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

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Figure 1: Travel times in Public Transportation

Interreg Central Baltic

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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 notes

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.

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).

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).

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. (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. 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 (Sweco, 2017).

In connection with this analysis, new construction rules for timetables have been introduced on the lines. The new design rules mean, among other things, that the node extensions are moved to the critical points along the 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).

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

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[2] on those line sections in which VR currently operates. In future all railway companies with acceptable qualification to get infrastructure capacity

[1] Tightness between trains
[2] 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 (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 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).

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 not all planners have 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.

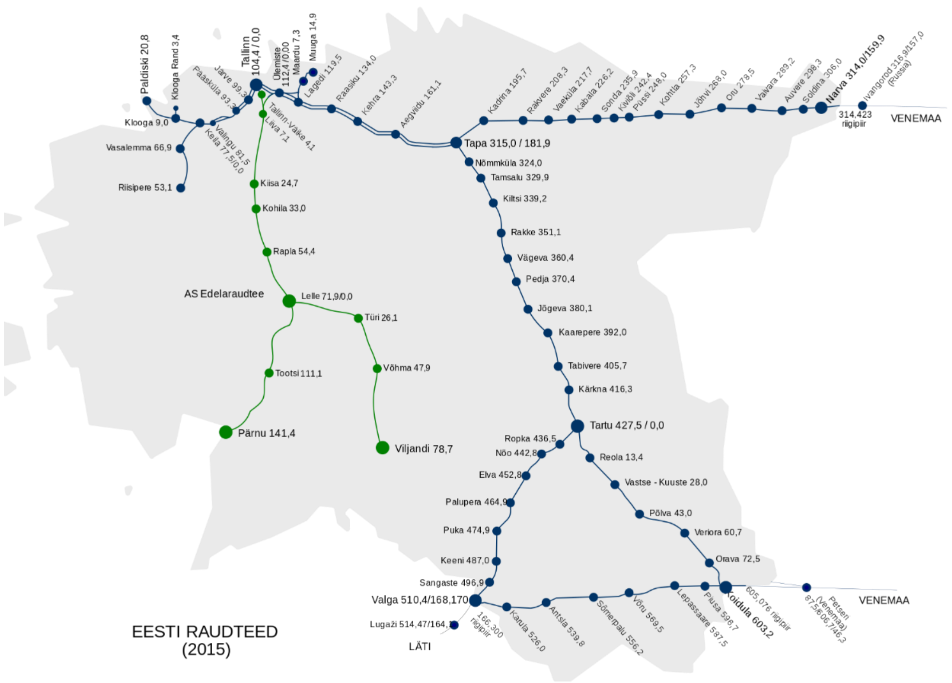

Figure 2 Map of the Estonian railway network with blue lines indicating lines owned and managed by Estonian Railways (Eesti Raudtee) and green indicating the lines of Edelaraudtee (Southern Railways).

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.

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.

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).

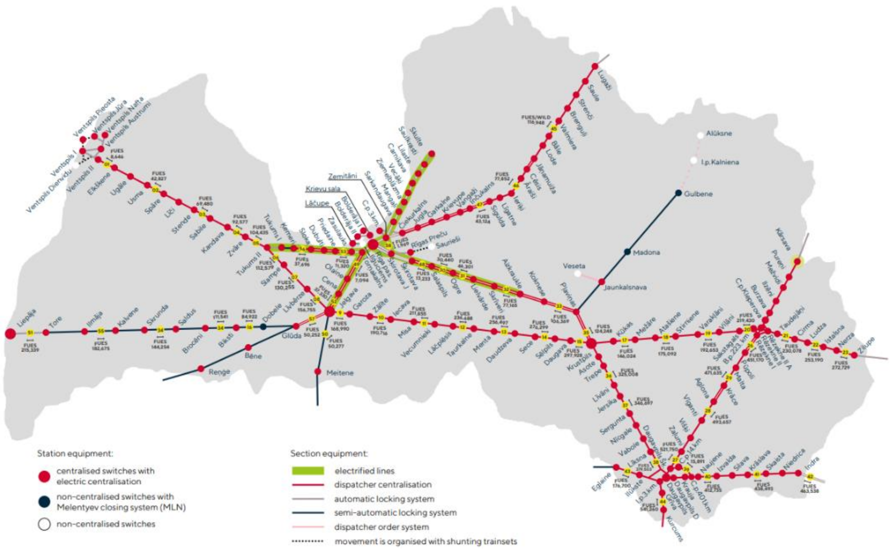

Figure 3 Infrastructure equipment of railways in Latvia.

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.

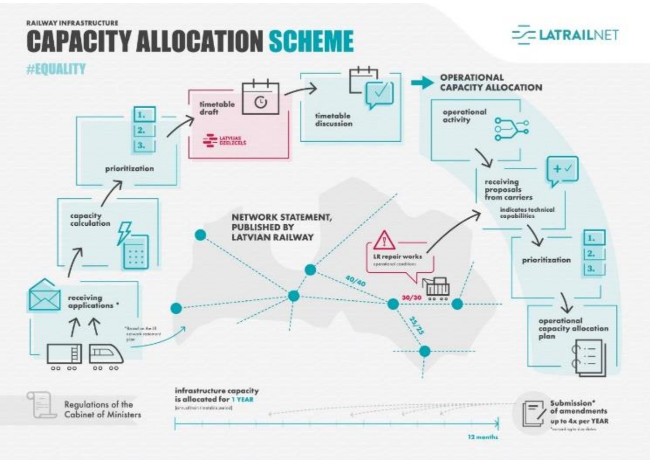

Figure 4 The railway capacity allocation scheme of Latvia.

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

The most common data-driven, automatic aids used on the market today are different types of driver advisory systems, which are described in more detail under the heading Driver Advisory Systems below. In the study, we have not found any established aids for timetable construction - however, we have found that both Sweden and Finland have simulators that are under development to better reflect reality. How simulators can be used in the train planning process is described under the heading Through driver advisory systems, the train driver can get more detailed information about speed and throttle in order to be able to better plan their driving at, for example, train meetings. At longer stations with simultaneous access, this means that trains could meet without having to stop. Widespread use of driver assistance systems could therefore contribute to reduced time in train meetings.

With driver support systems, the driver can also get more detailed information about the train ahead, and therefore has greater opportunities to adjust the speed to be able to be as close as possible, without receiving restrictive signals. This could allow for denser traffic.

Support in the train planning process.

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)

In Table 1, 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 -)
EBI Drive 50 / DSM	Bombardier	
FASSI	DB Kommunikationstechnik GmbH	
ESF-EBuLa	DB Systel GmbH	

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

Table 1 Several DAS-systems that are available on the market

How driver advisory systems can reduce travel time

Through driver advisory systems, the train driver can get more detailed information about speed and throttle in order to be able to better plan their driving at, for example, train meetings. At longer stations with simultaneous access, this means that trains could meet without having to stop. Widespread use of driver assistance systems could therefore contribute to reduced time in train meetings.

With driver support systems, the driver can also get more detailed information about the train ahead, and therefore has greater opportunities to adjust the speed to be able to be as close as possible, without receiving restrictive signals. This could allow for denser traffic.

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

The travel time analysis has been done through the traffic simulation tool Railsys. We have, among other things, looked at the nodes' traffic load and where there may be possible travel time reductions.

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".

Mälarbanan stretches from Stockholm, via Västerås, to Hovsta just north of Örebro. The section consists of mixed single and double tracks.

The freight route through Bergslagen extends from Storvik in the north to Mjölby in the south. The section consists of mixed single and double tracks.

Today, Värmlandsbanan runs between Laxå and Charlottenberg.

On the Stockholm-Örebro-Oslo section, there are plans for two new railway lines, the Nobel line between Örebro and Kristinehamn, and the border line between Karlstad and Oslo. The goal of the new railway is to complete the travel time goal between Stockholm and Oslo in 2 hours and 55 minutes.

Kolbäck - Västerås (Mälarbanan)

Passenger traffic gives a certain sensitivity to delays for northbound trains around Kolbäck during peak hours. This is because a train that stops in Kolbäck is followed by a high-speed train that does not stop at the station. In addition, the faster trains will catch up with the forward, northbound, slower trains along the section Västerås västra - 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. This results in trains with a axle load of 25 tonnes having to be run as special transports with special transport conditions, for example limited speed.

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 special transport conditions,

Kristinehamn - Kil (Värmlandsbanan)

Värmlandsbanan is 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. By line capacity it is meant how many trains can be run on a line section during a period of time, provided a certain train composition. 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.

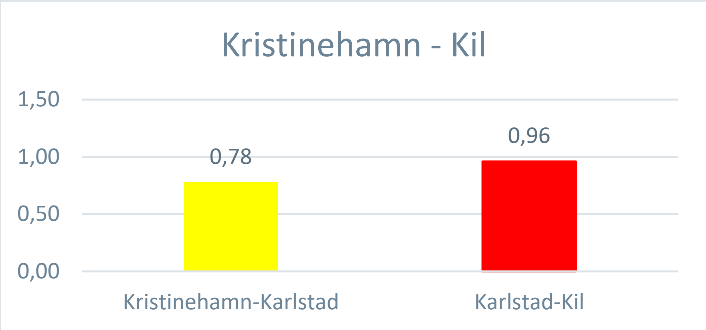

Figure 5 Theoretical capacity utilization 2021, Kristinehamn - Kil, (WSP, 2021)

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 completely exhausted and gives a picture of a disturbance-sensitive track with a low or no resilience.

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

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 6 below. The trains next stop in Storå, will have longer stops for waiting for trains from the north.

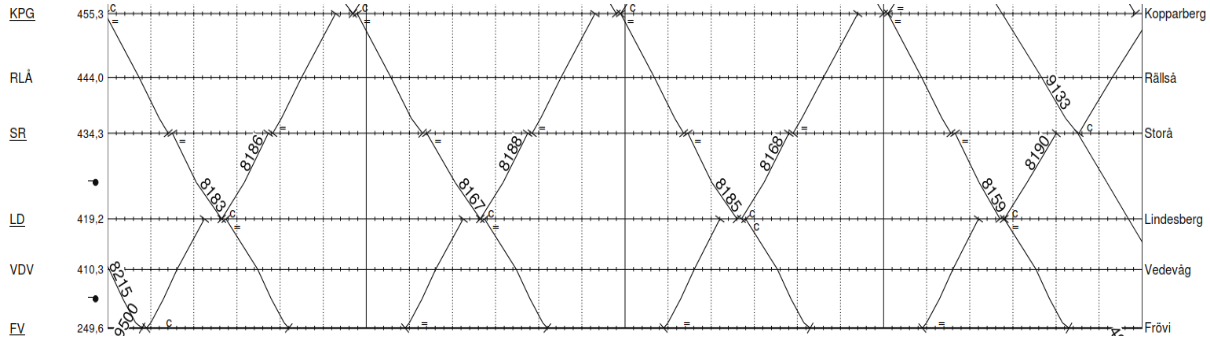

Figure 6 Daily graph 212013 22, Kopparberg-Frövi

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 double tracks with a higher load of traffic.

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.

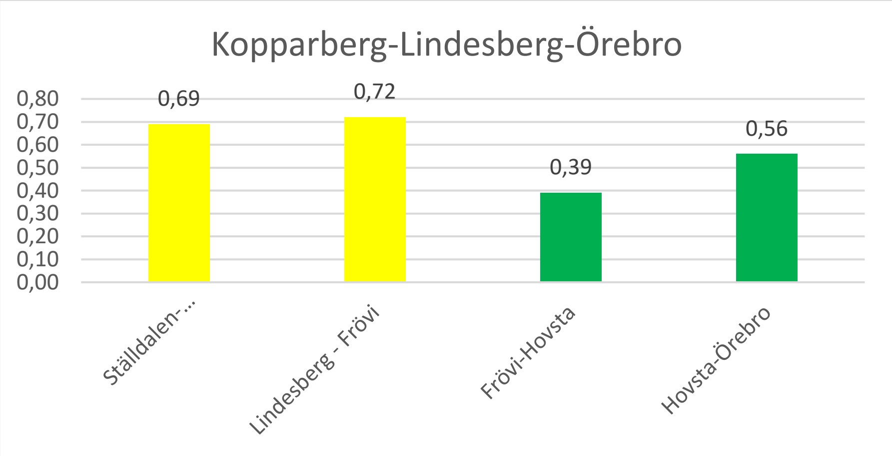

Figure 7 The theoretical capacity utilization for the section Kopparberg - Lindesberg - Örebro, today

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.

Train meetings take place in Skogstorp, Hållsta, Flen and Hälleforsnäs, and 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. If train meeting times can be minimized, the running time for most trains could be reduced.

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.

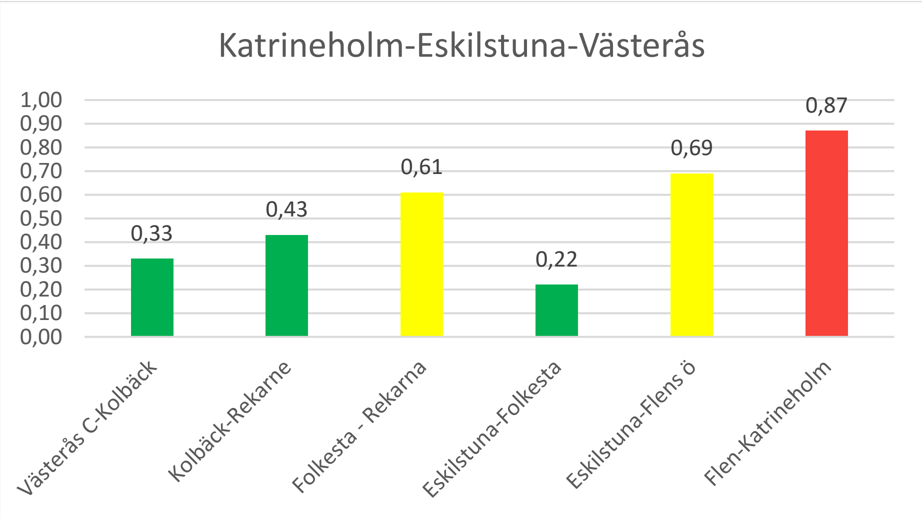

Figure 8 The theoretical capacity utilization for the section Katrineholm - Eskilstuna - Västerås

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 and at 17:55.

Nodes in Finland

Primary node: 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 9).

Figure 9 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. Today's distances and travel times for cars respectively trains for the Helsinki - Turku section are shown in Table 2.

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 2 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.

Secondary nod: Helsinki – Tampere

The Helsinki - Tampere section extends over two lines: Riihimäki – Tampere and Helsinki – Riihimäki. 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). There are no bypasses on the line on the Purola - Sääksjärvi double track. 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. The platform capacity is also bad at most stations on the route. On the Riihimäki - Toijala route, there are challenges with the timetable for getting mixed passenger and freight traffic together, as there is no possibility of bypassing on the line and that side tracks at the stations are on the east side; which makes it difficult for the traffic heading south (Liikennevirasto, 2018).

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.

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.

Nodes in Estonia

Primary Node: Tallinn-Narva

The Tallinn - Tapa section consists of double tracks, while the Tapa - Narva section consists of single tracks. The power supply to the railway is limited, which means that electric trains must not run more frequently than at 16-minute intervals.

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. Some freight trains take almost seven hours to run from Narva to Ulemiste (east of Tallinn).

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 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

Primary Node: Tukums-Tornakalns/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.

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 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

The Riga - Cesis line has an 80 km long track, where only the first 4 km are electrified on the Riga - Valga section, while the remaining part is not electrified. Thus, diesel-powered trains are used on the Riga - Cesis - Valga route. About 45 km of the Riga - Cesis line is single-track and the remaining 35 km is double-track.

The travel time between Cesis and Riga is only 65 minutes to drive 80 km at an average speed of 74 km / h. To attract more passengers on this line, a more frequent timetable should be developed, tested and implemented.

Due to the lack of a graphical timetable and more detailed infrastructure information, it is difficult to suggest which concrete measures are reasonable, but given that today there are only 5 departures / day / direction, there should be sufficient capacity to expand the range of departures with skip - stop traffic, without adversely affecting freight traffic.

Tertiary node: Cesis - Smiltene

There is currently no railway connection between Cesis and Smiltene, but there are plans to carry out upgrades or new road construction covering 135.64 km along Riga - Valka during 2021-2023. The P18 motorway (Valmiera - Smiltene) is 17.28 km long, corresponding to 13% of the planned expansion. The travel time by bus between the cities is about 40 minutes.

Given that a well-functioning public transport system requires coordination between different modes of transport, it is proposed that arrival and departure times for passenger trains and buses be integrated into Cesis. According to the timetable for rail traffic in 2021, for example, two trains will arrive in a row from Riga to Cesis, at 8:37 and 12:25, while buses are planned to depart from Cesis to Smiltene at 6:40, 8:05 and

12:25. This indicates that the timetables for passenger trains and bus lines today are not sufficiently integrated for a functioning change.

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 10 for train 644 at the Väse station.

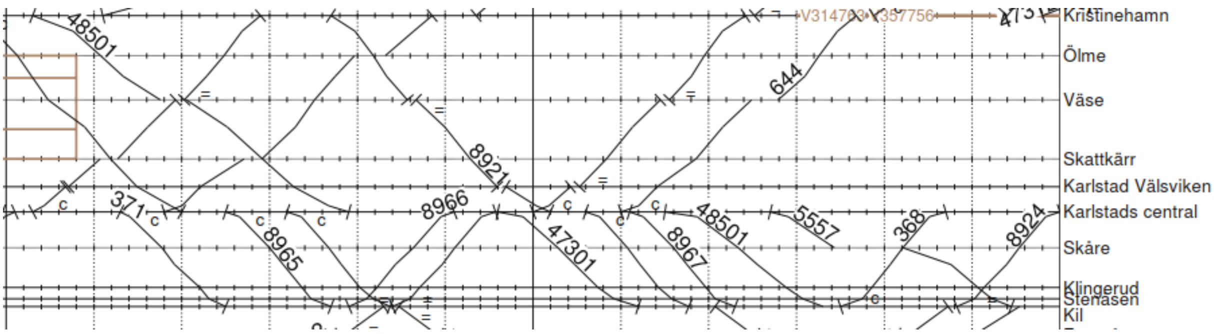

Figure 10 Daily graph Kristinehamn - Kil

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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