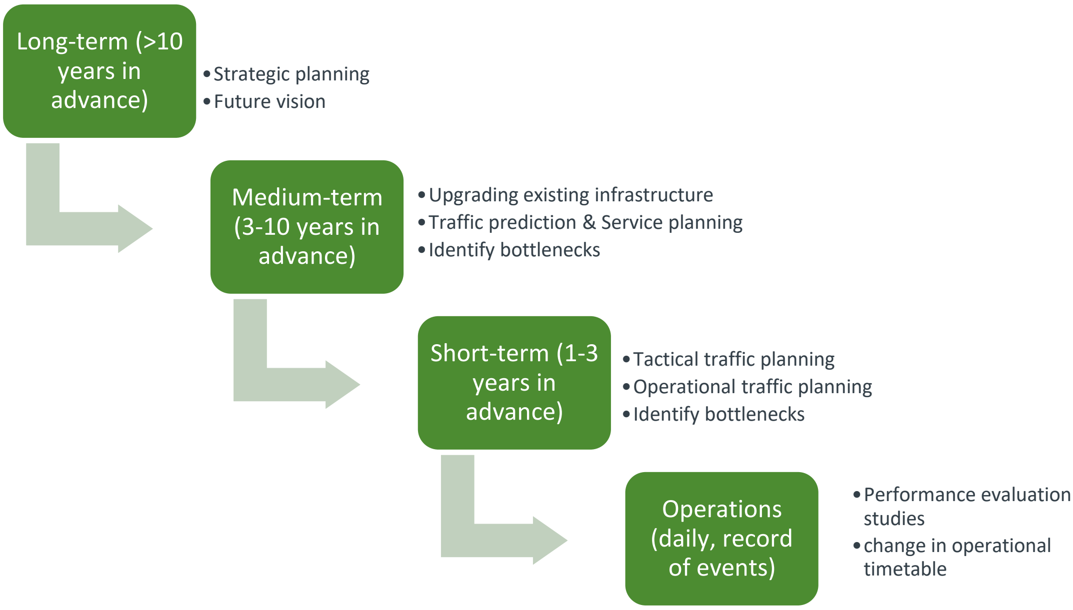


Figure 6 General overview of lifecycle railway planning process

Figure 6 shows very briefly the lifecycle of railway planning process. Long-term strategic planning and visions to the future mostly starts in 10 years or even way longer in advance. Medium-term term planning focus on upgrading of existing infrastructure, traffic prediction and service planning, identification of bottlenecks in the infrastructure. Medium-term planning extends 3-10 years and at times even longer as in the Long-term planning. Short-term planning which normally begins 1-3 years in advance of Operations, may constitute for instance tactical traffic planning, operational traffic planning, and identification of bottlenecks. Finally, during Operations phase activities like timetable performance evaluation based on records of delays and delaying events, last-minute change in timetables due to unplanned incidents, etc. are performed, the results of which in-return can be used in Long, Medium or Short-term planning.

Delimitations

This project focuses on identifying bottlenecks of the existing infrastructure as well as solutions to minimize travel times for some nodes in Sweden, Finland, Estonia and Latvia. As such upgrading of infrastructure is not within the scope of this project. Thus, only Short-term and Operations phases of the planning process described above will be considered.

Nodes in Sweden and Norway

Primary node: Oslo-Örebro-Stockholm

Analysis of the node Oslo – Örebro – Stockholm will in the study take place on Mälarbanan, Godsstråket through Bergslagen, the planned Nobel line and the border line between Karlstad and Oslo, which is the current route for the project "Stockholm - Oslo 2.55".

Existing infrastructure

Mälarbanan stretches from Stockholm, via Västerås, to Hovsta just north of Örebro. Mälarbanan between Örebro and Västerås consists of double tracks and single tracks, see Figure 7. On the section, there are meeting tracks located in Munktorp and Köping. The line between Jädersbruk and Hovsta, which is also single-track, has steep slopes of up to 25 per mille and is primarily intended for passenger traffic. But lighter freight trains (max. 1200 tonnes) also operate on the route (WSP, 2020).

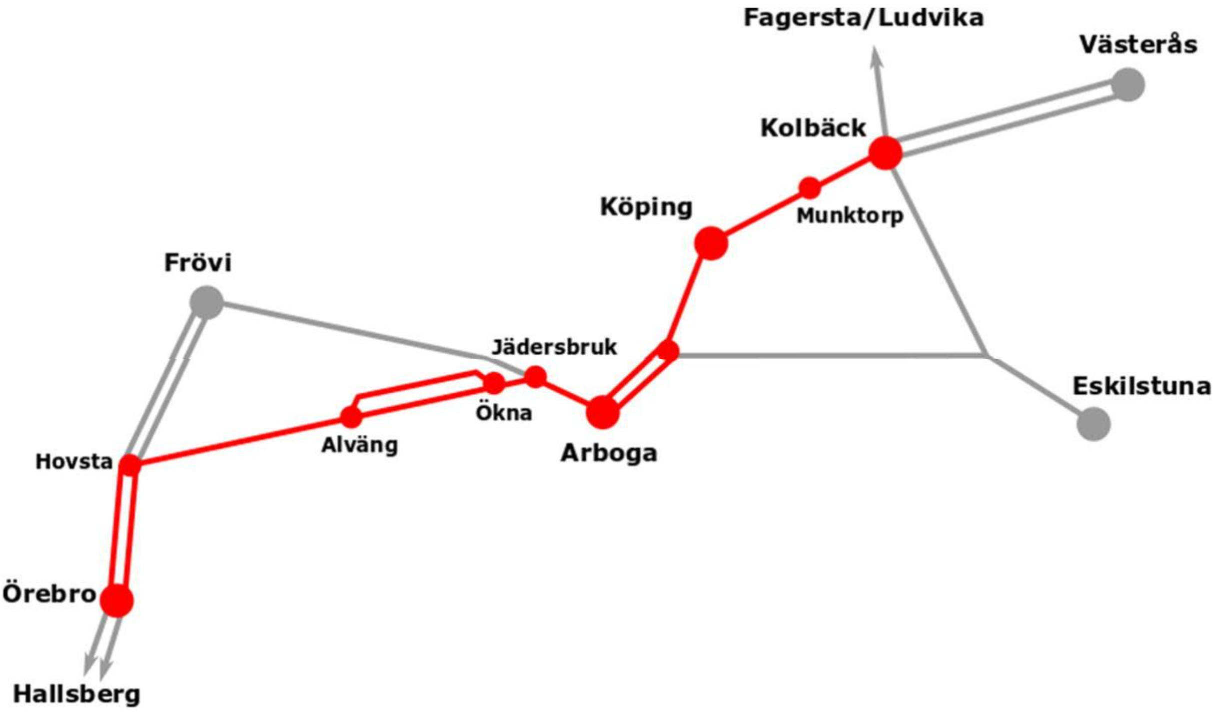


Figure 7 Schematic map of Mälarbanan between Örebro and Västerås.

The maximum permitted speed varies on the section between Örebro and Västerås, from 80 to 200 km / h, see Figure 8. Speed reductions are primarily found on the single-track section between Kolbäck and Hovsta.

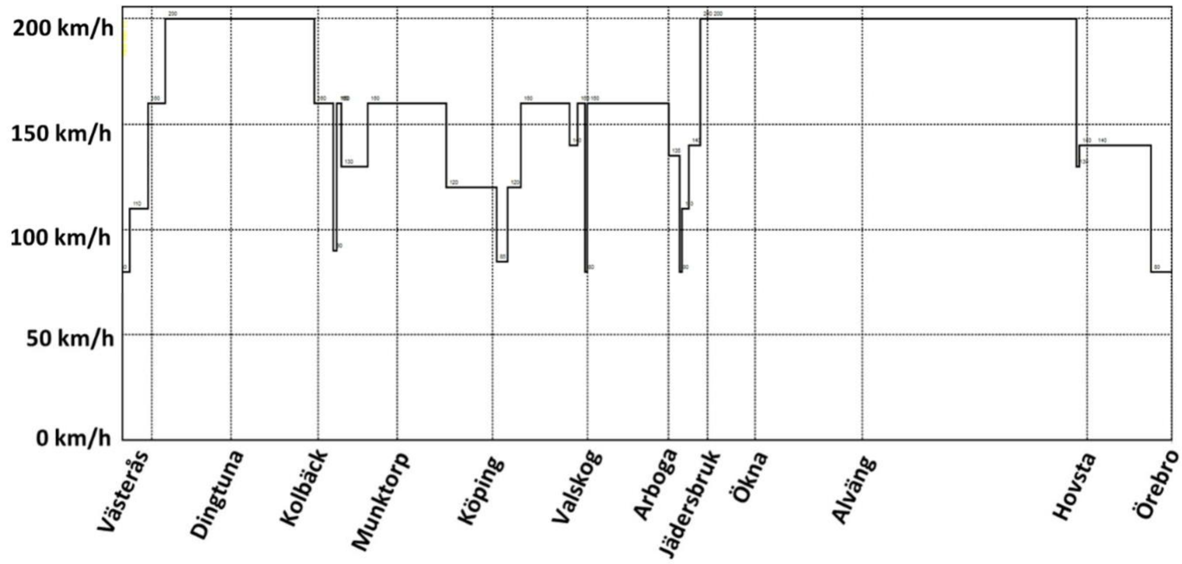


Figure 8 Speed diagram Västerås - Örebro,

After Västerås, Mälarbanan consists of double tracks, to Tomteboda, where the Swedish Transport Administration is currently expanding the railway to four tracks.

The freight route through Bergslagen extends from Storvik in the north to Mjölby in the south. The Storvik – Frövi section is single-track, while the Frövi – Örebro – Hallsberg section is double-track. According to the Line Book (Swedish Transport Administration, 2021a), the maximum permitted speed is consistently 130 kilometers per hour on the route, with reduced speed in the connections to Frövi and Örebro to 80 kilometers per hour.

Today, Värmlandsbanan runs between Kristinehamn and Kil, and consists of a single-track railway with a number of meeting tracks and stations for passenger exchange. Existing meeting tracks are located in Ölme, Väse, Skattkärr, Skåre and just south of Kil

(Swedish Transport Administration, 2021c) On the section between Karlstad and Kristinehamn, the permitted speed varies between 70 and 175 km / h, see Figure 9.

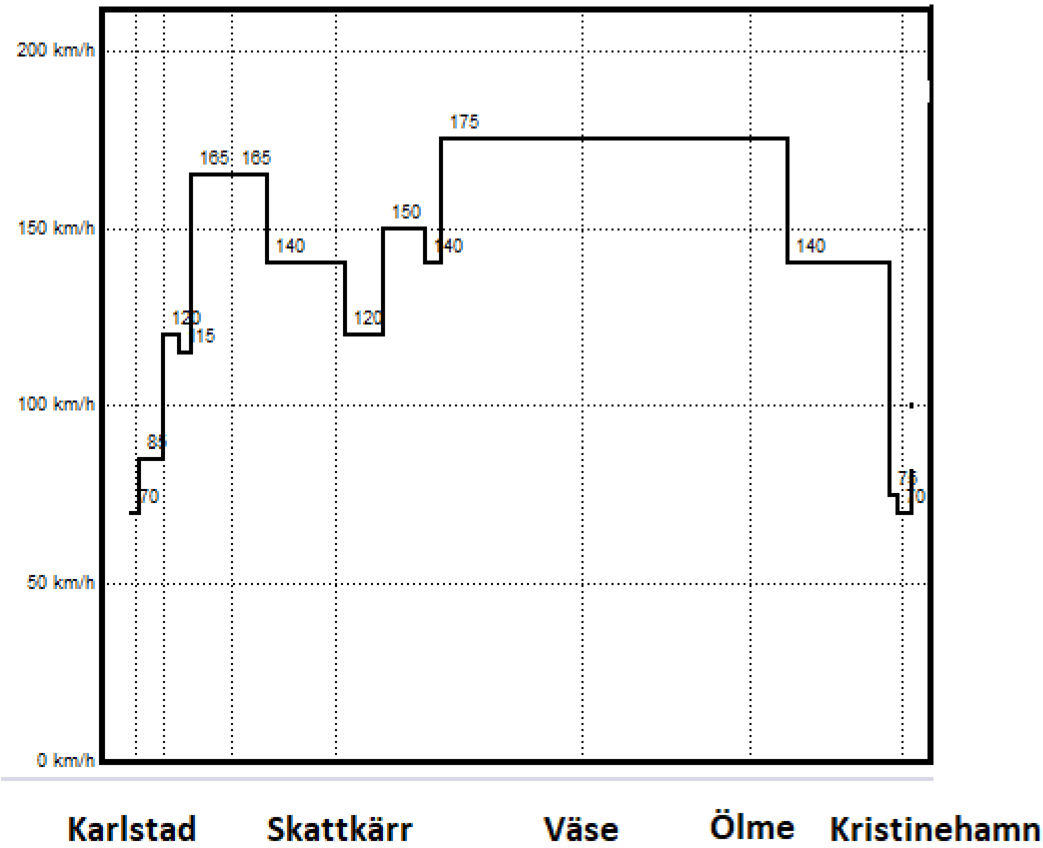


Figure 9 Speed diagram, between Karlstad and Kristinehamn (Railsys)

On the stretch between Karlstad and Kil, the speed limit is relatively constant - about 140 km / h, with speed reductions in Klingersid and Stenåsen, and before Kil and Karlstad.

Figure 10 Speed diagram Karlstad - Kil

As with almost all railway lines in Sweden, the affected lines are electrified, equipped with ATC and operated with traffic system H (Swedish Transport Administration, 2021c).

Planned infrastructure

On the route Oslo – Örebro – Stockholm, there are plans for two new railway lines, the Nobel line between Örebro and Kristinehamn, and the Border line between Karlstad (Arvika) and Oslo (Sweco, 2017).

The Nobel line is planned as a double-track railway, about 70 kilometers long, between Kristinehamn and Örebro, with a new station on the stretch between the towns of Karlskoga and Degerfors. Between Arvika and Lilleström, in Norway, a double-track railway of approximately 92 kilometers is planned (Sweco, 2017).

The goal of the new railway is to complete a travel time goal between Stockholm and Oslo in 2 hours and 55 minutes.

Traffic

On Mälarbanan, SJ's regional trains operate mainly with hourly traffic, as well as with extra trains during peak hours. The trains operate in Stockholm – Hallsberg and

Stockholm – Gothenburg, among other places. In addition to these relations, individual trains run on the routes Stockholm – Örebro, Västerås – Gothenburg, Stockholm – Arboga and Hallsberg – Västerås (Swedish Transport Administration, 2020b).

The section Örebro – Frövi is one of Sweden's busiest of long-distance goods. Most freight transports starting in Norrland/Dalarna heading to Gothenburg, Malmö or the marshalling yard in Hallsberg all operate the route.

Värmlandsbanan is currently served by both long-distance train traffic by SJ and Tågab in relationships such as Stockholm – Hallsberg – Karlstad – Oslo, (Stockholm) – Hallsberg – Karlstad – Gothenburg and Falun – Hällefors – Kristinehamn – Gothenburg. In total, the route is served by ten single trips per day (Swedish Transport Administration, 2020b).

Värmlandstrafiken operates local and regional passenger traffic, a total of 40 single journeys between Kristinehamn and Kil, and another 20 single journeys between Karlstad and Kil - a total of 60 single journeys per day (Swedish Transport Administration, 2020b).

In addition to passenger traffic, there is a relatively extensive freight traffic on the route. Traffic is primarily provided by Green Cargo, but also by other operators such as Vänerexpressen, Hector Rail and Tågab. In total, the Kristinehamn – Karlstad section is served by 31 freight trains per day and 47 freight trains per day run the Karlstad – Kil section (Swedish Transport Administration, 2020b).

The traffic on the planned Nobel Line and the Border Line has been described in target images for long-distance and regional traffic. According to the target picture, long-distance traffic must run with high-speed trains with a maximum permitted speed of 250 km / h, while regional traffic operates with express trains with a maximum permitted speed of 200 km / h. This is to meet the travel time target of two hours and 55 minutes between Oslo and Stockholm (Sweco, 2017).

Analysis of the node Oslo – Örebro – Stockholm

Kolbäck – Västerås (Mälarbanan)

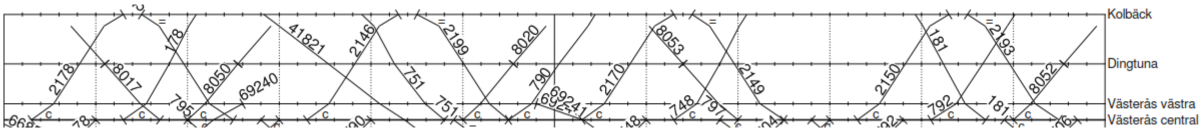


Figure 11 Daily graph, between Kolbäck and Västerås, 16: 00-18: 00 2021-10-13

Passenger traffic gives a certain sensitivity to delays for northbound trains around Kolbäck during peak hours. This is because the UVEN that stops in Kolbäck is followed by a high-speed train that does not stop at the station. In addition, the faster trains catch up with the forward, northbound, slower trains (Bergslagspendeln) along the section Västerås West - Västerås C.

Frövi - Hallsberg (Godsstråket through Bergslagen)

The freight route through Bergslagen is adapted for freight trains with a maximum permissible axle load of 22.5 tonnes (STAX D) and a wagon meter weight of 6.4 tonnes. A large part of the freight trains are heavy and most of the southbound trains have a carriage weight between 1500 and 2600 tonnes. This results in trains with an axle load of 25 tonnes (STAX E) having to be run as special transports with special transport conditions, such as limited speed. Maximum permitted speed varies between 80 km / h, Frövi - Hovsta, to 50 km / h, Hovsta - Örebro, see figure Figure 12.

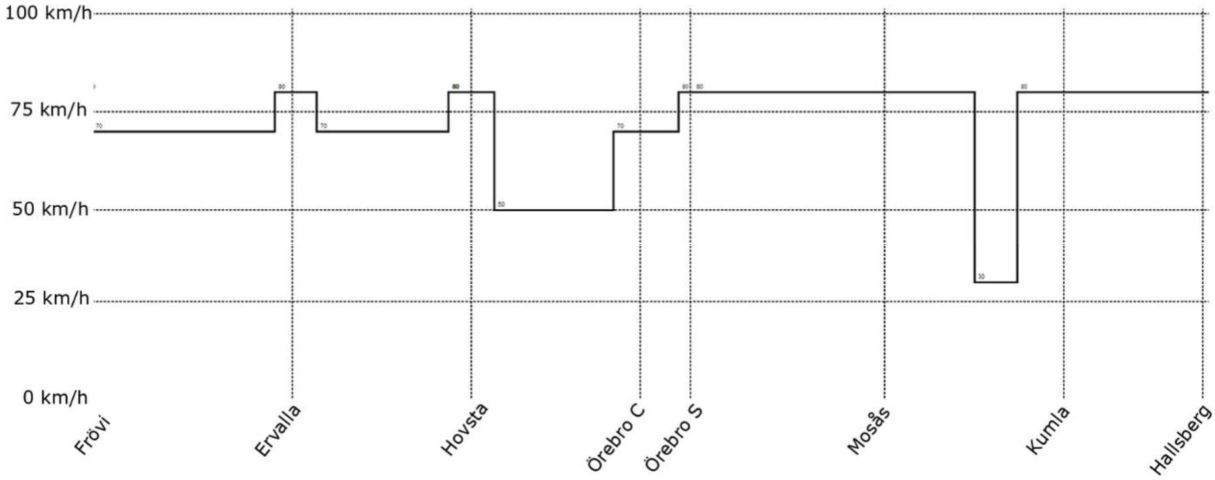


Figure 12 Speed profile for STAX E, Frövi - Hallsberg. Railsys

The speed limits mean longer running times for the freight trains, but also a risk that other trains will have longer transport times or be delayed in an operational situation, should they end up behind a freight train with STAX E.

Kristinehamn - Kil (Värmlandsbanan)

Värmlandsbanan is, as previously mentioned, heavily congested with large amounts of traffic. The traffic is mixed and consists of both long-distance, regional and freight trains.

The theoretical capacity utilization for the Kristinehamn – Karlstad – Kil section is reported below. The theoretical capacity calculations have been performed using the same methodology as the capacity calculations for line capacity that the Swedish Transport Administration performs in connection with the annual report of capacity utilization. Line capacity means how many trains can be run on a line section over a period of time. Capacity utilization means how much of the track's theoretical capacity is utilized. The optimal level for capacity utilization is a balance between quantity and quality. From the theoretical capacity utilization, it is possible to illustrate at a general level where there are capacity limitations, punctuality problems and where any measures are needed in the system.

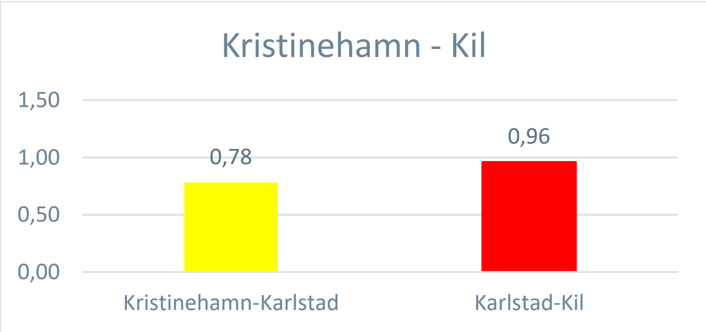


Figure 13 Theoretical capacity utilization 2021, Kristinehamn - Kil, (WSP, 2021)

The problem on Värmlandsbanan becomes clear when studying the capacity utilization on the line. Both Karlstad – Kil and Kristinehamn – Karlstad have high levels of capacity utilization, much due to the high load, the mixed traffic and the fact that the track consists of single tracks. On the section between Karlstad – Kil, the capacity is flat out and gives a picture of a disturbance-sensitive track with a low or no resilience. Resilience means the ability to handle delayed trains in the traffic system and to prevent these trains from leading to delays for other traffic.

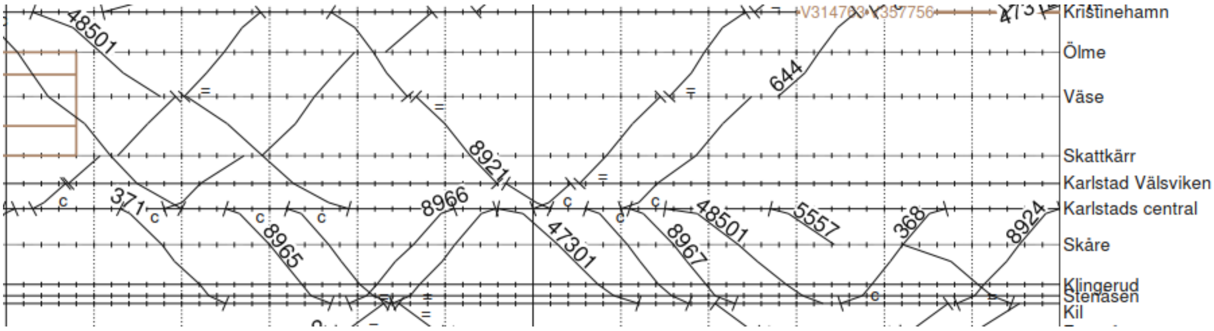


Figure 14 Daily graph, between Kristinehamn and Kil, 16: 00-18: 00, 2021-10-13

A study of the daily graph, see Figure 14, shows that several of the trains have relatively long residence times at the meeting stations, such as Ölme, Väse, Skattkärr and Skåre.

Even if the residence times could be minimized with timetable optimization, the large capacity shortage remains on the line between Kil and Kristinehamn. The punctuality problems and the load situation become difficult to plan away and the track has a great need for new infrastructure investments, for example longer meeting tracks or double tracks.

Secondary Node: Kopparberg - Lindesberg - Örebro

Traffic between Kopparberg – Lindesberg – Örebro takes place on the Bergslagsbanan and Godsstråket through Bergslagen.

The section between Frövi and Örebro overlaps the previously treated section, Oslo – Örebro – Stockholm. The route's infrastructure and traffic are therefore already described in previous chapters.

Existing infrastructure

Bergslagsbanan consists of single tracks between Kopparberg and Frövi. According to the Line Book (Swedish Transport Administration, 2021a), the maximum permitted speed on the route varies between 60 and 120 kilometers per hour. The line is characterized by most level crossings with road protection facilities, where, for example, the level crossing in Vasstorp lacks road protection signaling.

As with almost all rail in Sweden, both the lines concerned are electrified, equipped with ATC and operated with traffic system H.

Traffic

The regional traffic on Bergslagsbanan is operated in one-hour traffic starting in Gävle, Borlänge and Mora. During peak hours, extra trains start in Lindesberg. In Frövi, the regional trains connect via Avesta Krylbo, which operates along Godsstråket through Bergslagen. The trains start in Gävle and run every two hours. The trains from the north turn in Örebro S, Mjölby, Hallsberg and Laxå. Hovsta also connects SJ's traffic, which consists of regional traffic that runs with hourly traffic between Stockholm – Västerås – Hallsberg, and Stockholm – Västerås – Gothenburg. Traffic from Svealandsbanan also connects in Hovsta, this is Mälardalstrafik's regional train that runs in the Stockholm – Örebro relationship. The trains run in one-hour traffic, but half of the trains turn in Arboga and therefore do not burden the Hovsta – Örebro section (WSP, 2021).

Analysis of the node Kopparberg - Lindesberg - Örebro

A study of daily graph (Swedish Transport Administration, 2021b) shows how northbound trains to Kopparberg have to wait for southbound regional trains in Lindesberg. The time for the stop varies with the intervals 5-8 minutes during weekdays between 8:00 and 12:00. See Figure 15 below. The trains next stop in Storå, will have longer stops for waiting for trains from the north.

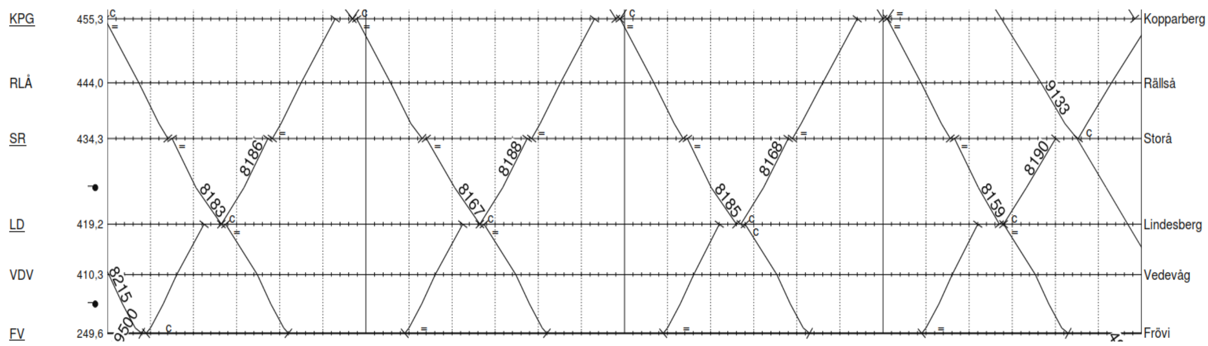


Figure 15 Daily graph 212013 22, Kopparberg-Frövi

An optimization of the timetable could result in a lower running time for trains running the route.

On Godsstråket through Bergslagen, between Frövi and Örebro, it is, as mentioned above, double tracks with a higher load of traffic. See Figure 16 below.

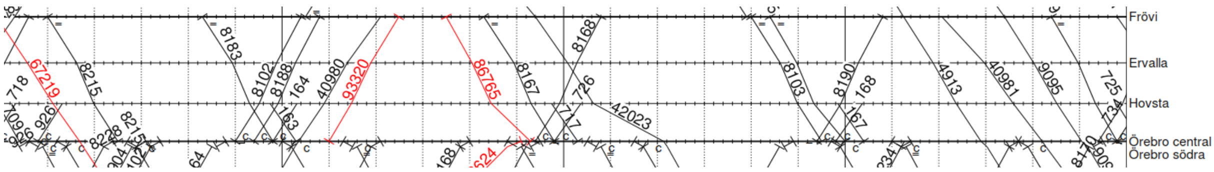


Figure 16 Daily graph 212013 14, Frövi -Örebro

The theoretical capacity utilization for the Kopparberg – Lindesberg – Örebro section is reported below. The optimal level for capacity utilization is a balance between quantity and quality. From the theoretical capacity utilization, it is possible to illustrate at a general level where capacity limitations, punctuality problems and where any measures are needed in the system.

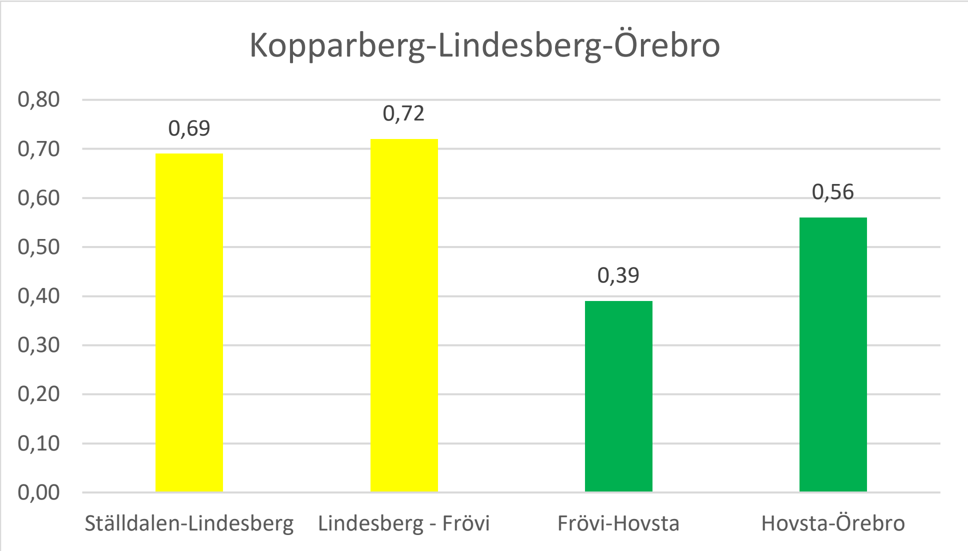


Figure 17 The theoretical capacity utilization for the section Kopparberg - Lindesberg - Örebro, today

The freight route through Bergslagen, with the sections Frövi – Hovsta and Hovsta – Örebro, is today at an almost optimal level of capacity utilization. Robustness problems cannot be deduced from the theoretical capacity utilization.

The Bergslagsbanan, with the sections Ställdalen – Lindesberg and Lindesberg – Frövi, has a higher capacity utilization, largely due to the fact that the rail consists of single track. The levels of theoretical capacity utilization provide a picture of a disturbance-sensitive section with a low resilience.

Secondary node: Katrineholm - Eskilstuna - Västerås

Traffic between Katrineholm – Eskilstuna – Västerås takes place on the line Sala – Oxelösund, also called the TGOJ line, and the West main line. Between Eskilstuna C and Rekarne, the TGOJ line shares tracks with Svealandsbanan.

The section between Västerås and Kolbäck overlaps the previously treated section, Oslo – Örebro – Stockholm. The route's infrastructure and traffic are therefore described in previous chapters.

Existing infrastructure

The TGOJ line, which stretches via Västerås, Eskilstuna and Flen, is largely single-track. From Västerås to Kolbäck the rail consists of double-track and from Kolbäck to Folkesta it is single-track. The remaining section of Svealandsbanan up to Eskilstuna consists of double tracks. South of Eskilstuna, there are single tracks all the way to Oxelösund with meeting tracks in Skogstorp, Hållsta, Bälgviken, Hälleforsnäs and Mellösa before the line reaches Flen (WSP, 2018).

The West main line is one of Sweden's most important and most heavily loaded railways. The western main line runs from Stockholm via Katrineholm and Hallsberg to Gothenburg. The western main line has double tracks, but there are also four tracks. The section Flen – Katrineholm is double-track.

As with almost all rail in Sweden, both lines concerned are electrified, equipped with ATC and operated with traffic system H (Swedish Transport Administration, 2021c).

Traffic

Mälardalen is connected in a north-south direction by the UVEN train, which operates from Sala via Västerås in the north to Linköping via Katrineholm in the south. UVEN currently has one-hour traffic on the entire route and an extra trains Västerås – Eskilstuna during peak hours.

On the Rekarne – Folkesta route, Mälardalstrafik operates one-hour traffic in the relationship Stockholm – Arbgoa / Örebro. Freight traffic on the route consists of SSAB's steel trains that run Borlänge – Oxelösund, as well as wagon trains to and from Folkesta (WSP, 2021).

The section Folkesta - Eskilstuna C has the same passenger traffic as on Rekarne-Folkesta. In addition to passenger traffic, the route is served by approximately 24 freight trains per day (Swedish Transport Administration, 2020b).

On the section Eskilstuna C – Flen, passenger train traffic takes place as mentioned above by UVEN. In hourly traffic, system meetings take place in Hälleforsnäs. With the densification to half-hour traffic during peak hours, this means that system meetings also take place in Skogstorp, Hållsta and Flen. The route operates according to daily graph 2021-10-13 of 13 freight trains (WSP, 2021).

The section Flen – Katrineholm is operated, as mentioned above, by UVEN. Also, by long-distance trains by SJ and MTRX. The southern main line long-distance train, between Katrineholm and Stockholm, will also be added to the route. The western main line is heavily congested with intensive freight traffic. The section between Flen and Katrineholm was operated in daily graph 2020-10-14 by 32 freight trains (WSP, 2021).

Analysis of the node Katrineholm – Eskilstuna – Flen

In daily graph, date 211013 at 16:00-20:00, see Figure 18, the previously mentioned system meetings can be read out on the TGOJ line, between Eskilstuna and Flen. The system meetings that take place in Skogstorp, Hållsta, Flen and Hälleforsnäs mean an extension of the running time for several of the trains. Especially in Hållsta and Hälleforsnäs there are longer stops to wait for oncoming traffic, for example train 2147 waits about 4 minutes in Hållsta for meeting with train 2152 and in Hälleforsnäs train 2192 awaits train 2179 for about 4 minutes. If train meeting times can be minimized, the running time for most trains could be reduced.

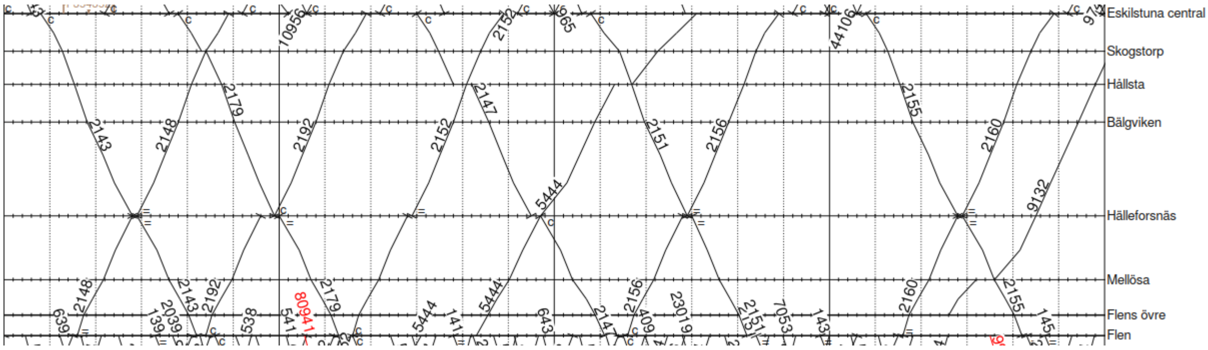


Figure 18 Daily graph, date 211013 at 16: 00-20: 00

The theoretical capacity utilization for the section Katrineholm – Eskilstuna – Västerås is reported below. The optimal level for capacity utilization is, as previously mentioned, a balance between quantity and quality. From the theoretical capacity utilization, it is possible to illustrate at a general level where capacity limitations, punctuality problems and where any measures are needed in the system.

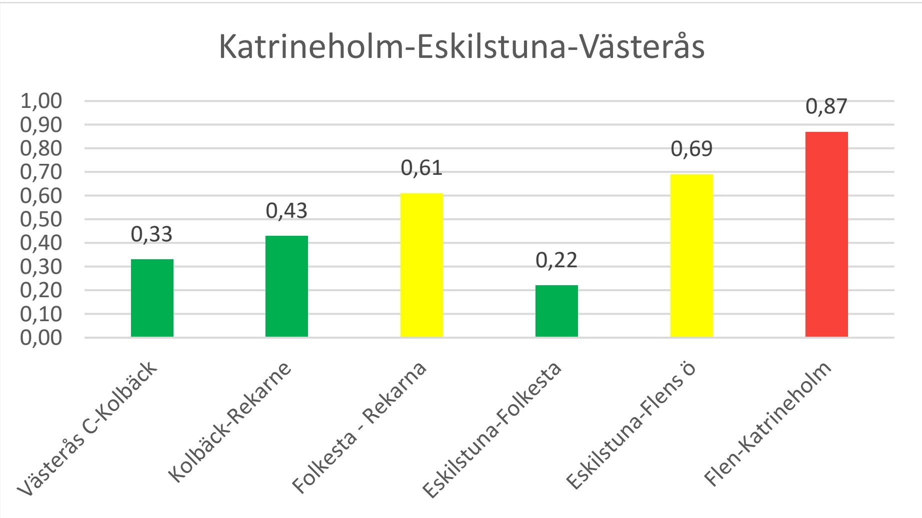


Figure 19 The theoretical capacity utilization for the section Katrineholm - Eskilstuna - Västerås

The sections Västerås – Kolbäck and Kolbäck – Rekarne are today at an almost optimal level of capacity utilization. Robustness problems cannot be deduced from the theoretical capacity utilization. Folkesta – Rekarne, which is right on the border at 60% capacity utilization, should also be able to handle its traffic without major disruption problems. Eskilstuna – Folkesta instead has a slightly too low capacity utilization. Eskilstuna – Flen has a higher capacity utilization, largely due to the fact that there are single tracks on the rail. The levels of the theoretical capacity utilization give a picture of a disturbance-sensitive section with a relatively low resilience.

On the West main line, between Flen and Katrineholm with its high load of mixed traffic, with a lot of goods, capacity utilization is at almost critical levels and there is a very low resilience and relatively high sensitivity to disturbance.

Tertiary node: Örebro – Askersund

Örebro C has a good connection with Örebro travel center, which is directly connected by bus terminal to the platforms on Örebro C, which enables fast and smooth exchange between trains and buses in Örebro.

Länstrafiken Örebro operates the route via bus line 841, Örebro – Åsbro – Askersund. The journey takes about 53 minutes. The bus line operates with hourly traffic, as well as half-hour traffic in peak traffic (Länstrafiken Örebro, 2021). The bus line departs 15 minutes over every hour, except in peak traffic when further journeys depart at minute 45.

The departure times mean that almost all departures can be connected to train traffic from Örebro C. For example, SJ regional trains arrive from both Stockholm (via Västerås and Arboga) and Hallsberg just before the departure of the bus line (Jernhusen, 2021). TIB / SJ's tours from Laxå and Gävle also arrive just before bus line 841 departs. This gives travelers a possible change time of about 5-15 minutes.

Tertiary node: Örebro – Hällefors

Länstrafiken Örebro operates the route via bus line 802, Örebro – Hällefors. The journey takes about 1 hour and 15 minutes. The bus line operates with 7 trips a day, Monday to Friday (Örebro, Länstrafiken, 2021)

In the morning, the bus line departs at 06.20 from Örebro travel center. It is then possible to change from one of SJ's regional trains from Hallsberg or Västerås, which arrives at 05:55, 06:04 and a second train from Hallsberg at 06:15 (Jernhusen, 2021).

In the same way, the bus line arrives in Örebro from Hällefors in the morning at 07:00, which makes it possible to change to trains, via SJ Regional to Västerås, via Köping, Arboga, 07:05 or Västtågen to Lidköping, via Mariestad, Laxå, Hallsberg , 07:13 or TIB / SJ's train to Borlänge, via Ludvika, Frövi, 07:15 (Jernhusen, 2021).

In the afternoon, there are worse opportunities for direct changes between train and bus line 802. From Örebro, the buses depart at somewhat odd times of 15:05 and 19:20 (Länstrafiken Örebro, 2021), which means longer waiting times in Örebro for changes to Hällefors. The trip in the opposite direction arrives in Örebro at 15:30 or at 17:55.

Nodes in Finland

Primary nod: Helsinki – Tampere

Existing Infrastructure

The Helsinki - Tampere section includes two lines: Riihimäki – Tampere and Helsinki - Riihimäki (see Figure 20). Both tracks are double-track, but with four tracks between Purola - Ainola and Kytömaa - Helsinki, as well as three tracks on the section Sääksjärvi - Tampere. The entire route is electrified and is served by both passenger trains and freight trains. (Finnish Transport Infrastructure Agency, 2020)

The Riihimäki – Tampere line is 116 km long and has 10 stations (including Tampere and Riihimäki). The entire route has a speed limit of 200 km / h. Helsinki - Riihimäki is 71.4 km long and has 22 stations. The speed limit on the Helsinki - Pasila route is 80 km / h, Pasila - Tikkurila 160 km / h, and Tikkurila - Riihimäki 200 km / h. (Finnish Transport Infrastructure Agency, 2020)

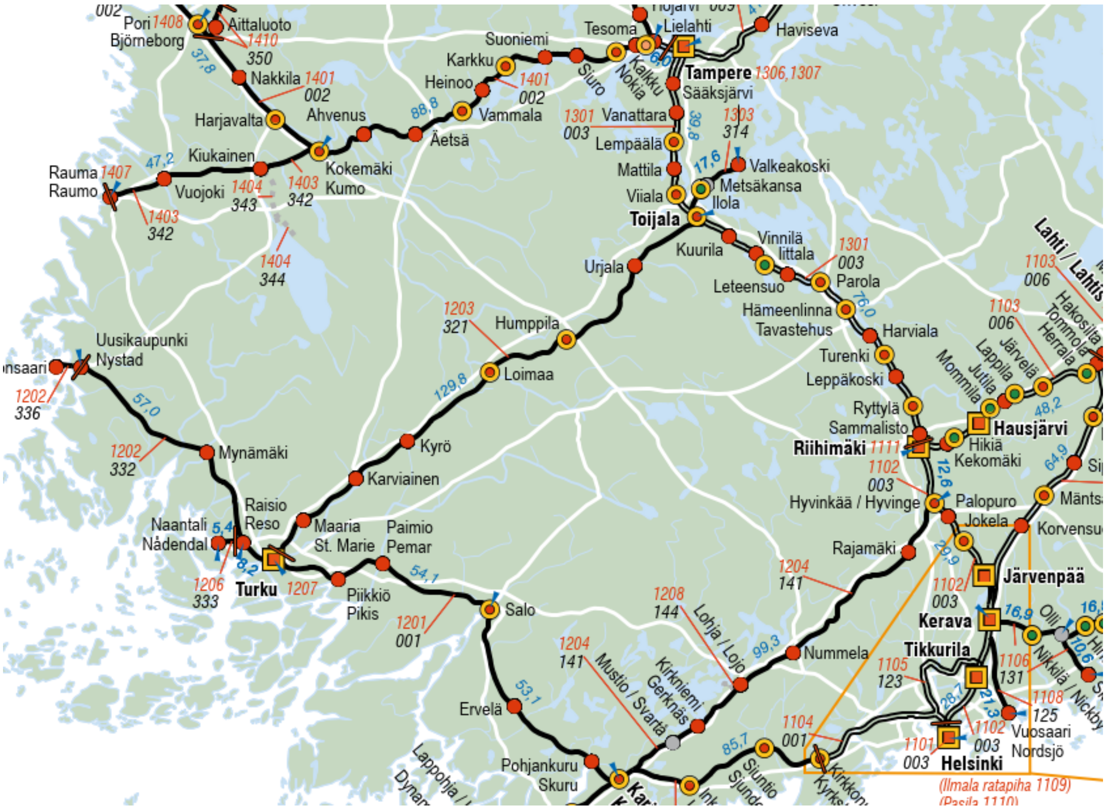


Figure 20 Railway network in South West of Finland.

On the double-track section Purola – Sääksjärvi, there are no overtaking tracks on the line. Stations on the line mainly have platform locations at main tracks (see Table 11).

	Platforms	Platforms along side tracks
Tampere	5	Yes
Lempäälä	2	No
Viiala	2	No
Toijala	4	Yes
Iittala	2	No
Parola	2	No
Hämeenlinna	3	Yes
Turenki	2	No
Ryttylä	2	No
Riihimäki	6	Yes
Hyvinkää	3 (1)	Yes
Jokela	3	Yes
Järvenpää	3	Yes
Kerava	4	Yes
Tikkurila	6	Yes
Pasila	11	Yes
Helsinki	19	Yes

Table 11 Stations (with stop in the time table) along the line Helsinki – Tampere

Infrastructure Development

On the line, there is reduced speed (applies to 2022) on the following routes, see Table 12 below.

003	Helsinki	Kerava	7+690 – 7+790 100 km/h	Oulunkylä, track kondition
003	Helsinki	Kerava	21+200 – 21+530 120 km/h	Hanala, track geometry
003	Helsinki	Kerava	29+650 – 29+805 140 km/h	Kerava, track geomety
003	Kerava	Hyvinkää		No speed limits due to track condition expected at the moment
003	Hyvinkää	Riihimäki		No speed limits due to track condition expected at the moment
003	Riihimäki	Toijala	2 km, 80 km/h	Average limit in 2021
003	Toijala	Tampere	2 km, 80 km/h	Average limit in 2021

Table 12 Speed limitations on the line Tampere – Helsinki. (Railway Network Statement 2022, 2020)

Traffic

Although most of the Helsinki - Tampere route allows speeds of 200 km / h, the travel time is limited by the train's maximum speed. Distance and travel time for car and train for the route are shown in Table 13.

Route	Distance (km)	Travel time by car (2018)	Travel time by train (VR 2019)
Helsinki-Tampere	178	1:50	1:34

Table 13 Travel times for Helsinki-Tampere (Väylävirasto, 2020)

There is already a shortage of capacity on the line today, at the same time as there is a need for time slots for maintenance. Platform capacity is also poor at most stations on the route. On the section Riihimäki - Toijala, there are challenges with the timetable for getting mixed passenger and freight traffic together, as there is no possibility of passing on the line and that side tracks at the stations are on the east side; which makes it challenging for the traffic to the south (Finland has right-hand traffic so southbound traffic, which needs to enter side tracks, must then cross northbound tracks) (Liikennevirasto, 2018).

The national traffic forecast for 2030 estimates a significant growth in traffic on the Helsinki - Riihimäki route for both long-distance and local traffic. As capacity utilization today is high on the route, an increase in the number of passenger trains requires investments in infrastructure. There are also plans to expand commuter train traffic in the region around Tampere, which would lead to a further increase in the number of trains on the route towards Tampere. (Liikennevirasto, 2018)

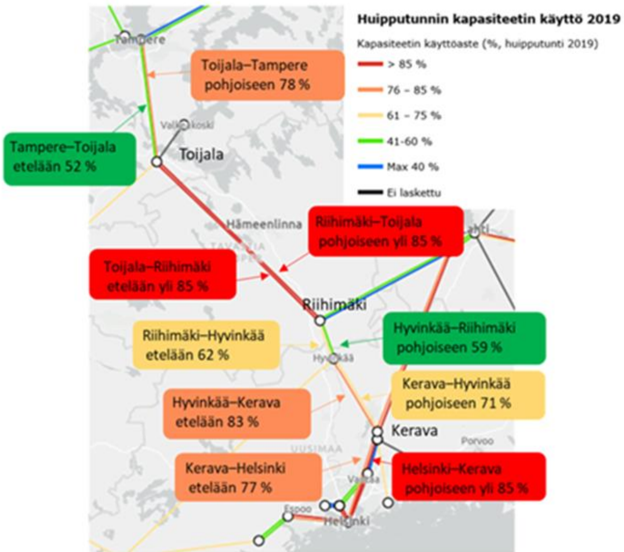


Figure 21 Capacity utilization for southbound and northbound trains during rush hour on the Helsinki - Tampere route, 2019

As the possibility of overtaking on the route is limited, the gap between long-distance and local traffic needs to be longer than desired to reduce the risk of overtaking (see Figure 21), which reduces the possibility of more train paths and makes the track more sensitive to disturbance.

Kaukoliikenteen aikataulut 28.3.–6.6.2021 (muutokset mahdollisia!)

v. 12.2.2021
(muutokset kauteen 11.1.–27.3.2021 verrattuna korostettu keltaisella)

3 TAMPERE–HELSINKI

perutaan toistaiseksi >															M-P				
kulkupäivät >		M-S	M-P	M-P	M-P	M-P	L	M-S	M-P	M-P	M-S	M-P	M-S	M-P	M-L	S	M-L	M-P	M-S
junatyyppi >		IC	R	R	D	IC	S	R	IC	R	IC	R	R	IC	IC	S	R	R	R
junan numero >		266	9618	9622	9626	162	162	9628	166	9632	274	9602	9636	40	80	80	9638	9606	9640
Tampere		3:45				5:45	5:45		6:22		6:08	6:37		7:00	7:04	7:04		7:30	
Lempäälä	o	|				5:56	5:56		|		|	6:47		|	7:15	7:15		7:42	
Lempäälä		|				5:57	5:57		|		|	6:48		|	7:16	7:16		7:43	
Viiala		|				|	|		|		|	6:55		|	|	|		7:51	
Toijala	o	4:10				6:06	6:06		|		6:33	6:59		|	7:25	7:25		7:55	
Toijala		4:12				6:07	6:07		|		6:42	7:00		|	7:26	7:26		7:56	
Iittala		|				|	|		|		|	7:10		|	|	|		8:07	
Parola		|				|	|		|		|	7:18		|	|	|		8:16	
Hämeenlinna	o	4:36				6:27	6:27		6:58		7:06	7:23		|	7:45	7:45		8:21	
Hämeenlinna		4:38			6:17	6:29	6:29		7:00		7:08	7:24		|	7:47	7:47		8:22	
Turenki		|			6:25	|	|		|		|	7:32		|	|	|		8:31	
Ryttylä		|			6:32	|	|		|		|	7:39		|	|	|		8:39	
Riihimäki	o	5:00			6:39	6:47	6:47		7:18		7:30	7:46		|	8:04	8:04		8:46	
Riihimäki		5:03	5:25	6:19	6:41	6:50	6:50	6:55	7:20	7:25	7:40		7:55	|	8:08	8:08	8:25		8:55
Hyvinkää	o	|	5:32	6:29	6:48	|	|	7:02	|	7:32	|		8:02	|	|	|	8:32		9:02
Hyvinkää		|	5:33	6:29	6:49	|	|	7:03	|	7:33	|		8:03	|	|	|	8:33		9:03
Jokela		|	5:39	6:37	|	|	|	7:09	|	7:39	|		8:09	|	|	|	8:39		9:09
Järvenpää		|	5:48	6:47	7:00	|	|	7:18	|	7:48	|		8:18	|	|	|	8:48		9:18
Kerava	o	|	5:55	6:54	7:06	|	|	7:25	|	7:55	|		8:25	|	|	|	8:55		9:25
Kerava		|	5:56	6:55	7:07	|	|	7:26	|	7:56	|		8:26	|	|	|	8:56		9:26
Tikkurila	o	5:45	6:04	7:03	7:15	7:21	7:21	7:34	7:51	8:04	8:29		8:34	8:20	8:39	8:39	9:04		9:34
Tikkurila		5:47	6:05	7:04	7:16	7:22	7:22	7:35	7:52	8:05	8:30		8:35	8:21	8:40	8:40	9:05		9:35
Pasila	o	6:19	6:13	7:13	7:24	7:30	7:30	7:43	8:00	8:13	9:07		8:43	8:29	8:48	8:48	9:13		9:43
Pasila		6:21	6:14	7:14	7:25	7:31	7:31	7:44	8:01	8:14	9:09		8:44	8:30	8:49	8:49	9:14		9:44
Helsinki	o	6:27	6:19	7:19	7:30	7:36	7:36	7:49	8:07	8:19	9:15		8:49	8:35	8:54	8:54	9:19		9:49

perutaan toistaiseksi >		Ti-P		L				Ti-P	L		L-S		Ti-To						M-To	
kulkupäivät >		M-L	M-P	L-S	M-S	M-P	M-L	M-L	M-L	M-S	M-S	M-S	M-L	M-S	M-S	M-S	M-S	M-S	(3)	M-S
junatyyppi >		IC	S	IC	R	M	R	IC	S	R	IC	R	IC	IC	R	R	R	IC	S	R
junan numero >		42	140	140	9642	9986	9646	150	44	9650	20	9656	36	142	9662	9664	9666	22	94	9670
												#				#				
Tampere		8:00	8:04	8:04		8:16	8:37	9:00	9:04		10:00	10:04	11:00	11:04		11:30		12:00	12:04	
Lempäälä	o	|	8:15	8:15		8:29	8:47	|	9:15		|	10:15	|	11:15		11:42		|	12:15	
Lempäälä		|	8:16	8:16		8:30	8:48	|	9:16		|	10:18	|	11:16		11:43		|	12:16	
Viiala		|	|	|		8:38	8:55	|	|		|	10:25	|	|		11:51		|	|	
Toijala	o	|	8:25	8:25		8:43	8:59	|	9:25		|	10:29	|	11:25		11:55		|	12:25	
Toijala		|	8:26	8:26			9:00	|	9:26		|	10:30	|	11:26		11:56		|	12:26	
Iittala		|	|	|			9:10	|	|		|	10:40	|	|		12:07		|	|	
Parola		|	|	|			9:18	|	|		|	10:48	|	|		12:16		|	|	
Hämeenlinna	o	|	8:45	8:45			9:23	|	9:45		|	10:53	|	11:45		12:21		|	12:45	
Hämeenlinna		|	8:47	8:47			9:24	|	9:47		|	10:54	|	11:47		12:22		|	12:47	
Turenki		|	|	|			9:32	|	|		|	11:02	|	|		12:31		|	|	
Ryttylä		|	|	|			9:39	|	|		|	11:09	|	|		12:39		|	|	
Riihimäki	o	|	9:04	9:04			9:46	|	10:04		|	11:16	|	12:04		12:46		|	13:04	
Riihimäki		|	9:08	9:08	9:25		9:55	|	10:08	10:25	|	11:25	|	12:08	12:25		12:55	|	13:08	13:25
Hyvinkää	o	|	|	|	9:32		10:02	|	|	10:32	|	11:32	|	|	12:32		13:02	|	|	13:32
Hyvinkää		|	|	|	9:33		10:03	|	|	10:33	|	11:33	|	|	12:33		13:03	|	|	13:33
Jokela		|	|	|	9:39		10:09	|	|	10:39	|	11:39	|	|	12:39		13:09	|	|	13:39
Järvenpää		|	|	|	9:48		10:18	|	|	10:48	|	11:48	|	|	12:48		13:18	|	|	13:48
Kerava	o	|	|	|	9:55		10:25	|	|	10:55	|	11:55	|	|	12:55		13:25	|	|	13:55
Kerava		|	|	|	9:56		10:26	|	|	10:56	|	11:56	|	|	12:56		13:26	|	|	13:56
Tikkurila	o	9:20	9:39	9:39	10:04		10:34	10:20	10:39	11:04	11:20	12:04	12:20	12:39	13:04		13:34	13:20	13:39	14:04
Tikkurila		9:21	9:40	9:40	10:05		10:35	10:21	10:40	11:05	11:21	12:05	12:21	12:40	13:05		13:35	13:21	13:40	14:05
Pasila	o	9:29	9:48	9:48	10:13		10:43	10:29	10:48	11:13	11:29	12:13	12:29	12:48	13:13		13:43	13:29	13:48	14:13
Pasila		9:30	9:49	9:49	10:14		10:44	10:30	10:49	11:14	11:30	12:14	12:30	12:49	13:14		13:44	13:30	13:49	14:14
Helsinki	o	9:35	9:54	9:54	10:19		10:49	10:35	10:54	11:19	11:35	12:19	12:35	12:54	13:19		13:49	13:35	13:54	14:19

perutaan toistaiseksi >									M-To						M-To			M-To	
kulkupäivät >		(4)	L-S	M-S	M-S	M-P	M-S	M-S	M-S	M-P,S	L	M-S	M-P	M-S	M-P,S	L	M-S	M-S	P-S
junatyyppi >		S	IC	R	IC	IC	R	R	IC	IC	S	R	M	IC	IC	S	R	IC	IC
junan numero >		46	46	9676	38	178	9682	9686	48	144	144	9690	9990	24	86	86	9700	50	180
				#															
Tampere		13:00	13:00	13:07	14:00	14:04		14:37	15:00	15:04	15:04		15:30	16:00	16:04	16:04	16:37	17:00	17:04
Lempäälä	o	|	|	13:17	|	14:15		14:47	|	15:15	15:15		15:43	|	16:15	16:15	16:47	|	17:15
Lempäälä		|	|	13:18	|	14:16		14:48	|	15:16	15:16		15:44	|	16:16	16:16	16:48	|	17:16
Viiala		|	|	13:25	|	|		14:55	|	|	|		15:52	|	|	|	16:55	|	|
Toijala	o	|	|	13:29	|	14:25		14:59	|	15:25	15:25		15:57	|	16:25	16:25	16:59	|	17:25
Toijala		|	|	13:30	|	14:26		15:00	|	15:26	15:26			|	16:28	16:28	17:00	|	17:28
Iittala		|	|	13:40	|	|		15:10	|	|	|			|	|	|	17:10	|	|
Parola		|	|	13:48	|	|		15:18	|	|	|			|	|	|	17:18	|	|
Hämeenlinna	o	|	|	13:53	|	14:45		15:23	|	15:45	15:45			|	16:47	16:47	17:23	|	17:47
Hämeenlinna		|	|	13:54	|	14:47		15:24	|	15:47	15:47			|	16:49	16:49	17:24	|	17:49
Turenki		|	|	14:02	|	|		15:32	|	|	|			|	|	|	17:32	|	|
Ryttylä		|	|	14:09	|	|		15:39	|	|	|			|	|	|	17:39	|	|
Riihimäki	o	|	|	14:16	|	15:04		15:46	|	16:04	16:04			|	17:06	17:06	17:46	|	18:06
Riihimäki		|	|	14:25	|	15:08	15:25	15:55	|	16:08	16:08	16:25		|	17:08	17:08	17:55	|	18:08
Hyvinkää	o	|	|	14:32	|	|	15:32	16:02	|	|	|	16:32		|	|	|	18:02	|	|
Hyvinkää		|	|	14:33	|	|	15:33	16:03	|	|	|	16:33		|	|	|	18:03	|	|
Jokela		|	|	14:39	|	|	15:39	16:09	|	|	|	16:39		|	|	|	18:09	|	|
Järvenpää		|	|	14:48	|	|	15:48	16:18	|	|	|	16:48		|	|	|	18:18	|	|
Kerava	o	|	|	14:55	|	|	15:55	16:25	|	|	|	16:55		|	|	|	18:25	|	|
Kerava		|	|	14:56	|	|	15:56	16:26	|	|	|	16:56		|	|	|	18:26	|	|
Tikkurila	o	14:20	14:20	15:04	15:20	15:39	16:04	16:34	16:20	16:39	16:39	17:04		17:20	17:39	17:39	18:34	18:20	18:39
Tikkurila		14:21	14:21	15:05	15:21	15:40	16:05	16:35	16:21	16:40	16:40	17:05		17:21	17:40	17:40	18:35	18:21	18:40
Pasila	o	14:29	14:29	15:13	15:29	15:48	16:13	16:43	16:29	16:48	16:48	17:13		17:29	17:48	17:48	18:43	18:29	18:48
Pasila		14:30	14:30	15:14	15:30	15:49	16:14	16:44	16:30	16:49	16:49	17:14		17:30	17:49	17:49	18:44	18:30	18.49
Helsinki	o	14:35	14:35	15:19	15:35	15:54	16:19	16:49	16:35	16:54	16:54	17:19		17:35	17:54	17:54	18:49	18:35	18:54

perutaan toistaiseksi >																			P	
kulkupäivät >		M-S	M-S	M-S	M-L	S	M-S	M-S	S	M-S	M-P,S	L	M-S	P,S	L	M-S	P-S	M-S	P	M-S
junatyyppi >		R	R	IC	S	IC	R	IC	S	R	S	S	R	S	IC	R	IC	R	S	R
junan numero >		9702	9706	26	146	146	9710	54	184	9720	88	186	9724	56	56	9728	28	9732	58	9734
Tampere			17:37	18:00	18:04	18:04		19:00	19:04	19:37	20:04	20:04		21:00	21:00	21:07	22:00		23:00	23:07
Lempäälä	o		17:47	|	18:15	18:15		|	19:15	19:47	20:15	20:15		|	|	21:17	|		|	23:17
Lempäälä			17:48	|	18:16	18:16		|	19:16	19:48	20:16	20:16		|	|	21:18	|		|	23:18
Viiala			17:55	|	|	|		|	|	19:55	|	|		|	|	21:25	|		|	23:25
Toijala	o		17:59	|	18:25	18:25		|	19:25	19:59	20:25	20:25		|	|	21:29	|		|	23:29
Toijala			18:00	|	18:26	18:26		|	19:28	20:00	20:26	20:26		|	|	21:30	|		|	23:30
Iittala			18:10	|	|	|		|	|	20:10	|	|		|	|	21:40	|		|	23:40
Parola			18:18	|	|	|		|	|	20:18	|	|		|	|	21:48	|		|	23:48
Hämeenlinna	o		18:23	|	18:45	18:45		|	19:47	20:23	20:45	20:45		|	|	21:53	|		|	23:53
Hämeenlinna			18:24	|	18:47	18:47		|	19:49	20:24	20:47	20:47		|	|	21:54	|		|	23:54
Turenki			18:32	|	|	|		|	|	20:32	|	|		|	|	22:02	|		|	0:02
Ryttylä			18:39	|	|	|		|	|	20:39	|	|		|	|	22:09	|		|	0:09
Riihimäki	o		18:46	|	19:04	19:04		|	20:06	20:46	21:04	21:04		|	|	22:16	|		|	0:16
Riihimäki		18:25	18:55	|	19:08	19:08	19:25	|	20:08	20:55	21:08	21:08	21:25	|	|	22:25	|	23:25	|	0:25
Hyvinkää	o	18:32	19:02	|	|	|	19:32	|	|	21:02	|	|	21:32	|	|	22:32	|	23:32	|	0:32
Hyvinkää		18:33	19:03	|	|	|	19:33	|	|	21:03	|	|	21:33	|	|	22:33	|	23:33	|	0:33
Jokela		18:39	19:09	|	|	|	19:39	|	|	21:09	|	|	21:39	|	|	22:39	|	23:39	|	0:39
Järvenpää		18:48	19:18	|	|	|	19:48	|	|	21:18	|	|	21:48	|	|	22:48	|	23:48	|	0:48
Kerava	o	18:55	19:25	|	|	|	19:55	|	|	21:25	|	|	21:55	|	|	22:55	|	23:55	|	0:55
Kerava		18:56	19:26	|	|	|	19:56	|	|	21:26	|	|	21:56	|	|	22:56	|	23:56	|	0:56
Tikkurila	o	19:04	19:34	19:20	19:39	19:39	20:04	20:20	20:39	21:34	21:39	21:39	22:04	22:20	22:20	23:04	23:20	0:04	0:20	1:04
Tikkurila		19:05	19:35	19:21	19:40	19:40	20:05	20:21	20:40	21:35	21:40	21:40	22:05	22:21	22:21	23:05	23:21	0:05	0:21	1:05
Pasila	o	19:13	19:43	19:29	19:48	19:48	20:13	20:29	20:48	21:43	21:48	21:48	22:13	22:29	22:29	23:13	23:29	0:13	0:29	1:13
Pasila		19:14	19:44	19:30	19:49	19:49	20:14	20:30	20:49	21:44	21:49	21:49	22:14	22:30	22:30	23:14	23:30	0:14	0:30	1:14
Helsinki	o	19:19	19:49	19:35	19:54	19:54	20:19	20:35	20:54	21:49	21:54	21:54	22:19	22:35	22:35	23:19	23:35	0:19	0:35	1:19

(3) M-S; ei 10.–14., 17.–21., 24.–28.5. (4) M-P; ei 10.–14., 17.–21., 24.–28.5. # osuus Tampere–Riihimäki peruttu 10.–14., 17.–21., 24.–28.5.

Taulukossa ei näy Helsinki–Riihimäki-lähiliikenne kokonaisuudessaan. Sesonkiyöjunat eivät näy tässä taulukossa (ks. taulukko 7).

Figure 22 Timetable for the route Tampere – Helsinki (VR, 2020)

Analysis of the node Helsinki – Tampere

Without the possibility of overtaking, on the line or most stations on the route, it is difficult to increase the number of departures or to shorten travel time. Since long-distance traffic is dependent on getting on the regional trains at the few waystations that enable overtaking, there is a risk that the system's robustness will be reduced if traffic on the line increases, which could then lead to more delays. Based on this, it is therefore difficult to optimize capacity with scheduling without risking making the track more sensitive to disturbance. There is already a high speed on the line today, so speed optimizations are not relevant to increase capacity either.

However, capacity can be improved by increasing the number of trains that can utilize the maximum speed on the track - which does not seem to be the case today. But as the track is served by both freight trains and passenger trains, there is a risk that there will be a large difference in speeds between the trains, which instead reduces capacity; freight traffic should therefore in such a case be moved to other lanes, or less busy times.

In order to increase capacity further, in addition to the effect obtained by faster trains, infrastructure measures need to be taken that increase the possibility of bypasses for long-distance trains. For example, bypass tracks on the line or sidetracks at stations that enable long-distance trains to pass local trains that have stops for passenger exchange.

Secondary nod: Helsinki – Salo – Turku

On the route Espoo (Helsinki) - Salo, a new high-speed line is planned. The single-track line between Helsinki - Salo today takes a detour past Karjaa (see Figure 23).

Figure 23 New line for high-speed railway (Väylävirasto, 2020)

The new line would shorten the distance between Turku and Helsinki by about 26 kilometers and make the entire section double-track (the Kirkkonummi-Helsinki section is currently double-track). Today's distances and travel times for cars respectively trains for the Helsinki - Turku section are shown in Table 14.

Route	Distance (km)	Travel time by car (2018)	Travel time by train (VR 2019)
Helsinki-Salo-Turku	168	1:40	1:57 (1:48)

Table 14 Travel times Helsinki-Salo-Turku (Väylävirasto, 2020)

The new high-speed line is planned for a maximum speed of 300 km/h, although there is a risk that it will land at 220 km / h - with the goal of reaching a travel time between Helsinki - Turku of 1 hour and 15 min. New stations on the route have not yet been decided, but it is likely that a new station will be built in Lohja. During the construction of the high-speed line, it is planned that the Salo - Turku section will be rebuilt into a double track and additional actions will be taken to enable increased speed to support the travel time target (Väylävirasto, 2020a).

Today, the Helsinki - Turku line is served by freight trains; with a future high-speed line, there is therefore a risk that freight traffic will reduce capacity if the traffic is not moved to another route (difference in speed leads to overtaking problems). However, a relocation can in turn lead to reduced capacity on lines that already have high capacity utilization, such as Tampere - Helsinki. An alternative is to, like the high-speed lines in Sweden, keep the current line and let the freight trains operate on it. Freight traffic and regional traffic (with several stops along the line) risk reducing possible departures for long-distance traffic due to the risk of catching up.

Tertiary node: Turku – Pori

The distance from Turku to Pori is 140 kilometers and today there is no direct railway connection between the two cities. To travel by train between Turku and Pori, travelers must travel via Tampere, which makes the travel time long: in the fastest case 3 hours and 42 minutes (Perille, 2020). There are also problems with trains crossing the Tampere - Helsinki section, which already has high capacity utilization, making it difficult to get more timeslots for trains.

One possible solution could be to build a new train line Turku - Toijala and have a travel exchange there to reduce capacity impact. However, this solution takes up platform capacity in Toijala which is limited and increases travel time even more. Train travel between Turku - Pori can be compared with bus travel which takes about 2 h 10 min, and car which takes about 1 h 43 min (Perille, 2020). Today, the route has about nine bus trips a day. It can be compared to trains where there are around 8 double trips per day between Turku - Tampere and Tampere - Pori, with train changes in Tampere.

The Tampere - Pori section has reduced speed (applies to 2022) on the following sections:

002	Tampere	Kokemäki	231+0500–231+0650 100 km/h	Condition of the turnout Kru V002
002	Kokemäki	Pori	305+000–306+000, 315+000–317+000, 322+000–324+000 50 km/h	Speed limits for heavy trains of more than 3,000 tonnes due to vibration

Table 15 Speed limitations on the route Tampere – Pori (Railway Network Statement 2022, 2020)

Nodes in Estonia

Primary Node: Tallinn-Narva

Existing Infrastructure

The railway line from Tallinn-Narva has the longest double-track section of the whole network extending between Tallinn–Tapa (between kilometrage 104,4 and 181,9) and single-track line Tapa–Narva (between kilometrage 181,9 and 314,0). The track has been electrified between Tallinn and Aegviidu, which is located west of Tapa. See Figure 24.

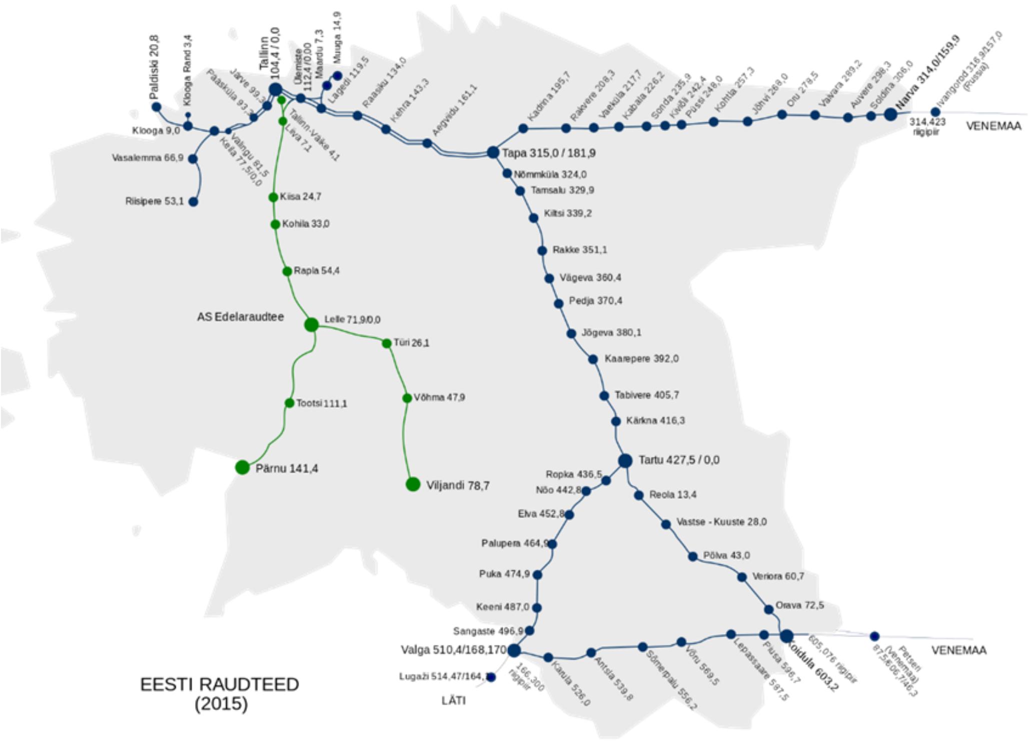


Figure 24: Map of Estonian Railway network with blue lines indicating lines owned and managed by Estonian Railways (Eesti Raudtee) and green indicating the lines of Edelaraudtee (Southern Railways)

In addition, departing electrical trains from Aegviidu may not use over 80 % of their maximum power. There are plans to have the whole railway electrified by 2028.

Traffic

The power supply of the electrification system imposes some limits on the capacity of the railway: between Raasiku and Aegviidu the minimum headway between electrical trains needs to be 16 minutes in each direction. If trainsets with two electrical units are used in succession to each other, the headway between the trainsets needs to be 32 minutes.

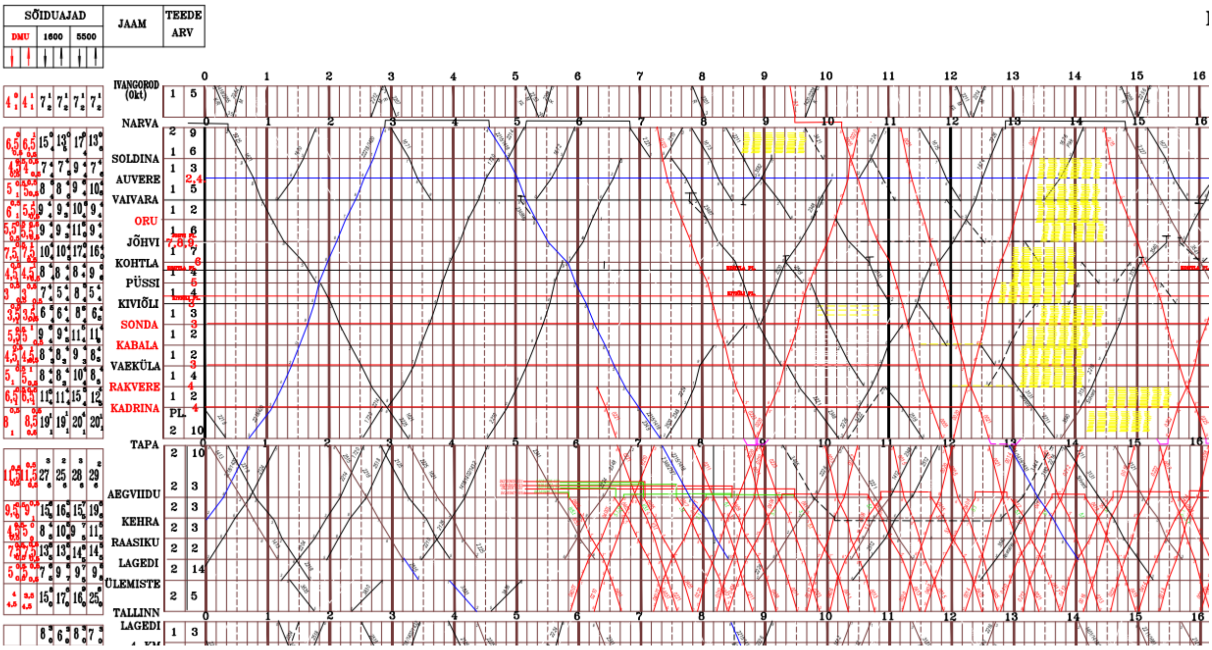


Figure 25: Graphical timetable between 0:00-13:00 Narva-Tapa (single-track), Tapa-Tallinn (double-track), (Source: Estonian Railways)

Figure 25 shows graphical timetable between 0:00-13:00 on Narva-Tapa (single-track), Tapa-Tallinn (double-track) lines. Total number of passenger train runs between Narva-

Tapa-Tallinn varies significantly on the single and double-track sections. The double-track section has train services from south (Tartu) and East in addition to commuter trains from and to Aegviidu-Narva-Tapa. Passenger traffic relations from the graph are summarised below:

- Aegviidu-Tallinn: average of 15 commuter trains per day per direction.
- Narva-Tapa-Tallinn: total of six trains per day per direction. Travel times between Tallinn and Narva vary between 2 hours and 13 minutes (express train) and 2 hours and 37 minutes (stops at most stations between Narva and Tapa)
- Tartu-Tallinn: about 10-11 trains per day per direction

Analysis of the node Tallinn - Narva

Passenger traffic running in opposite direction meet only once on the single-track section Narva-Tapa with an estimated maximum dwell time of about 3 minutes for either one of or both trains. The dwell time seems reasonable.

However, freight trains which have the lowest priorities compared to trains with international connections and local passenger traffic are forced to make frequent stops on the single-track Narva-Tapa line thereby yielding priorities to passenger trains or avoid conflicts. Se freight train 2211 (Figure 25) as an example. The freight train takes almost seven hours to run from Narva to Ulemiste (east of Tallinn).

The Estonian railway network have very high punctuality of services. In 2019, more than 99% of trains are on time (excluding delayed and cancelled trains). On time arrival is measured only at end stations and have 4 minutes and 6 minutes limit for electric and diesel trains respectively. Delays over 15 minutes and over 30 minutes constitute 0,15% and 0,13% respectively (AS Eesti Liinirongid (Elron), 2020).

The electric power supply seems to be one of the main reasons restricting the speed, capacity and flexibility of the timetables for both freight and passenger traffic.

Improving the electrification system of the Tallinn-Narva route demands a major investment. In short and medium-term, however, express train services (alike two trains running per direction in off-peak hours) should also be dedicated in both morning and afternoon rush-hour traffic to reduce the collective travel time for passenger traffic services. Increasing express trains may negatively affect the travel time of freight trains. To avoid such negative effects to freight trains and even increase the capacity, a short-double track section somewhere in the middle of Narva-Tapa line is recommended.

Nodes in Latvia

Figure 26 displays passenger train traffic services lines and respective stations along with zonal tariffs. The primary node, Tukums-Tornakalns/Riga, and secondary node, Riga-Cesis, which are shown in blue and green lines respectively will be examined under the following sub-sections.

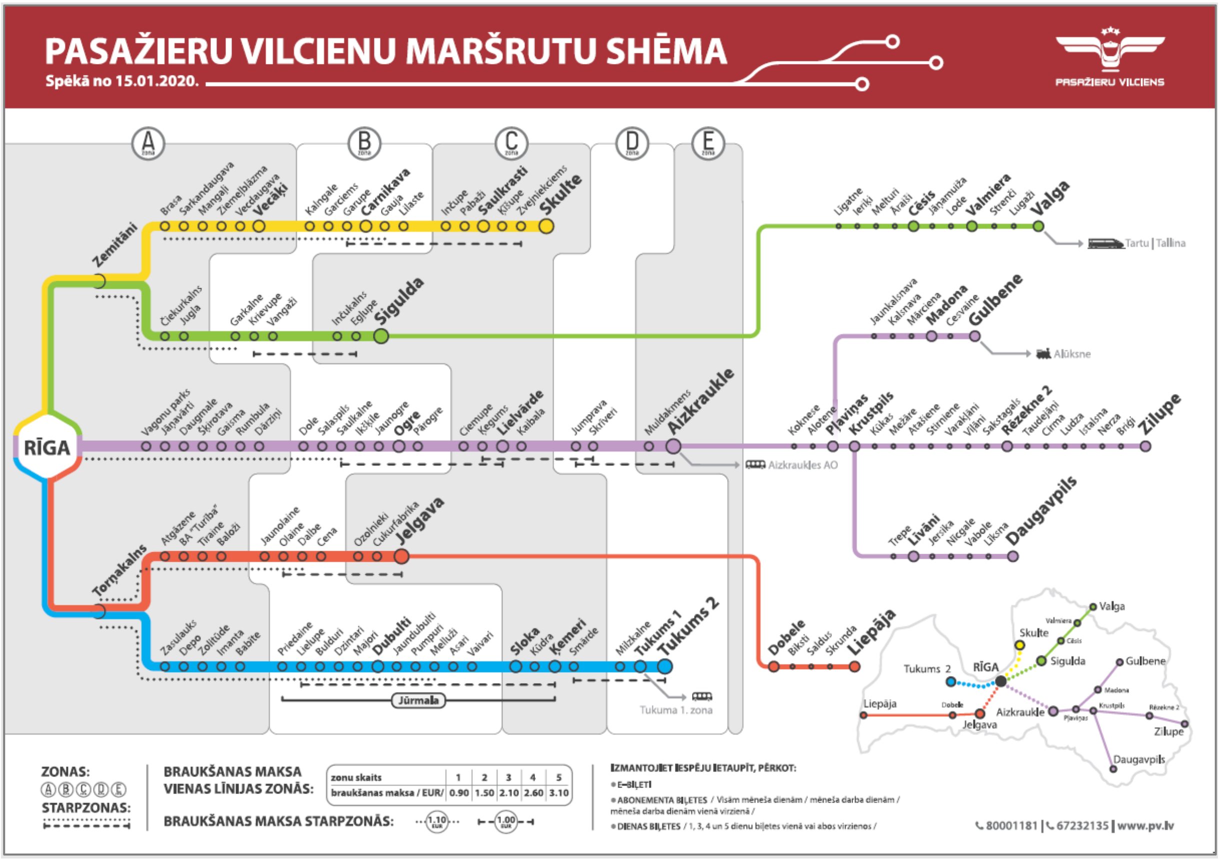


Figure 26: Latvia Railway network with zonal tariffs. Riga-Cesis and Tukums 2-Tornakalns/Riga are shown in green and blue lines respectively

Primary Node: Tukums-Tornakalns/Riga

Existing Infrastructure

Tukums 2 – Torankalns is about 65 km long, electrified and wide track gauge infrastructure which has a permissible axle load of 25 tonnes. The section between Sloka – Tornakalns is double-track while the remaining section of the infrastructure Tukums 2 – Sloka is single-track.

There are 25 stations (18 stop points including Riga passenger station, and six Way stations, one freight station) that are open not only for alighting and boarding of passengers but also bypassing Freight trains. Each Way station has at least three tracks to accommodate two passenger trains and a freight trains simultaneously at the station.

The Netework statement summarizes infrastructure Tornakalns - Tukums 2 (Latvijas dzelzceļš, 2020). The distance between passenger train stopping locations on double-track sections varies from 1 km to 4 km with the average distance between stops of about 1,9 km. The distance between stops for passenger traffic is relatively longer on the single-track section (Tukums 2 – Sloka), varying from 3km to 10 km. The maximum distance between stops on Way stations for freight trains is 10 km and 21 km on the double-track respective single-track section of the line.

Generally, the interlocking systems for the railway line Tukums-Tornakalns/Riga are installed with centralized dispatching system whereby stations are connected to Centralized Traffic Control (CTC) except the Tukums 2 – Tukums 1 (3 km) and Tukums 1 – Kemeri (21 km) which deploys electric staff/dispatcher order system and semi-automatic interlocking system respectively. Generally, the signalling systems ensure train traffic with a speed of up to 120 km/h (Latvijas dzelzceļš, 2020) where the infrastructure and timetable. See Figure 27.

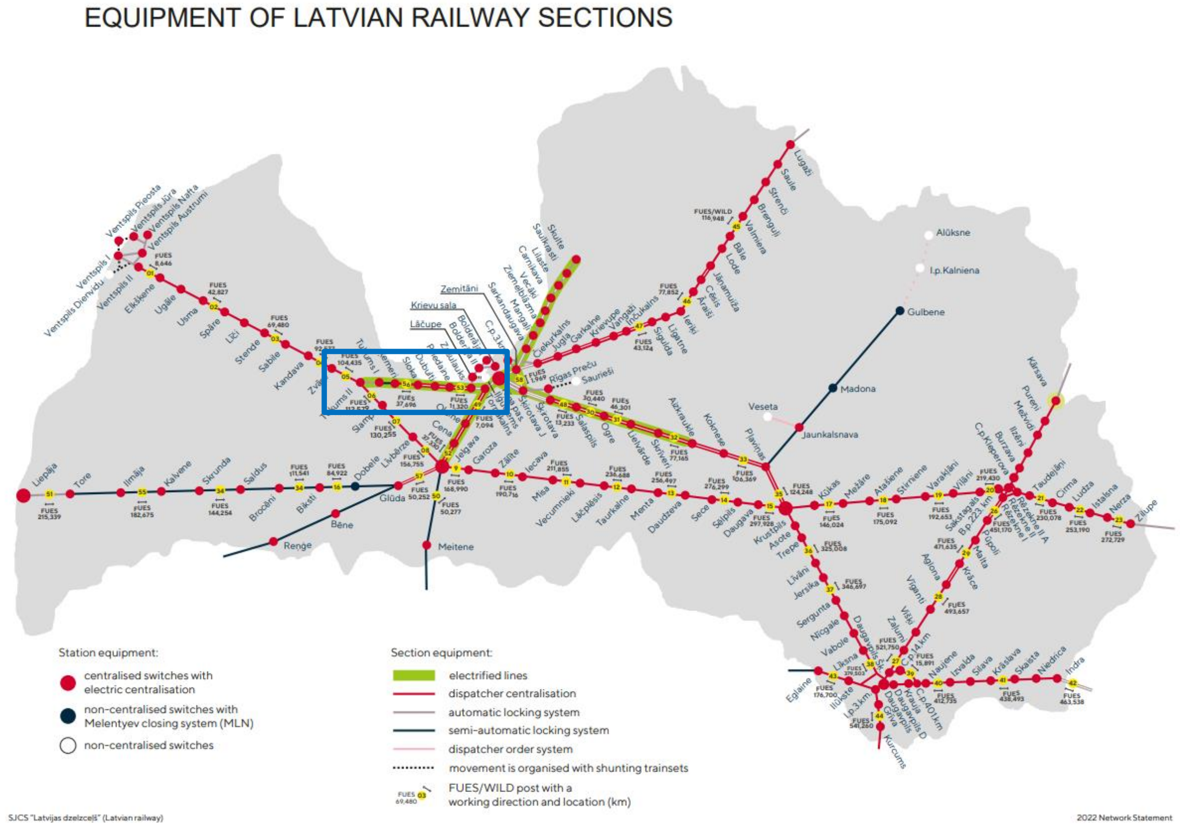


Figure 27: Equipment of Latvia Railway Sections. Marked in blue rectangle is Tukums 2 -Tornakalns-Riga. Green lines indicate electrification

Infrastructure Development

Out of the total 25 stations on Tukums-Riga line, 15 stations were reconstructed in 2015 thereby improving accessibility and modern passenger services. Those Stations are: Asari, Babīte, Bulduri, Dubulti, Dzintari, Imanta, Lielupe, Majori, Melluži, Pumpuri, Sloka, Vaivari and Zolitūde. (AC Konsultācijas, Ltd, 2021)

Traffic

The railway line Tukums 2-Riga are provided with three possible routes: Riga-Dubulti, Riga-Sloka and Riga-Tukums 1/2. The frequency of the services are summerized below:

- Riga - Dubulti
    - Morning peak: 7-8 trains in three morning peak hours, 2 passenger trains/hour/direction
    - Afternoon peak: 2-4 passenger trains/hour/direction

- Riga-Dubulti-Sloka
    - Morning peak: 6-8 trains in three morning peak hours, 2-3 passenger trains/hour/direction
    - Afternoon peak: 7-9 train in three afternoon peak hours, 2-3 passenger trains/hour/direction

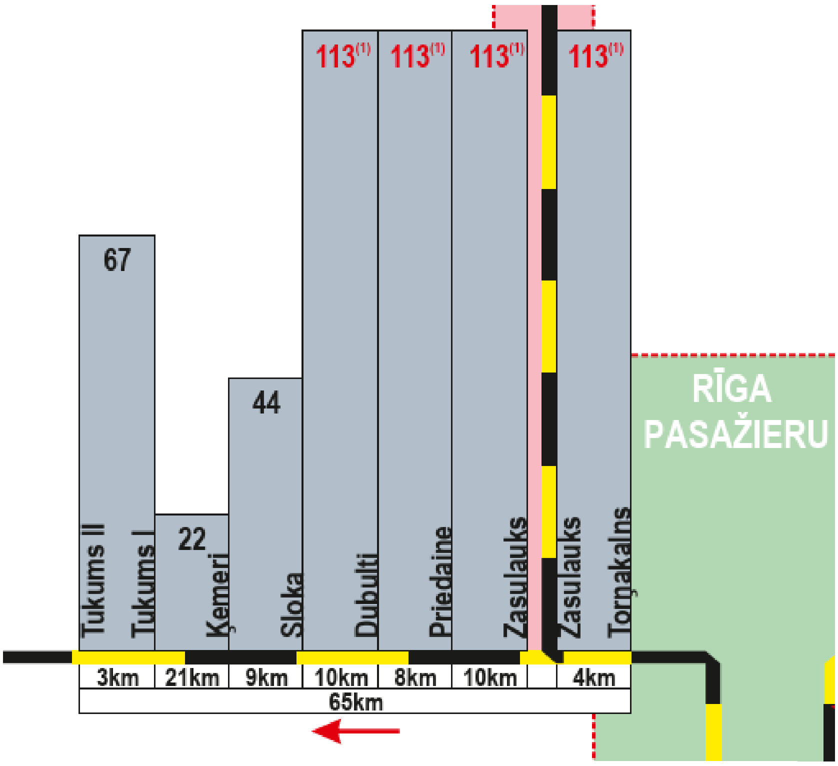
- Riga-Sloka-Tukums 1/2:
    - Morning peak: 3 trains in three morning peak hours, 0,5-1 passenger trains/hour/direction
    - Afternoon peak: 3 trains in three morning peak hours, 0,5-1 passenger trains/hour/direction

According to scheduled timetables and Table 16 daily average number of trains runs on any working day is about 35 trains/direction between Dubulti and Riga and 14 trains/direction between Tukums and Riga. The average travel time from Tukums to Riga is 78 minutes (82 minutes according to peak-hour timetable 2021), the average time from Dubulti to get to Riga is 34 minutes (47 minutes according to peak-hour timetable 2021) and Sloka to Riga takes about 40 minutes.

Corridor/ Direction	Apdzīvotā vieta	Train		
		Avg. No. Of trips/work day/direction	Average arrival time min.	Average number of passengers per day
Rīga-Tukums	Jūrmala (Dubulti)	35	34 (47 timetable)	5689
	Sloka	(32 timetable)	(40 timetable)	
	Tukums	27 (14 timetable)	78 (82 timetable)	954

Table 16 Railway traffic Tukums-Riga. Our observations from peak-hour timetable data is given in brackets. (Source: JSC "Pasažieru vilciens" and ATD data via (AC Konsultācijas, Ltd, 2021) complemented by WSP)

Figure 28 illustrates train throughput capacity in the odd direction of train movement, i.e. from Riga/Tornakalns to Tukums 2, for allocation of Railway infrastructure capacity for the year 2022 timetable. Accordingly, there are about 113 train paths available for allocation per direction between Riga/Tornakalns-Sloka with possibility of increasing passenger trains by 30%. On the Sloka-Tukums 2 section the available train path is relatively fewer for the fact that the line is single-track.



Legend:

- odd direction of train movement
- 32 amount of train paths for allocation of capacity (for pairs of freight trains)
- 113(1) amount of train paths can be increased to 30 % for passenger train traffic
- 10(2) amount of train paths for freight trains in length of more than 40 closed wag.
- 33(3) coordinated amount of train paths, based on the possibilities of railways of neighbouring states

Figure 28: Train throughput capacity of Tukums 2 - Tornakalms,

Analysis of the node Tukums – Tornkalns/Riga

There is a general view that “the existing rail passenger services at regional and local level are not sufficiently developed and convenient for passengers, as there is a long time to be waited between transfers.” (AC Konsultācijas, Ltd, 2021). Frequency of train services from Riga to Tukums is low as only one or occasionally two trains running every two hours per direction.

However, since Sloka-Tukums 2 (33 km) is a single-track line, it is expected to be the major bottleneck that could impact allocation of higher frequency train runs. Particularly Kemeri-Tukums 1 (21 km) is the major infrastructure bottleneck. Today, considerable number of passengers still use other forms of transport, such as private and public passenger and freight vehicles on the route.

Therefore, in order to make the railway services more attractive to both passenger and freight services, cutting the travel time by train is paramount importance not only in short-term but also long-term perspectives.

Investigate the measures to be taken to minimize the travel-time have been hampered by lack of the following information:

- Graphical timetables for the lines showing interaction between person and freight trains, dwell times, during ordinary holiday-free weekdays
- Infrastructure information (such as speed along the lines or speed-distance diagram, bottlenecks, signal system and headway, etc)
- Proposed improvement plans on timetables, infrastructure and services in short term, if any

Notwithstanding the above, however, the travel time can be reduced by changing the timetable structure. In peak-hours passenger trains stop at every station for alighting and boarding along Riga-Tukums route. Stopping distance of around 1 km between stations will probably make it impossible for the trains to attain permissible speed of 120 km/h for passenger trains.

Therefore, provision of skip-stop-system and express train in combination with trains that stop at every station may be recommended for further studies. The time loss for acceleration and deceleration is considerable as summarized below based on passenger timetable 2021.

- Every stop extends the travel time by about 1 minute, i.e. skipping a stop results in saving one minute from schedule travel time
- Skipping two stops shortens the travel time by about 3 minutes
- Skipping three stops saves about 4 minutes
- At least one regional express train per direction in both morning and afternoon rush-hours with relation Riga-Dubulti-Sloka-Tukums (skipping other stops)
- More trains can be run in the system, especially in the double-track section, in order to maintain every station with enough trains stopping with reasonable interval.

Further study of feasibility and applicability of traffic scenarios and timetable concepts with combination of stop at every station, skip-stop-system, and express train are recommended.

The distance between freight train meeting/way stations on double-track sections (Riga-Sloka) deemed to be particularly reasonable to accommodate mixed passenger traffic as suggested herein above. Although WSP have not been provided with graphical timetables with passenger and freight traffic, 30-minutes passenger traffic on double-track section and once every two hours on single-track (Sloka-Tukums 1/ 2) section implies availability of unused capacity on route Riga-Tukums that may be used to accommodating skip-stop and express train on the system without major implications to freight traffic.

In general, except those 15 railway stations reconstructed in 2015 the infrastructure of the stations on the line is outdated major improvement on stations infrastructure, incl. multimodal interconnection is required.

Secondary Node: Riga-Cesis

Existing Infrastructure

There is an 80 km long railway line in Riga-Cesis, the route Riga-Valga of which only the first 4km (Riga-Zemitani) is equipped with electrification, while the remaining part of the infrastructure is not electrified. Thus, diesel trains run in the corridor Riga-Cesis-Valga.

About 45 km of the Riga-Cesis line is single-track and the remaining 35 km is double-track infrastructure. The links are as follows:

- Double-track: Riga-Krievupe (16 km), Vangazi-Sigulda (19 km)
- Single-track: Krievupe-Vangazi (5 km), Sigulda-Cesis (40 km)

There are 15 passenger traffic stations (Riga passenger station, and ten Way stations) and two freight stations. Most stations have four or more tracks which can be used for both passenger and freight trains.

The network statement summarizes technical development of infrastructure Riga-Cesis (Latvijas dzelzceļš, 2020). The distance between passenger train stopping locations on double-track sections varies from 2 km to 7 km with the average distance between stops of about 4,5 km. On the single-track sections, the distance between stops for passenger traffic is relatively longer, varying from 4 km to 11 km with average distance of 7,5 km. For freight, service trains and locomotives traffic have possibilities to stop in short distances, average distance between stops on Way stations being about 7 km.

Generally, alike Riga-Tukums, the interlocking systems for the railway line Riga-Cesis-Valga are installed with centralized dispatching system which deploys automatic interlocking system. Information about the permittable speed on the infrastructure, stations layouts, performance of rolling-stock, etc. are unknown at this juncture.

Traffic

According to timetable 2019 (see Table 17) or 2021, diesel passenger train services are available for routes Riga-Sigulda, Riga-Cesis-Valmiera, and Riga-Lugaži-Valga. Today, international trains Riga - Valka / Valga – Tartu transfer at Valga.

- Riga-Sigulda: total number of 13 trains per day per direction either passes through (after short dwell time) or turning-back at Sigulda; out of those trains an average of 8 trains per day per direction turnback at Sigulda. The scheduled timetable indicates that trips do not have regular headway. The travel time from Riga to get to Sigulda is 47 (with skip-stop) or 69 (stops everywhere) minutes according to scheduled timetable which his is not far from observed average travel time of 64 minutes, see Table 18.
- Riga-Cesis-Valmiera: Five trains per day per direction passes Cesis of which 3-4 passenger have turnback connection at Valmiera; travel time for passenger trains running Riga-Cesis-Valmiera is 99-136 minutes depending on whether the trains are scheduled to stop in all or some of the stations. The average observed travel time of 120 minutes (Table 18) reflects the very reason that some trains are skip-stopping while others do not.
- Riga-Cesis: On the other hand, the travel time between Riga-Cesis is about 65 minutes for trains that are skip-stopping and 96 minutes for trains stopping at every station. The observed arrival records of 88 minutes seem reasonable, see Table 18.
- Riga-Valga: 3 train runs/day/direction are provided. The average time to get to Riga is 156 minutes.

uz Siguldu, Cēsīm, Valmieru, Valgu														
Vilciena Nr.	862	832	834	874	838	840	842	864	844	876	876	866	846	848
Ceļa Nr.	**10**	**11**	**11**	**1**	**10**	**1**	**11**	**11**	**10**	**10**	**1**	**10**	**10**	**10**
Piezīmes		DARBD.		Valgā pārsēšanās uz vilcienu Nr. 0335 Valga – Tartu – Tallina				DARBD.		DARBD.	BRĪVD.		DARBD.	
Rīga	**6.32**	**6.50**	**7.55**	**10.34**	**12.30**	**14.33**	**15.50**	**17.27**	**17.50**	**18.15**	**18.15**	**18.51**	**20.02**	**21.35**
Zemitāni	6.41	6.59	8.04	10.43	12.39	14.43	15.59	17.36	17.59	18.24	18.24	19.00	20.11	21.44
Čiekurkalns	6.46	-	8.09	10.48	12.44	14.48	16.04	-	18.04	-	-	19.05	20.16	21.49
Jugla	6.52	7.07	8.15	10.54	12.50	14.54	16.10	-	18.10	18.32	18.32	19.11	20.22	21.55
Garkalne	7.03	7.18	8.26	11.05	13.01	15.05	16.21	-	18.21	-	-	19.22	20.33	22.06
Krievupe	-	-	8.35	-	13.10	15.13	16.30	-	18.30	-	-	-	20.42	22.15
Vangaži	7.16	-	8.42	11.18	13.17	15.20	16.37	-	18.37	-	-	19.35	20.49	22.22
Inčukalns	7.23	7.35	8.49	11.25	13.24	15.27	16.44	-	18.44	18.56	18.56	19.42	20.56	22.29
Eglupe	7.28	-	8.54	11.30	13.29	15.32	16.49	-	18.49	-	-	19.47	21.01	22.34
Sigulda	7.39	7.47	9.04	11.41	13.39	15.42	16.59	18.14	18.59	19.09	19.09	19.58	21.11	22.44
Līgatne	7.49			11.51				-		19.19	19.19	20.08		
Ieriķi	7.59			12.01				-		-	-	20.18		
Melturi	8.05			-				-		-	-	20.24		
Āraiši	8.12			12.11				-		-	-	20.31		
Cēsis	8.21			12.20				18.43		19.41	19.41	20.40		
Jāņamuiža	8.28			12.27				-		-	-	20.47		
Lode	8.36			12.35				18.56		19.54	19.54	20.55		
Valmiera	8.49			12.49				19.09		20.08	20.08	21.08		
Strenči				13.05						20.24	20.24			
Lugaži				13.23						20.42	20.42			
Valga				13.29						20.48	20.48			

Table 17 Passenger train arrival schedule Riga-Valga, December 2019

Corridor / direction	Station	Train		
		Number of trips avg. 1 working day in 1 direction	Average arrival time min.	Average number of passengers per day
Rīga-Valmiera-Valka	Vangaži	10	44	985
	Sigulda	13	64 (47-69 timetable	861
	Līgatne (Augšlīgatne)	4	68	861
	Cēsis	5	88 (65-96 timetable)	203
	Valmiera	5	120	203
	Valka	2	156	203

Table 18 Railway traffic Riga-Cesis, timetable data shown in brackets

During morning peak-hour 3 trains run every thirty minutes from Cesis/Valmiera to Riga before the headway between trains extends further during the remaining traffic period. The fastest train is the morning peak-hour train (goes only once in a day) from Valmiera which stops at Cesis, Sigulda, Zemitani before arriving at Riga. The travel time between Cesis and Riga for this train is only 65 minutes to run 80 km with average speed of 74 km/h. Thus, in order to attract more passengers on this line, more frequent skip-stop timetable concept should be developed, tested and implemented.

Figure 29 shows capacity allocation in the odd train direction on the Riga-Valga line. The figures on the bars shows the amount of train paths for allocation of capacity in odd direction with pairs of freight trains. On the route Riga-Cesis, the single-track sections Krievupe-Vangazi and Sigulda-Cesis are the bottlenecks of the infrastructure which could limit the capacity, flexibility and robustness of the system. However, in the absence of graphical timetable and detailed infrastructure information it is difficult of definitively suggest which measures are reasonable. However, given the fact that only five passenger trains per day per direction are running from Riga to Cesis, it is deemed that there should be enough capacity to accommodate skip-stop traffic without negatively impacting freight traffic.

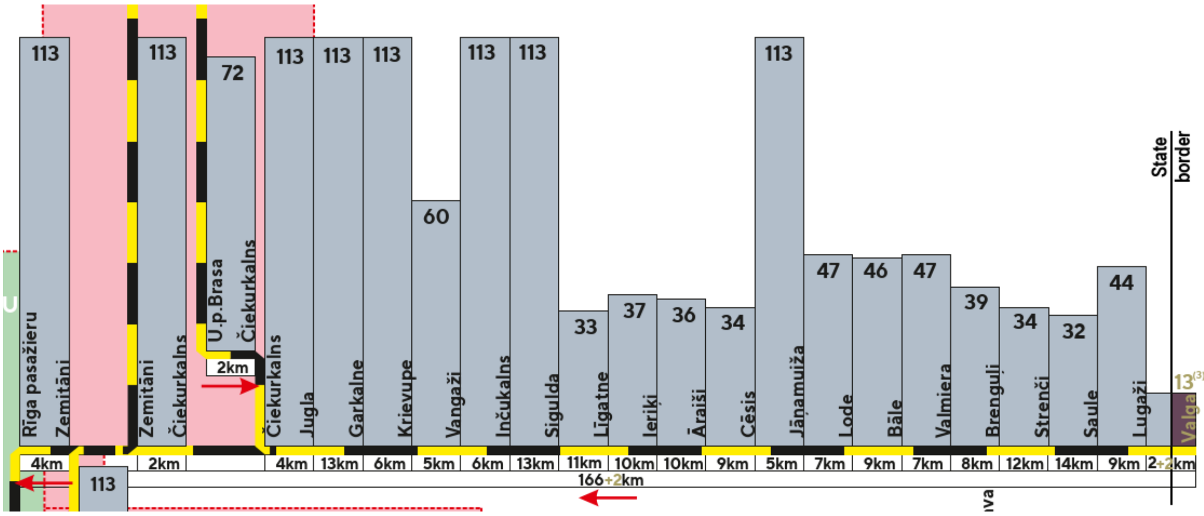


Figure 29: Train throughput capacity of Riga-Cesis-Valga

The conditions of the infrastructure of Valka line (line sections and stations) can be regarded as outdated and lacks electrification, accessibility as well as interconnection of rail services with other modes of transport which requires major infrastructure investment. On the other hand, in middle and short-term perspective, minor infrastructure adjustments such as construction of additional track of about 5 km to existing single-track section Vangazi - Krievupe may help to accommodate skip-stop traffic and more freight trains.

Tertiary Node: Cesis-Smiltene

Existing Infrastructure

There is no railway link between Cesis and Smiltene, however there are plans to carry out upgrading or new road construction works, total length of 135.64 km along Riga-Valka corridor during 2021-2023. The highway P18 (Valmiera - Smiltene) is 17.28 km long or 13% of the total planned amount of construction works in the corridor (AC Konsultācijas, Ltd, 2021).

Traffic

Table 19 is extracted from buses schedules from Cesis to Smiltene with diverse operators, among them are AS CATA and SIA NORMA-A. The travel time by bus between these cities is about 40 minutes. Well planned public transport system should have good level of integration between several modes of transport; in that respect, arrival times of passenger trains at Cesis and departure times of buses at the same station has to be integrated. For example, according to timetable 2021 for railway traffic, two consecutive trains from Riga arrive at Cesis 8:37 and 12:32 while buses are scheduled to depart from Cesis to Smiltene 6:40, 8:05 and 12:25. Considering this particular case, the schedules for passenger rail and buses services does not seem to be well integrated.

Intercity/International Buses from Cēsu AO to Smiltenes AO

5:55 AM Cēsu AO	6:48 AM Smiltenes AO	Cēsis-Rauna-Smiltene-Gaujiena-Alūksne 7770 AS CATA	€2.25 Ticket	46km	53min
6:30 AM Cēsu AO	7:35 AM Smiltenes AO	Cēsis-Smiltene-Ranka-Balvi-Kārsava 7766 AS CATA	€2.25 Ticket	46km	1h 5min
6:40 AM Cēsu AO	7:50 AM Smiltenes AO	Cēsis-Liepa-Smiltene-Trapene-Alūksne 7769 AS CATA	€2.15 Ticket	45km	1h 10min
8:05 AM Cēsu AO	9:25 AM Smiltenes AO	Cēsis-Bērzkrogs-Smiltene-Liepa-Cēsis 7771 AS CATA	€2.40 Ticket	51km	1h 20min
12:25 PM Cēsu AO	1:40 PM Smiltenes AO	Cēsis-Rauna-Smiltene-Liepa-Cēsis 7771 AS CATA	€2.25 Ticket	46km	1h 15min
2:35 PM Cēsu AO	3:40 PM Smiltenes AO	Cēsis-Smiltene-Ranka-Lejasciems-Gulbene 7620 SIA NORMA-A	€2.25 Ticket	46km	1h 5min

Table 19: Intercity buses schedule Cesis-Smiltene

In order to ensure multimodal connection and integration of railway traffic with other modes of public transport at stations with potential for high passenger turnover such as Cesis, it is essential to provide a public transport multimodal centers in the core of railway stations. Bus terminals, park-and-ride possibilities, first and last mile modes of transport modes, bicycle parking, etc must be properly integrated with railway stations.

Freight transport by road has particularly low speed (40km / h) in the section Riga–Valmiera whereas Riga-Cesis allows relatively higher speed (66 km/h) (AC Konsultācijas, Ltd, 2021). Although there is no specific information about the freight road condition of Cesis-Smiltene, there are plans to upgrade highway P18 (Valmiera - Smiltene).

Conclusions

Redundancy in the timetables

Of the countries studied, practice regarding timetable construction looks to some extent different. In Estonia and Latvia, there are few public documents showing the regulated practice of timetable construction.

In Finland, a percentage increase compared to the train's maximum speed must be added. For long-distance trains, this supplement is ten percent, and for commuter trains, the supplement is five percent. In addition to this, there is also a supplement for train meetings and bypasses. The purpose of the percentage supplement is to create redundancy in the timetable, but at the same time the supplements mean longer travel times compared to if the supplements had not been needed..

In Sweden there is a regulated practice regarding redundancy in timetables. Just as in Finland, there are regulations in Sweden regarding extra time at meetings and passages. There are also congestion surcharges and track work surcharges that are added if other activities will affect the train's journey. In addition to these extensions, there is the node extension, which aims to create redundancy in the timetable. The node extension is a certain number of minutes between different stations.

Trains on the Stockholm - Örebro - Charlottenberg route take about three hours. On this route, 12 minutes are added to the timetable with reference to the node extension. Trains on the Helsinki - Tampere route often take about 1 hour and 40 minutes. On this stretch, 10 minutes are then added to create redundancy. As the redundancy of the timetables is not calculated in the same way in the different countries, they are difficult to compare, but the conclusion that can be drawn is that on the primary nodes in

Sweden and Finland, the redundancy per travel minute is higher in Finland than in Sweden.

Possible time savings with driver advisory systems

The survey of data-driven and automated working methods has shown that there are a number of different driver advisory systems in Europe, which are already integrated into the operation of rail traffic. Driver advisory systems help drivers adapt their driving to streamline fuel consumption, avoid unnecessary stops and improve train meeting precision.

Integration of driver advisory systems has today come a to varying degrees in the different countries. In Estonia and Latvia we have not found a railway company that uses driver assistance systems.

In Finland, the CATO driver assistance system is today fully integrated into the metro system, while work remains to implement the system on the railway.

In Sweden, the driver assistance systems are still not fully integrated with the traffic management - several sections still lack the operational planning aid STEG, which is a prerequisite for the driver assistance systems to function optimally. The support systems are also not used by all railway companies.

Through the use of driver advisory systems, it is possible to improve the timetable by

- Train meetings can be planned with less redundancy, as the trains receive current information about the position of the oncoming train, as well as information about what speed the train should keep to avoid stopping at the meeting station.
- The trains could possibly be planned more densely on certain routes, as the driver advisory system can sense the position of the train in front, and

recommend a speed that means that the train behind maintains a sufficiently large distance to not receive restrictive signaling, and thus need to brake.

In order for the driver assistance systems to be as efficient as possible, it is required that

- Support systems must be used by all railway companies which operate the same routes. If only one of the trains at a train meeting has received information about the exact speed to be able to carry out the meeting without stopping, then there is a risk that the other train runs too slow or too fast, which means that some of the trains may need to stop. If the timetable is adapted for non-stop traffic, this will mean a delay that can also delay later train meetings.
- The support system must be fully integrated with the traffic management. If the traffic management is planning a train meeting, it is important that the drivers receive information about the new planning to ensure that the train maintains the right speed for the meeting.

If a well-developed driver support system contributes to reduced travel times in the train schedule, new risks may arise that need to be managed.

- In case of delayed train meetings, a meeting may need to be moved. It is then not certain that the new meeting can take place without the trains having to stop, and this may mean that an already delayed train suffers additional delays.
- Tighter planning also means reduced redundancy, which means a poorer resilience after traffic disruptions. It is therefore a trade-off if it is better with shorter travel times, but greater risk of delays.

Possible time savings with simulations

One way to find improvements in timetable design is to use simulators to test the timetable. By testing the timetable in an operationally mode, there are greater opportunities to find efficiency measures at, for example, meetings and traffic at stations with many tracks. The disadvantage of testing the timetable is that it can be very time and resource consuming. As an alternative, it may be possible to test run timetables for major track works, as the trains' routes differ greatly from practice. It can also be advantageous to use a simulator to test how different traffic disruptions affect the timetable, in order to see more clearly how much redundancy is actually necessary in different places.

Shorter travel times through daily timetables

Analysis of daily graphs has shown that in Sweden, so-called "ghost meetings" occur. These are times when a train has a planned meeting with a train that does not run that day. Such a meeting can be seen in Figure 30 for train 644 at the Väse station.

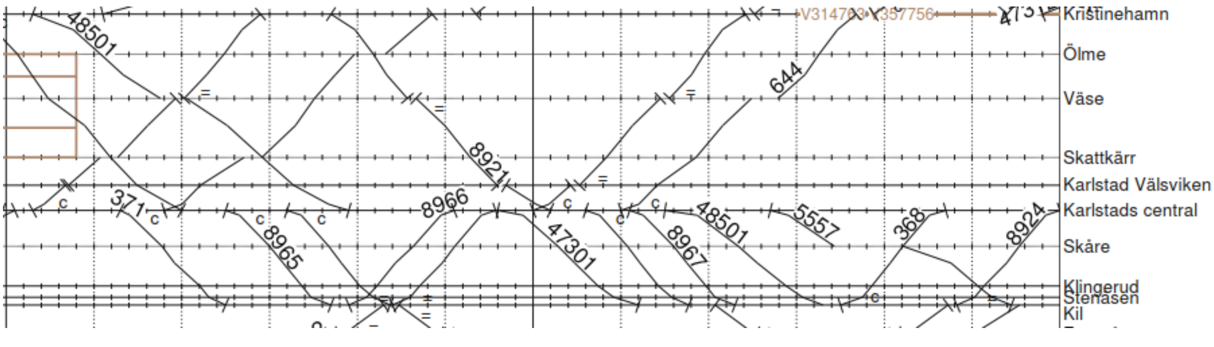


Figure 30 Daily graph Kristinehamn - Kil

It is likely that train 644 has a meeting scheduled for another day, alternatively that the train 644's meeting is canceled on this day. On this specific day, 644 has scheduled a 3-minute waiting time in Väse for no direct reason.

This type of problem is based on the fact that the timetable is planned for longer intervals, and that train 644 receives the same timetable during the entire timetable period, even though it could have had a more efficient timetable during parts of the period.

Creating different timetables for each traffic day is currently indefensible in terms of time, but by developing automated planning tools, it could in the future be possible to adapt the timetable daily.

Daily timetables could, however, mean difficulties for returning passengers, who often travel on the same train, as the timetable could differ between different travel days. It could also mean difficulties for connecting traffic if the train runs with different timetables during different travel days.

Shorter travel times through priorities

An alternative for creating shorter travel times can also be to create clearer prioritization of certain departures. Through a stated priority, it would be possible for the priority trains to avoid train meetings, and create better channels in the planning, which can then shorten the travel time for these trains. However, this option means that the travel time will be shorter on certain departures, at the expense of other departures, as you will have worse channels and more train meetings than they could have had if these time-sensitive obstacles were evenly distributed between the trains. An alternative with priority departures may also mean that operators need to apply more irregular timetables.

Travel times and delays - a trade-off

Although it is possible to identify certain occasions when the timetables could have been made more efficient with the help of various digital and automated working methods, most of the redundancy aims to compensate for the quality deficiencies that currently exist in the railway's operations. With the help of various digital and automated working methods, it is possible to create more efficient timetables, but if margins are reduced without investments in infrastructure and rolling stock, there is an imminent risk that the trains will be hit to a greater extent by delays in faults in the facility or vehicles. This means that shortened travel times will instead affect the degree of delay on the railway.

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