Problems in the Integration of Timetabling and Train Traffic Control

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INTRODUCTION

The aim of Work package 3 in the ON-Time project, WP3 ("Development of robust and resilient timetables"), is to develop common railway timetabling and capacity estimation methods for EU member states that reflect customers' satisfaction and enable interoperability, more efficient use of capacity, higher punctuality and less energy consumption.

Uppsala University has a minor part of WP3 and is responsible for the task 3.3 which has the following objectives:

- To get a clear understanding about the problems in the integration of timetabling and operational control.
- To describe existing approaches of how to solve the integration problems and improve the railway system.
- To describe innovations and development in these areas.

In every country the integration of timetabling and operational control and its problems are in focus. There are a lot of issues involved in this integration and a thorough investigation of them all is out of scope for this small investigation. Here we have focused on the following main issues, more or less excluding the issues dealing with problems that have its roots in how the work is organised.

- The time spans of in first-hand the timetabling process. Shortening the time span of the timetabling process is of vital interest to all operators (RU's) as well as the IM´s.
- The rules and regulations. The rules and regulations that have to be obeyed by the IM when scheduling trains of several train operators. They have a significant influence on the time needed to create the "final" timetable and also its quality.
- The tools used in the creation of the timetable. The time to produce the "final" timetable is influenced by the tools available within the IM when constructing the timetable and how this construction work is organised. The quality of the timetable is also affected by the models and parameters used in the construction phase. Of course the quality of the data used is also of significant importance.
- The quality of the timetable. How is the quality of the timetable, the production plan, validated? The usability of the timetable in the traffic control process is here one important sub question.
- The feedback process. The feedback, short or long term, from the traffic control process – including experiences and knowledge that are accumulated in traffic controllers and train drivers - back to the planning process is also of greatest importance in order to, in the end, enhance the punctuality.

Within the scope described above the work reported here focuses primarily on the prevailing conditions in Sweden. The work done is divided into four main parts:

The first part gives an overview of the timetabling and operational control processes in Sweden.

The second part is based on interviews with people working in the timetabling and operational processes and tries to give a brief overview of the most important, noted problems in the mentioned processes.

The third part tries to briefly summarize what is reported in the scientific community in Sweden within the described scope.

The fourth part describes promising innovations and developments in these areas.

After that follows a short chapter with conclusions in the form of a structured summary of revealed problems and finally there is a chapter indicating the future work that need to be done. In this last chapter we are trying to point out the main underlying problems that must be dealt with in the short term on the "railway" towards a more customer friendly, modern, and punctual Swedish railway system.

THE PROCESSES OF TIMETABLING AND OPERATIONAL CONTROL IN SWEDEN

Sweden has deregulated train traffic and there are many railway companies operating trains and maintaining the infrastructure. In timetable 2012 there were 46 railway companies applying for train paths and time slots for maintenance.

The annual timetable process is synchronized between the IM (Trafikverket) and RNE (Rail Net Europe). RNE co-ordinates and develops the European timetable planning process, i.e. Network statement, annual timetable and ad-hoc timetable planning.

The annual timetable process is in Sweden a negotiation process. The involved RU's tries, in co-operation with Trafikverket, to adapt their desired train paths to each other as far as possible. The unsolved train path conflicts between different railway undertakers (RU´s) that in the end is left result in "saturated infrastructure" and is handled by Trafikverket according to European legislation.

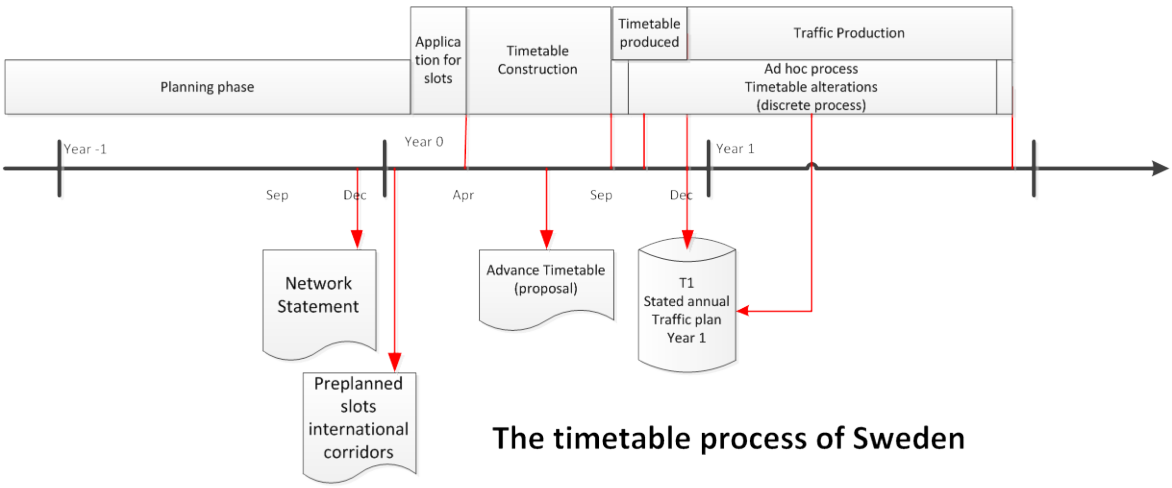

Figure 1: The timetable process of Sweden

For traffic and timetable planning the "processes" are:

- In the period 1 – 5 years ahead, preplanning of the annual timetable
- The yearly planning of the annual timetable:
    - Network statement – (decided 1th of December, one year before traffic start)
    - In the beginning of April, applications for annual timetable
    - In July a draft annual timetable is sent out to the RU's and international co-ordination for cross boarder traffic is finished.
    - September annual timetable decided – unsolved conflicts results in "saturated infrastructure" decisions.
    - September – December, the production of the scheduled annual timetable. Timetable change in mid-December.

Large infrastructure maintenance works is reported in Network statement and is planned in parallel.

The “railway network statement” (JNB) of the timetable for 2014 is presented in September 2012 and is laid down in the beginning of December 2012. The network statement shows the conditions for running trains and shows the major engineering works that are planned to be performed. For the large urban areas Stockholm, Gothenburg, and Malmö, there also exists so called “Capacity congestion plans” that describes how many slots that are available for different types of trains during the peak traffic period. The timetable planning process is described in chapter 4 of the Network statement.

During the period December – April there are some pre planning activities. Parts of these planning activities are done in dialogue between Trafikverket and the RU’s. There are also some traffic simulations to study the capacity limit for major lines where large construction works are planned.

During the period April – September the planning of the next timetable takes place. This planning is done in an iterative process between the IM and the RU´s. There are a number of conflicts of interest between different trains and between trains and planned maintenance work to be solved.

Annual timetable planning process:

In the beginning of April Trafikverket receives request for the next timetable (T14). Requests after that are treated in the ad hoc process.

The traffic control department inspects the produced timetable in June.

The produced timetable is simulated (so called “provtryckning”) in Railsys identifying capacity conflicts in the period June – August.

In beginning of July there is a first annual timetable proposal with remaining conflicts.

There is a meeting concerning the new timetable in the beginning of June where all RU´s and Trafikverket participate. This is followed by another meeting in the end of August.

In the beginning of August a conflict co-ordination process is started. During this period the involved organisations try to solve remaining conflicts. Trafikverket uses a priority classification described in the Network statement when solving conflicts.

The yearly timetable is stated in the middle of September and is valid from the beginning of December and one year forward. There are normally some unsolved conflicts left which then causes statements about “saturated infrastructure”. Trafikverket have had 14 decisions of “saturated infrastructure” during the period 2008 – 2012. For each case capacity analyses and capacity enhancement plans have then been done within a year according to European legislation.

For annual timetable planning the web based application have made it possible to increase the number of iterations between Trafikverket and the railway undertakers.

In determining the timetable is also defined, in the form of so called reduction plans, how traffic should be conducted at major weather disturbances.

The ad hoc planning process:

The ad hoc planning process handles all infrastructure work and also the short term train path requests. The time limit for planning is 24 hour before the traffic starts.

For new train paths it is possible to handle an application within 5 days. The RU will get a proposed train path that the RU can accept or reject.

The timetable for the next day is handed over from the timetable department to the traffic control department at 15.00 the day before it is to be used.

During the annual timetable adaptations are made. Planning perspectives are from 8 weeks to 24 hours. This planning process includes traffic changes as well as needed maintenance of the infrastructure. During 2011 about 120 000 trains were re-planned. It is then especially the freight trains that are affected.

Methods and tools used to estimate the available capacity:

Line capacity is calculated using a variant of UIC 406 in a simple way for the line sections in the Swedish network. For timetable planning the system Trainplan is used. A traffic simulation system is to some extent used for capacity analyses, timetable analyses, headway calculation, and running time calculation. There are functions in Trainplan to handle timetables from application, through annual timetable planning, and the planning of infrastructure work to the ad hoc planning phase (to within 24 hours).

For power supply empirical data is collected about the power consumption and “the line voltage keeping”. The traffic is then measured in number of trains and type of trains. Forecasts are made for where power supply restrictions may be needed and measures are made to avoid problems.

To follow up traffic the systems Lupp and Banstat is used.

Organisation:

In Trafikverket there are about 60 persons to handle the annual timetable and ad hoc planning process. There are 3 groups of timetable planners (north, middle and south) and 1 group to plan timetable changes because of infrastructure work.

Resource planning is made by railway companies. The timetable planners and planners at the Train control centres working for Trafikverket have some knowledge about resource planning and communicate with the railway companies.

The interaction during the annual timetable planning process, ad hoc planning process and operational process needs to be developed further to handle the mentioned new circumstances. Primarily there is a need to improve and formalise the interaction between IM (Trafikverket) and the RUs (Railway undertakers).

Trafikverket is currently working with the following activities:

- Changing the organisation to be more operational
- Establishing a national traffic control and developing the working processes

- Development of co-operation groups together with RUs concerning the operational traffic
- Establishing new departments to communicate with the RU:s both about production and market
- Establishing a more customer oriented organisation

Operational control in Sweden

In Sweden almost all railway traffic is controlled from traffic control centres (DLC's). With the help of train control systems, the trains along the tracks are remotely controlled and monitored through signalling systems. The introduction of centralized control which started in the sixties and seventies has enabled large staff savings. The signal boxes along the tracks do not need to be staffed by local dispatchers. The centralisation requires that the lines are equipped with a block system and has also meant a possibility of rational management of trains over a larger area with improved capacity and safety.

Figure 2: The traffic control centres (DLC) of Sweden

Centralised train traffic control is managed from eight places in Sweden.

- Boden, mixed traffic, single track, Swedish Iron Ore line (Malmbanan), border traffic to Norway, (STEG is implemented).
- Ånge, mixed traffic, single track, (ERTMS L2 on Botnia Line).
- Gävle, mixed traffic, mainly single track, some double track.
- Stockholm, very dense mixed traffic, multi-track, local commuter trains, the hub of long distance train traffic in Sweden.
- Hallsberg, mixed traffic, multi-track, border to Norway.
- Norrköping, mixed traffic, (STEG is implemented).
- Göteborg, mixed traffic, multi-track, commuter traffic
- Malmö, mixed traffic, multi-track, border to Denmark, dense commuter traffic

Centralised traffic control is implemented with three different systems.

- Argus (Ansaldo) – Boden
- Ebicos TMS (Bombardier) – Gävle, Hallsberg
- Ebicos 900 (Bombardier) – Ånge, Stockholm, Göteborg, Norrköping and Malmö

At the DLC computers are equipped with application software for the features that the train control system cover. The users, mostly dispatchers and traffic informers, use a display-based human-machine system. The signal boxes that controls and monitors the trains are connected to the central system via a data communications network. A special unit, the substation (or RTU = Remote Terminal Unit), serves as the fit between interlocking and data communications.

There is one exception. The control system in Ånge is based on relays, so called “rfjb”.

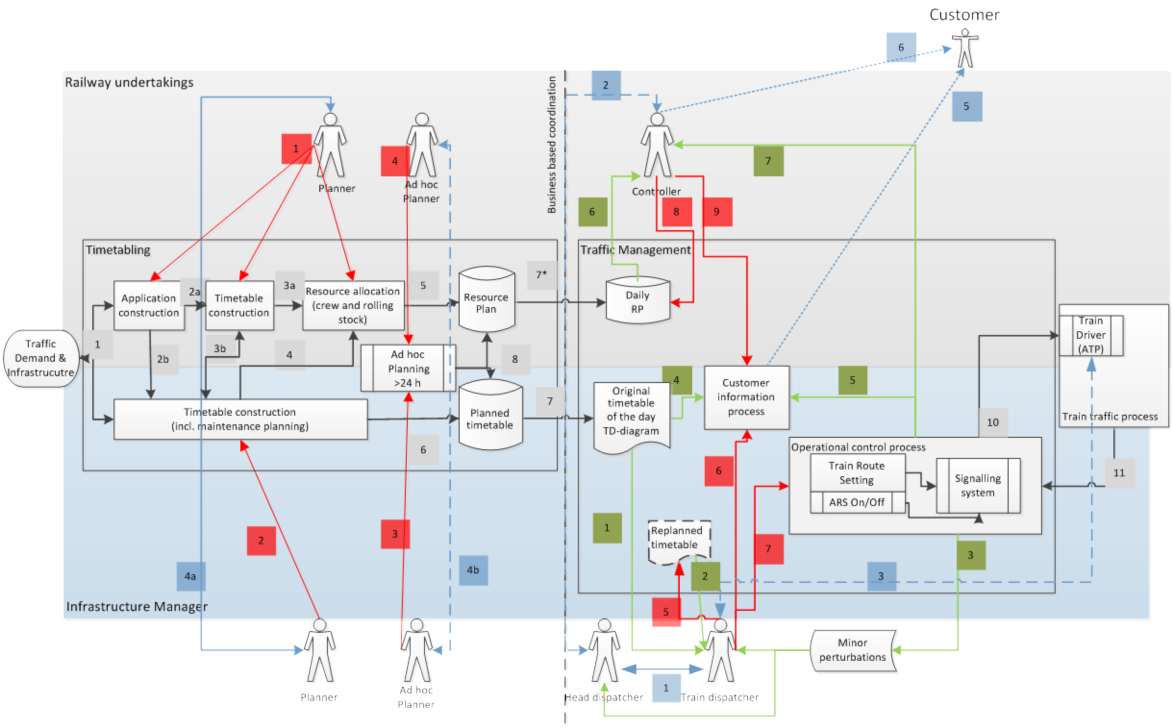

Figure 3: The operational control process of Sweden

The operational train traffic control has the following main process operations:

- Operations management. Operations management leads the proactive work by identifying and managing risk for disturbances in operations management area. Head dispatcher should be informed of all events affecting the operations management capabilities within their own operations management area, and overall in the other DLC´s.
- Train traffic control. The dispatcher should work proactively by implementing a plan ahead in order to early identify any future discrepancies. The dispatcher shall stay constantly updated about the traffic situation on their own and adjacent routes, as well as actively monitor trains and other devices, in order to directly observe deviations.
  The dispatcher ensures train routes and other manoeuvres in such a way that traffic is not disrupted.
- Train Traffic Information informs customer on stations about changes in the plans. Traffic information officer is responsible to proactively monitor the traffic flow at the planned location by monitoring via existing facilities and systems, and through collaboration with other operational functions.
- Power management. The power management shall proactively monitor and analyse alarms in the system.
- Infrastructure management, to proactively monitor progress in the status of the infrastructure. Change of status in the infrastructure is documented.

Existing control systems used in the operational control:

Train dispatchers perform traffic re-planning by drawing time table lines on a paper based time-distance graph, except where the new STEG prototype system is used.

Dynamic information about process status is presented in track diagrams on large distant panels and/or on several computer screens close to the individual workplace.

Dispatchers observe train movements and control train routes by remote blocking. Track usage is controlled either by ordering automatic functions or by directly executing interlocking routes for each station. Automatic functions are either implemented locally, in the centralised control systems or as a separate automatic control system. Together with the human traffic controller there are up to four levels of more or less autonomous automatic functions that try to solve partially the same problems. Interactions between these levels of decision making and execution are complex.

While the solutions vary between the different types of systems, reflecting a gradual development, the functionality is largely uniform. The same is true for human machine interfaces; for example, where different generations of display technologies are represented, but where the principles of presentation and interaction are largely common to the various types of systems.

The existing information and decision support systems used in operational control are:

- Opera – Provides train information, e.g. current weight, length, telephone number etc
- Basun – System used in order to report and get information regarding deviations in timetable and causes of delays.

- ASTA – Tele communication system with queue handling, functional calls, identification of caller etc.
- STEG - “Control of trains via electronic train graph (time-distance diagram)”. Prototype system implemented in Norrköping and Boden TCC, based on research at Uppsala University.

The Swedish transport administration has, together with the private company Transrail, implemented and tested computer aided train operation (CATO) as an R&D-project at the Swedish iron ore line in the far north of Sweden.

Current timetable is delivered to the CATO-system and the on-board system calculates if the given target point is reachable or not taking into account the current properties of the train and the infrastructure conditions.

The CATO-system acknowledges to the train traffic control system if the target point is reachable or not. The dispatcher then acts on the information in order to keep the current timetable updated and feasible.

The railway undertakers RU’s) are responsible for rostering and vehicle planning. The railway undertakers can handle the situation through new circulation strategies or by having extra vehicles ready.

Deviations from agreed plan are announced to the traffic service offices. Measures to handle the deviation are done in dialog with the traffic service offices.

The dispatcher announces deviation in train order to the train driver. With improved traffic information systems traffic service offices will be updated on the current timetable of each train and at an early stage realise the consequences of that plan.

Development of operational processes within the Transport Administration is on-going.

A software tool supporting advanced track usage planning is implemented and tested at the moment in the Norrköping DLC.

NOTED PROBLEMS BASED ON INTERVIEWS

This part is based on short interviews, in person or by phone, with people working in Sweden in the timetabling and operational processes, or in close connection to them. Representatives of both freight and passenger operators (RUs) as well as representatives of the IM have been interviewed.

The purpose of these interviews was to get a brief overview of the most important, noted problems in the mentioned processes. The interviews where performed with focus on the main issues mentioned above in the introduction.

1.1 Rules and regulations

The timetabling process of today is far too long. It is impossible for especially the freight companies to specify their needs for slots a year or more in advance. They are therefore to a large extent requesting their slots in the ad hoc process.

The rule that states that trains "on time" always have higher priority than delayed trains causes problems for the dispatchers when they are trying to re-plan the timetable in an (from their point of view) effective way.

The ad hoc-process, i.e. the process of adding new train slots to the existing timetable with a short planning horizon (also including removing or changing old ones), is today quite cumbersome and inefficient. One factor is that the new trains have to be adapted to the timetable without any alterations of the trains already in the planned timetable. The tools are not adapted to this process making it even more cumbersome to make necessary changes. Especially trains running long distances is hard to plan in an efficient way.

There are also problems with overbookings, especially of freight trains. It is a way for the freight companies to, at a low cost, have a flexible planning of the future traffic. The result is a huge amount of late cancellations of trains. But the problem also exist with passenger trains.

So called "Capacity congestion plans" (in Swedish "Trångsektorsplan") are used in Sweden in order to, already in the timetable planning phase, regulate the traffic for areas with a very high capacity utilisation. Often they cover parts of the network in connection to the larger cities like Stockholm, Malmö, and Gothenburg. There are freight operators having opinions about them. One is that the Capacity congestion plans are too rigid and are "stealing" useful capacity. Another is that railway freight traffic is based on the industries needs for transports which doesn´t fit with a "dictated" plan.

The two main types of freight transports - wagonload rail and system transports – have quite different needs. These differences are another reason to why it is a bad idea to base the short time planning of the freight timetables on "pre-planned slots".

In recent years Sweden has had growing regional railway traffic in many areas and as a consequence cyclic timetables have been introduced locally. The cyclic timetables are more capacity consuming than non-cyclic ones and creates conflicts between the local trains on one hand and the freight and long distance trains on the other. Many freight trains in Sweden runs quite long distances (500-1500 km and sometimes even more) and may have to pass several areas where the local traffic is based on cyclic timetables. This makes it sometimes impossible to create efficient timetables for the freight trains without making changes in the mentioned cyclic patterns.

The rules and regulations of today supports the “traditional” behavior of letting a train that runs for example daily, to have exactly the same timetable every day despite the fact that it would be more optimal to make different timetables for each and every day. One operator found that making different timetables for every day led to that these trains were given lower priority and thereby worse timetables.

The rules and regulations of today makes it tempting for the freight operators to always ask for slots for the heaviest possible and longest possible trains thereby sometimes unnecessarily consuming capacity in the timetable. Probably it is also causing many (lighter) trains to run before its timetable on its way to its final destination.

There is a reported problem in Sweden concerning new heavy freight wagons. They get poor “brake values” and therefore according to the Swedish rules reduce the allowed train speed to 80 km/h. It is said that this isn´t the case with the same wagons in for example Denmark.

Trafikverket receives more requests for slots than they have capacity to inspect. It is a problem that the RU´s only pay for utilized slots and not for every requested slot. Trafikverket has plans for introducing fees also for every requested slot.

1.2 Timetabling and its tools

One large problem is that the timetable is not planned for every specific day but on some kind of “weekly basis”. Trafikverket does not have enough resources (and/or appropriate tools) to be able to create one specific timetable for every day.

The effect of this is that trains and especially freight trains, in their timetables some days have planned meetings or overtakes with trains that are not running on that particular day.

The total time that trains are planned to stay still waiting for a meeting with another train to pass by, is in Sweden called “time in the forest” (in Swedish “skogstid”). It corresponds to considerable costs. One large freight operator estimates its costs to around 20 MEuro per year. It is estimated that the average freight train in Sweden spends 1-12 per cent of its journey time standing still in the “forest”, waiting for some other train to pass by. Twenty per cent of the heavy freight trains have a “time in the forest” of around 25 %. For passenger trains the corresponding value is approximately 2-4 %.

The timetable tools used today have no developed functions for dealing with different versions of infrastructure or different versions of the same timetable in an effective way.

The timetable constructors specify time supplements in the timetable for planned track maintenance, sometimes based on estimations done by Capacity centre.

Unfortunately there are also a lot of irregular maintenance activities that emerges during the production period and has to be dealt with in the short time planning process. These maintenance activities are often difficult to fit in in the existing timetable, partly due to the “static structure of the planning process, and often causes disturbances in the traffic system.

The main timetable tool (Trainplan) used today has no functions for an appropriate handling of the planning of tracks on larger stations and yards. Track usage is planned in Trainplan only for passenger trains at stations where they have traffic related stops. The planning of track usage is instead done in a sub process. The planning of track usage for larger stations and yards is done with the help of a special tool (Simul). Also there is normally no planning of tracks on minor stations for planned train meetings and overtakes. But there is an on-going project that will change this. For the moment much of the details of track usage is taken care of by the dispatchers in the operational process.

In Trainplan it is very time consuming to alter the timetables for trains running long distances. The timetable construction done in Trainplan are, apart from existing rules and regulations concerning allowances, based on pre specified headway limits and personal experiences.

It is also difficult to further develop Trainplan because its built in database is, to say the least, not modern.

The dwell times used are decided by RU´s themselves but can be overridden by Trafikverket.

1.3 Quality of the Timetable

There is often insufficient information in RU´s requests for slots in the timetable.

The timetables created for the freight trains by Trafikverket are in many aspects not optimised. A much more flexible and efficient timetabling process is needed.

The timetables must contain more information concerning how the wagons are planned to be handled. And this information must be easily accessible to the dispatchers and train drivers. Otherwise they cannot act or make plans that are optimal for the near future.

The timetable for the year to come is decided in October. From the end of October when the ad hoc process is started to the beginning of December when the Timetable starts to be valid there are already hundreds of changes. This continues during the rest of the period not at least due to ad hoc applications of new train routes (and timetables) caused by irregular infrastructure faults and maintenance activities. This amount of changes and the fact that many trains aren’t optimally planned from the beginning leads to a deteriorating timetable that becomes more and more “fragmented”. The described process makes it difficult for the operators to produce transports with the right quality and to lower their costs.

Trafikverket is responsible for the ad hoc planning process, i.e. the planning of primarily freight trains on the so called “remaining capacity” (in Swedish: “restkapaciteten”). Trafikverket has problems fulfilling this duty. The reason is said to be a lack of resources, but the main impression is that the main causes are inadequate and old fashioned support systems making an efficient planning process impossible.

The construction of the timetable is based on old principles when it comes to so-called buffer times, running time supplements, and other allowances etc. The precision in the planned timetable for individual trains varies a lot. Especially the running times for the freight trains deviates quite often from what is planned in the timetable.

It is also reported that the planning of track usage on larger stations and yards isn´t good enough. The precision in the data and models used as a basis for the calculations of running times and margins is too simplified.

There is said to be an overhaul of the timetable by Trafikverket every time a major change of the infrastructure is finished.

The running time calculations that are done as a basis for the construction of the timetable have several drawbacks. Firstly, they are calculated in advance for a specific number of different types of trains for every link[1] in the Swedish railway network and the values are stored in the system (called TIGRIS). This means that the calculations are made for a limited number of different types of freight trains and have to be transferred to Trainplan. Secondly, the running time calculations (including start and stop time supplements) are made from station centre to station centre on the main track without considering effects of the signalling system and also leaving to the timetable constructors to add time for trains running through one or more points on its way into/out of the station. Of course are also the stopping and starting points seldom at the station centre and the station centre is sometimes at the front or rear end of the station. Thirdly, it is also observed that the calculated running times for long and heavy freight trains many times are wrong. The long and heavy freight trains are modelled in the shape of a "point". This fact in combination with that their length and weight affects both where in a station they will stop and the time to get to the stopping point, makes it difficult to create good, detailed timetables for these trains. Fourthly, the models and the train data used in the calculations are not always the best possible and needs an overhaul of persons with high competence in the field. The calculated values are not validated on a more regular basis today. In fact it is seldom done.

The construction of the timetable is done with Trainplan based on pre calculated running times and a (very) simplified infrastructure model. During construction the timetable is represented as a "Train graph". This tool has no "built-in intelligence" and is just a mere "drawing board". In the used infrastructure model there is no representation of the signalling system whatsoever which have several effects on the quality of the timetable. The following "deficiencies" are noted by representatives of Trafikverket, Transrail, as well as the author himself:

There are quite often hidden conflicts between trains (or strictly speaking between train routes) in the timetable due to a mix of too tight planning of the trains and a too rough estimation of the actual running of the train. This happens for example when the first train starts from a side track on a station in the middle of a line just a couple of minutes before the second train in the same direction passes through that station.

[1] A link is here the railway line between one station and the following station.

The effect is that the second train has to brake for “waiting stop in the next signal”. The same thing also happens sometimes when two trains are entering a station from different directions and they have train routes crossing each other or when a faster train catches up with another (slower) train on the same main track.

Planned train meetings (on single track) are sometimes impossible to carry through according to plan, even if both trains are on time. The cause of this is that there are time delays in the interlocking system that is not considered in the timetable. This effect is especially noted on the iron ore line were the train passing through on the main track has a low maximum speed and often is both of full length and extremely heavy compared to “normal” trains. Also note that the mentioned time delays to some extent varies between different interlocking systems (and usually is not documented).

Another problem with the Swedish timetables is that the planning is done with almost no consideration to the variations of the adhesion. Sweden is a quite large country with very large seasonal variations in temperature, precipitation (snow) etc. and there are also very large variations between different parts of the country. In order to get stable timetables it is a must to take these differences into consideration in the planning process.

The time supplements that are added to trains in the yearly timetable due to planned maintenance work are often based on rough estimations done by the Capacity centre.

When planning for the next yearly timetable, the main passenger operator in Sweden creates a timetable including all their own trains that is free from conflicts and with realistic time allowances. Their requests for new slots are then based on this timetable.

The main passenger operator uses an (really) old system when creating their timetable. They work with allowances in much the same way as Trafikverket. But they think that the running time allowances should be done differently. Today they added at certain “nodes”. This passenger operator thinks they should be added more continuously along the train’s itinerary.

According to the main passenger operator, today’s traffic system isn´t capable of delivering trains with a “minute precision”.

Trafikverket don´t have time and resources to check every slot request. There are far too many as it is today. The requests made by the RUs are also quite imperfect, i.e. important information is missing.

It has happened that some RU has specified wrong type of train in their slot request in order to keep the priority. For example a train with a slot based on maximum speed 100 km/h which contain a wagon with max speed 80 km/h.

The larger freight companies make themselves requests on the so called “rest capacity”. But it is often a problem to do that for the smaller companies with limited resources.

One large passenger RU thinks it is far too many trains on the tracks, especially on the main lines between the major cities.

One “feeling” concerning the running time allowances added to certain nodes in the system is that Trafikverket sometimes modifies the distribution in order to have one more train in the timetable.

Planning the trains with a low precision as in Sweden, creates large punctuality problems, especially in areas with high capacity consumption.

“Too often the timetable is not used as a timetable but mere as a broad outline for running trains on the tracks”.

1.4 Operational control and the usability of the timetable

One effect of the prioritisation rules of today (i.e. trains on-time are prioritised) is that trains running long distances are treated unfairly. The probability that a train is on time is much higher if it is running only a short distance.

Train drivers are normally not informed about changes of the actual timetable (i.e. changes made by dispatchers due to different perturbations or disturbances). Therefore they cannot adapt their driving to the actual timetable.

Sometimes there are intentions in the originally planned timetable not known by train drivers and dispatchers. I.e. information that is necessary in order to take correct replanning actions is lacking in the planned timetable. For example drivers know that they are leaving a couple of wagons at a specific station or yard but they do not have information concerning the near future of these wagons. Will they be placed in another train and if so, when this will happen. Also the dispatchers have much of the same problems.

Train drivers in Sweden seem to always drive the trains as fast as possible according to the actual speed limit. This makes trains sometimes running out of its schedule. This problem concerns above all freight trains, but sometimes also passenger trains that have large margins in its timetable.

It is very common with freight trains running early in Sweden, i.e. trains running ahead of its timetable. Some trains can be up to 4 hours before their schedule. There are no guiding principles for this in Sweden and there are many explanations to this phenomenon.

The numbers of freight trains that are carried forward in their timetable channel (plus/minus 5 minutes) are only around 20-30 % of the total number of freight trains. Another cause for this severe fault is that the actual train running on the tracks often does not have the same length, weight, allowed maximum speed, loco or type of wagon etc. as the train for which the timetable was made (i.e. running times where calculated etc.).

The professional skill varies a lot among the dispatchers and so much that the overall quality of the control process is affected as is the punctuality.

The signalling system (i.e. the control system and the interlockings) in itself is said to often be equipped with “small” faults or “peculiar” behaviours, making them impolite and thereby making the operational control even more difficult for the dispatchers.

The operational train control is in Sweden primarily based on the so called “train graph”, which is a time-distance diagram representation of the timetable. It is created from the Trainplan version of the timetable where the planning is done on a second basis (at least theoretically). One problem with this transformation is that all times in the timetable are truncated. Thereby further decreasing the precision in the operational control of the trains. It has happened that the dispatchers have had problems to see which of two trains that is the first to pass a particular point of the line and therefor prioritised wrong train.

On the single tracked Iron ore-line in the north of Sweden where Trafikverket has started using modern tools, in the form of a combination of the STEG system and the CATO system, in the operational control process many weaknesses and faults in the timetable have been revealed. The tools and planning procedures used today in the timetabling process are not detailed and accurate enough for a modern, high quality operational control.

Train meetings on single track stations are an extremely frequent event in Sweden, whose railway net has only around 20 % double track (or more). I.e. around 80 % of the Swedish network is single tracked. In order to make every train meeting as smooth as possible it would be of great value if both the involved train drivers have quite detailed information about it (when, where, and how). Then they could adapt their driving according to the plan. This is true even if the stations are equipped with so called “simultaneous entrance” (in Swedish: “samtidig infart”). Today it is often the case that both trains are affected by the meeting resulting in delays that spreads further on in the traffic system.

A general problem in both the timetabling and operational processes is the quality of the information structures and also the quality of the data stored in them. There are today a large number of different IT tools and systems involved and a general problem seems to be that the used information and data structures used differs a lot between the systems and for example makes a transfer of data from one system to another quite complicated and difficult to perform. Another effect is also that for example dispatchers must use several different systems in order to obtain the needed data.

A general problem in the operational process of today is that the actual timetable (RTTT) used exists only in the head of the dispatcher or at best also on the “train graph” in front. The RTTT isn´t communicated and almost not possible to communicate to the persons directly involved in the process.

Some of the larger RU´s, as for example SJ, have their own traffic control centre. They state that they would like to have continuous access to the actual timetable (RTTT). Today they just try to closely follow their trains and they don´t act in case of smaller delays (5- 10 minutes for a train). It is only in case of larger disturbances that they act by cancelling or rerouting their trains and at the same time re-planning their crew rostering and vehicle plans.

A general opinion today amongst dispatchers is that there are too many trains on many lines in Sweden, or in other words, that there are capacity problems in the Swedish railway system. But in this context it is important to remember that these opinions are based on current precision in the planning and production of the train services.

There are weekly meetings between the timetable department and the traffic control department when they discuss the planned maintenance activities to come.

Temporary speed restrictions are quite frequent and are a source for delays spreading through the traffic system. The timetable is normally not adapted to them and it is left to the dispatchers to handle them in their re-planning procedures.

1.5 Feedback from operational control

Within Trafikverket there are several systems involved in the follow up of the traffic production and specifically the punctuality:

- Basun, is an IT-system handling traffic information. It is used for reporting incidents and events. It is linked to Ofelia.
- Ofelia, which is an IT-system used to register faults and disturbances on the railway infrastructure.
- Lupp, which is used to present statistics concerning punctuality and disturbances. Lupp combines traffic and construction information from other source systems into a data warehouse, making it possible follow up the construction and its traffic from an overall point of view.

One part of LUPP, “Business objects”, is used to produce standardised as well as expert level diagrams reflecting the actual “production quality”.

In Trafikverket’s new organisation punctuality analyses are done on a regular basis in four of the “traffic control areas”. The analyses are done both daily and weekly which is much more frequent than before. Most of them are reported directly in terms of diagrams or tables of results. Normally no written reports are made. Some larger analyses are made by the Capacity centre (in Swedish “Kapacitetscenter”). There is also a department called Statistics centre (in Swedish “Statistikcenter”) that makes analyses of amongst other things punctuality data.

The punctuality data that is stored in the above mentioned systems may have some small errors due to a pair of sources of error. One (and the main) source of error is that the automate registration of trains passing, leaving, or arriving at stations is measured when the trains passes selected track circuits and not when the train stops, starts, or passes the station centre. To minimise the error there is a constant time added to the measured time but the added time is based on one special train type. The other source of error is that the time measured isn´t marked with what date it is. There is a simple algorithm dealing with this problem, but still this may sometimes produce inadequate values of the punctuality for some of the (freight) trains.

There are also regular daily meetings when the timetable for tomorrow is handed over from the TT organisation to the operational one. During this meeting there is a feedback of the most urgent problems noted and also a discussion about recent changes of the actual timetable. This is an improvement, because in the previous organisation feedback was often delayed and at best given after a month.

One thing that is mentioned as a draw back with the current organisation is that there are no meetings where the new yearly timetable is “delivered” from the TT process to the operational process. Where “delivered” includes that important information concerning the new timetable is clearly communicated to the operational staff.

There is a rule in Sweden that every primary and secondary delay of a train, both passenger and freight, that is larger than three minutes should be codified with the cause of the delay. This kind of reporting started in the eighties and now seems to be working quite well. It is only a few per cent of the delays that isn’t coded.

Based on changes of the Swedish legislation Trafikverket 2012 introduced a new business management model with quality fees. The purpose is to stimulate the involved actors to take quality enhancing actions in order to minimise divergences. The quality fees are based on the above mentioned coded delays (larger than 5 minutes). The fee is for the moment quite moderate, around 1.7 Euros per delay minute.

There are some general problems concerning the feedback reported in the interviews:

When there are badly planned trains in the original timetable and therefore an urgent need to make appropriate changes there is often a lack of energy in the organisation and the whole process is experienced as quite sluggish. One of the causes is probably that there always are many persons involved also representing different organisations. But it is a fact that - if it is a specific problem every day on a particular line or station - it often takes months before the corrections of the timetable are finalised. There are even trains that, in the same way, year after year are badly planned, without any corrections are being made.

The largest passenger RU in Sweden has a project where they closely follow up the punctuality of the 30 worst trains.

Internally the freight operators regularly follow up their “problematic Trains”.

One passenger RU says that it is difficult to change the timetable for a “problematic train” because all changes are done as a part of the ad hoc process. If changes are done “ad hoc” the train get a low priority and the travel time for a fast passenger train could increase with hours. Therefore normally no changes are done during the year!

The Quality department of the main passenger RU produces a lot of statistics concerning the punctuality. But unfortunately is the ability to produce more in-depth analyses and reports limited.

The accumulated proficiency of train dispatchers and train drivers is not fed back to the timetable construction process to any larger extent.

NOTED PROBLEMS IN RESEARCH DONE IN SWEDEN

This part briefly summarises what is reported within the described scope in the last years in the scientific community of Sweden.

The Department of Science and Technology, Linköping University, Sweden have conducted a research project “Robust Timetables for Railway Traffic”, which was financially supported by and conducted in co-operation with VINNOVA (The Swedish Governmental Agency for Innovation Systems), Trafikverket (The Swedish Transport Administration) and SJ AB. The aim of the project was to increase the reliability and punctuality of the railway traffic in Sweden.

In the project have a number of punctuality studies of the timetables in the period 2010-2012 been performed for the southern main line. The effects of the delays have also been analysed from the perspective of the national economy. By using cost benefit analysis of the delays it is possible to calculate the costs of both decisions concerning timetable construction details as well as operational decisions. The cost benefit analysis among other things showed that the rule stating that “trains on time always should have higher priority than delayed trains” often isn´t optimal.

One important result of the performed studies was the development of the concept of *critical points* in the timetable - points where trains enter a line behind an already operating train or where trains overtake each other - which can be used in the practical timetabling process to identify weaknesses in a timetable and to provide suggestions for improvements. In order to quantitatively assess how crucial a critical point may be, the measure RCP (Robustness in Critical Points) have been created. A high RCP value is preferred, and it reflects a situation at which train dispatchers will have higher prospects of handling a conflict effectively. The number of critical points, the location pattern and the RCP values constitute an absolute value for the robustness of a certain train slot, as well as of a complete timetable. The concept of critical points and RCP can be seen as a contribution to the already defined robustness measures which combined can be used as guidelines for timetable constructors.

The following conclusions were also found in the referred papers and reports:

In Sweden today the situation is new with a deregulated market with many operators. The Swedish Transport Administration should handle all requests equally in the timetable process and at the same time decide what the best solution for the whole society is. They want to keep the competition at a high level and do not want to build in too much periodicity in the timetable because everyone should be able to request whatever train slot they want. Therefore it is not possible to use a model for robust timetabling that solves problems only for periodic timetables. Another fact is that the Swedish railway network consists of both single and double track lines and that the traffic is highly heterogeneous. A model for robust timetabling must also be able to handle this [2].

In the time tables of 2011-12, IC services can recover from delays better than the fast X2000 services. Their margins are larger, and placed in a better way. The fast X2000 services have too small margins and these are not effectively located in the timetable.

These trains are delayed frequently and when so, they have difficulties in recovering. The X2000 services are affecting and are affected by several trains on-route. A few minutes delay results in a train dispatching decision which can be either in favour of the X2000 train or not. Conflicts with the freight trains running directly after X2000 are few in practice, as the freight trains rarely are on time. X2000 services often have higher priority and can overtake the freight trains somewhere on the line. A conflict with other slower trains, e.g. commuter trains, is more difficult to manage. The train dispatcher has to decide which train that will become additionally delayed; the slow train because of an overtaking, or the X2000 train, which has to run after the slow train and not be able to run at maximum speed which results in a longer running time than planned for [1].

An analysis of the punctuality by studying how the performance develops en route for single services was made. Typically the time spent in the stations is underestimated, which partly is compensated for by time margins along the line, giving rise to a saw tooth formed delay muster with an increasing trend. The standard deviation in the delay reports seems to be a good indicator for the precision in the traffic. An overall comparison of scheduled and consumed margin time shows that on average more margin time should be added to the schedule.

Whereas the average on time performance basically expresses where margins are scheduled and consumed, the standard deviation in the on-time reports gives a measure for the precision in the train operations. For both studied services this standard deviation is rather stably increasing and well approximated by a linear function. Per hour running time each service loses a good minute of precision in this sense. This conclusion is interesting. This standard deviation seems to be a good indicator for the robustness in the schedule. A question for future research is how to account for the observed decrease in precision already in the construction of the timetable [5].

The freight trains that operates on the southern main line has generally a very low punctuality. One effect of this is that the in the timetable planned overtakes on a station often are moved to other stations causing changed train orders and other disorders [4]. This is also yet another indication of the generally spread low ambition to adhere to the originally planned timetable.

A simple cost benefit analysis for the studied trains on the southern main line shows that it is often profitable to increase the travel time and thereby getting a higher punctuality. Delay time has a weight that is 1.87 times the travel time weight.

To have a higher precision in the operational process it also seems to be necessary to have much larger dwell times in the timetable on certain stations where the trains must stand waiting for their departure time [4].

Sipilä [9] uses simulation as a method to study how changes in the timetable affect the punctuality of fast long-distance trains (X2000) in the Swedish Western mainline. Four minutes are added to or subtracted from the margins in the timetable used 2009. The disturbances in the model are based on real delays along the train run and on stops with passenger transfer. Sipilä has also studied the effect of having corridors for the trains with at least five minute headway to all other trains.

The Swedish Institute of Computer Science, SICS [8] is running a project about timetabling. The idea in this project is to increase flexibility by loosening the timetable constraints and postponing the detailed timetabling to an operational level (i.e. shortly before the departure). The problem addressed is that of incomplete information used in the timetable construction process. The appearance of a given timetable is a result of a long construction process, where typically several trains later will be cancelled, or will have an adjusted speed profile (due to type of engine, number of wagons etc.). In the end, crossings and overtakings are not efficiently placed. With the increased flexibility, the margins added for robustness are available in a larger geographical area. The work is, of course, of larger interest for cargo trains with less number of non-avoidable stops than passenger trains have.

SICS has also in a previous project, The Dynamic Train Plan [11], proposed a distinction between deliverables and the production leading up to those deliverables. This approach suggests that the first result of the timetabling process should be an agreement between Trafikverket and the train operating companies on what Trafikverket commits to deliver during the operations. The commitment can involve punctual arrivals and departures to certain key locations in the railway network, traversal times for the trains, or something else of major importance to the train operating company. The made agreements constitute the goals for the traffic during planning and operation. Identifying deliverables and creating production plans is common practice in industry at large. The project The Dynamic Train Plan worked out how this philosophy can be transferred to the railway market in a general sense. By dividing the process into identifying the deliverables, making production plans, and finally managing the trains during operations, both the long term and short term variations can be taken care of appropriately and in a constructive way increase punctuality and optimize the utilization of the infrastructure.

PROMISING INNOVATIONS AND DEVELOPMENTS

This part briefly summarises a couple of interesting projects on-going in Sweden. What characterises them is that they are innovative and may create a basis for further developments and in the end a higher punctuality in the Swedish railway system.

1.1 Incremental planning

The railway traffic in Sweden congests the tracks. It is an inevitable consequence of the current traffic load together with a misuse of existing capacity in the timetabling process. There is a need for a new timetabling strategy that increases the ability to adapt to new situations and last-minute additions to the train plan.

Following the railway deregulation, the sector has been split into different fields of responsibility. Trafikverket, the Swedish Transport Administration, maintain and administer the infrastructure as well as plan and manage the traffic on it.

Traditionally, the train plan has been planned and published in great detail, and used as basis for the operations without any further adjustments. The train plan constitutes the framework for the traffic for a year. Alterations to it are made only at pre-scheduled, sparsely distributed occasions, so called timetable changeovers (in Swedish: tidtabellsskiften). Quality problems like decreased punctuality within the railway network have been tackled through more rigorous planning, requiring increasingly detailed information from the operators, in turn prolonging the lead times of the timetabling process. This is an inflexible way of managing the variations that naturally occur over a year of traffic.

Today, once the timetable has been fixed, there is no process with the aim of adjusting it to new circumstances. Trafikverket therefore has an on-going project Incremental planning (in Swedish “Successiv tilldelning”). It is believed that increased efficiency and quality can be obtained by applying ideas used elsewhere in industry, such as just-in-time and lean production, employing the inherent fluctuations to optimize the railway operations.

Incremental planning is planned to be implemented in a first step by January 2015.

1.6 NTL project

The NTL project (National Traffic Control, in Swedish “Nationell TågLedning”) is a complex business development and IT project containing a number of subprojects, which aims to establish a national train control system. The project also includes the development of new processes, new ways of working, efficient interfaces to the processes of Traffic planning, Delivery, and, Production follow up, and system support for this.

Today Trafikverket (The Swedish Transport Administration) has eight dispatch centres and a number of places where operational control of trains is done locally. Several different systems are used for train control. Various dispatch centres are, individually or together with additional centres, "islands" that can only control a certain geographical area. The redundancy between geographical areas is poor.

An effort to create a national centralised train traffic control system has been on-going since 2008 when a feasibility study on the topic was made by Banverket (The former Swedish Transport Administration). NTL was initially seen as a more streamlined technology project, but is now a business development project in which a new technology platform is part of the system and the focus is on the above mentioned project benefits. With the new train control system, the trains in Sweden will be directed by one common system and with the same way of working across the country.

With a train traffic control system we here mean a system that contains functionality to monitor and control the train traffic in the whole of Sweden, including functionality that makes proactive train control possible according to the concept Control by planning. The system interfaces interlockings through a transmission network which makes it possible to control any interlocking from any client computer.

The main goals of the NTL project are:

- Improved accuracy of train scheduling, improved traffic robustness and traffic capacity, which will also lead to more accurate traffic information.
- Continued high availability, less vulnerable design, increased flexibility and extendable functionality.
- More efficient maintenance, operation and support.
- A robust, efficient and less resource consuming national train control (in relation to traffic capacity).

In order to achieve these goals, among others the following main areas need to be addressed:

1. The creation of a “Train traffic management process” including efficient interfaces to the processes Traffic planning and Delivery and Production follow-up for a more convenient information flow.
2. The creation of a new nationwide working processes through a Hierarchical Task Analysis.
3. The creation of a train traffic control system that meets the identified requirements. Four major areas are of certain importance to get a good result:
    a. Create a technical platform that enables us to move from eight independent train control areas into one nationwide system for traffic control. In order to achieve this it must be possible to control any interlocking from any client computer.
    b. Create functionality that makes proactive train control possible according to the concept Control by planning. Management by awareness and situation awareness at all hierarchical operational levels are vital prerequisites when implementing the concept. Main functional areas are:
    -Resource planning of all existing traffic activities down to time of execution.
    -Conflict detection and resolution shall be integrated in the real-time planning tool.
    -The Execution plan shall be automatically executed without any

changes in the plan concerning the path for each train and train sequence for each track resource.

c. Create a train traffic control system that is developed in cooperation with the end users in order to get good usability.

d. Make sure that the train traffic control system has access to the infrastructure data needed to perform the identified functions.

To ensure a successful deployment of a nationwide train traffic control system, good knowledge of the present signalling system and transmission networks are necessary. Parts 1 and 2 above have been completed within the NTL project. Requirements for part 3 have been developed within the project and the train traffic control system that will be based on these requirements is now a subject of public tender.

The implementation of the NTL system will necessitate a production plan (including the timetable) that is much more detailed than today.

CONCLUSION

To conclude, there are as shown above a lot of quite complicated and often interrelated problems that must be solved in order to have an effective integration of timetabling and operational control processes. Trying to summarise in a somewhat structured way we have found that the main underlying problems - broken down in the same way as in the chapter “Noted problems based on interviews” - are the following.

Rules and regulations

The timetabling process of today has some strange rules for prioritisation between different trains in the planning phase, is by far too long and too rigid, especially compared to the needs of the freight companies, thereby creating problems with overbookings, cancellations, badly adapted train timetables, bookings with the “wrong” type of train etc.

The actual timetable of today, which is based on the yearly timetable, is in a constant state of deterioration due to the rigidity and sluggishness and the lack of appropriate tools of the current timetable process. The yearly process and the ad hoc-process are by no means coordinated in an optimal way.

The operational rules concerning the prioritisation are not working well at all. They do not give an overall effective operational control process.

The ad hoc-process is not allowing the creation of an – for the actual day – optimal plan, for example new trains have to be adapted to the timetable without any alterations of the trains already in the planned timetable.

The so called “Capacity congestion plans” used in Sweden are too rigid and are “stealing” useful capacity.

The cyclic timetables introduced locally are, at least in theory, more capacity consuming than non-cyclic ones and also creates conflicts between the local trains on one hand and the freight and long distance trains on the other. This is a complex problem that has to be solved.

Trafikverket receives more requests for slots than they have capacity to inspect. As already mentioned it is also a tool-problem. The RU´s only pay for utilised slots and not for every requested slot. Trafikverket has plans for introducing fees also for every requested slot.

Timetabling and its tools

The major problem is that the timetable is not planned for every specific day. Trafikverket does not have enough resources (and not the appropriate tools etc.).

The timetables are planned with a low degree of precision – in practice not even working on a “one minute” level – and therefore creating many problems. For example enhancing the so called “time in the forest”, introducing delays, spreading knock on delays etc. and in the end increasing transport, travel times, and energy consumption and decreasing punctuality.

The main timetable tool (Trainplan) used today has no functions for an appropriate handling of the planning of tracks on larger stations and yards. Furthermore it has no developed functions for dealing with different versions of infrastructure or different versions of the same timetable in an effective way. In Trainplan it is also very time consuming to alter the timetables for trains running long distances. The impression is that the main causes to the problems are inadequate and old fashioned support systems making an efficient planning process impossible.

The timetable constructors don't specify time supplements in the timetable in a structured and validated way. The timetable construction done in Trainplan are, apart from existing rules and regulations concerning allowances, based on pre specified headway limits and personal experiences.

The irregular maintenance activities that are needed are not dealt with in the short time planning process in an appropriate way. It is partly due to the "static structure" of the planning process, and partly because of the tools used.

Quality of the Timetable

Trafikverket don´t have time and resources to check every slot request. There are far too many as it is today. The requests for slots in the timetable made by the RUs are often also quite imperfect, i.e. important information is missing.

The timetables do not contain all information needed by dispatchers and train drivers in the operational process. For example concerning information about train connections and planned handling of freight wagons.

Trafikverket has problems fulfilling its duty for the ad hoc planning process. The reason is said to be a lack of resources, but the main impression is that the main causes are inadequate and old fashioned support systems making an efficient planning process impossible.

The construction of the timetable is based on old principles when it comes to so-called buffer times, running time supplements, and other allowances etc. The precision in the planned timetable for individual trains varies a lot. Especially the running times for the freight trains deviates quite often from what is planned in the timetable.

The planning of track usage on larger stations and yards is not good enough today. The precision in the data and models used as a basis for the calculations of running times and margins is too simplified.

The running time calculations that are done as a basis for the construction of the timetable have several drawbacks.

1. They are calculated in advance for a specific, limited number of different types of trains.
2. The running time calculations (including start and stop time supplements) are made from station centre to station centre on the main track. Without considering effects of points and the signalling system.
3. The calculated running times for long and heavy freight trains are many times wrong. The long and heavy freight trains are modelled in the shape of a "point". This fact in combination with that their length and weight affects both where in a

station they will stop and the time to get to the stopping point, makes it difficult to create good, detailed timetables for these trains.

4. The models and the train data used in the calculations are not always the best possible.
5. The calculated values are not validated on a more regular basis today. In fact it is seldom done.

The construction of the timetable is done with Trainplan based on pre calculated running times and a (very) simplified infrastructure model. During construction the timetable is represented as a “Train graph”. This tool has no “built-in intelligence” and is just a mere “drawing board”. In the used infrastructure model there is no representation of the signalling system whatsoever which have several effects on the quality of the timetable.

The following “deficiencies” in the used timetables are noted:

- Quite often hidden conflicts between trains in the timetable
- Planned train meetings (on single track) are sometimes impossible to carry through according to plan, even if both trains are on time. The time delays in the interlocking system are not considered in the timetable. It is especially noted on the iron ore line. Also note that the mentioned time delays to some extent varies between different interlocking systems (and usually is not documented).

Another problem with the Swedish timetables is that the planning is done with almost no consideration to the variations of the adhesion. Sweden is a quite large country with very large seasonal variations in temperature, precipitation (snow) etc. and there are also very large variations between different parts of the country.

The time supplements that are added to trains in the yearly timetable due to planned maintenance work are often based on rough estimations.

The traffic system of today isn´t capable of delivering trains with a “minute precision”.

Planning the trains with a low precision as in Sweden, creates large punctuality problems, especially in areas with high capacity consumption.

“Too often the timetable is not used as a timetable but mere as a broad outline for running trains on the tracks”.

Operational control and the usability of the timetable

Temporary speed restrictions are quite frequent and are a source for delays spreading through the traffic system. The timetable is normally not adapted to them and it is left to the dispatchers to handle them in their re-planning procedures.

One effect of the prioritisation rules of today (i.e. trains on-time are prioritised) is that trains running long distances are treated unfairly. The probability that a train is on time is much higher if it is running only a short distance.

Train drivers are normally not informed about changes of the actual timetable (i.e. changes made by dispatchers due to different perturbations or disturbances). Therefore they cannot adapt their driving to the actual timetable.

The train drivers involved in upcoming train meetings seldom have detailed information enough about to perform them in the best way possible. Train meetings on single track stations are an extremely frequent event in Sweden, whose railway net has only around 20 % double track (or more).

Sometimes there are intentions in the originally planned timetable not known by train drivers and dispatchers. I.e. information that is necessary in order to take correct re-planning actions is lacking in the planned timetable.

Train drivers in Sweden seem to always drive the trains as fast as possible according to the actual speed limit. This makes trains sometimes running out of its schedule. This problem concerns above all freight trains, but sometimes also passenger trains that have large margins in its timetable.

A severe fault is that the trains do not follow their timetable (especially the freight trains). The numbers of freight trains that are carried forward in their timetable channel (plus/minus 5 minutes) are only around 20-30 % of the total number of freight trains.

The professional skill varies a lot among the dispatchers and so much that the overall quality of the control process is affected as is the punctuality.

The signalling system (i.e. the control system and the interlocking) in itself is said to often be equipped with “small” faults or “peculiar” behaviours, making them impolite and thereby making the operational control even more difficult for the dispatchers.

The times in the time-distance diagram (“train graph”) used in operational train are truncated (not rounded). Thereby further decreasing the precision in the operational control of the trains.

On the single tracked Iron ore-line in the north of Sweden where Trafikverket has started using modern tools, in the form of a combination of the STEG system and the CATO system, in the operational control process many weaknesses and faults in the timetable have been revealed. The tools and planning procedures used today in the timetabling process are not detailed and accurate enough for a modern, high quality operational control.

A general and major problem in both the timetabling and operational processes (also in the investment planning process) is the quality of the information structures and also the quality of the data stored in them. There are today a large number of different IT tools and systems involved and a general problem seems to be that the used information and data structures used differs a lot between the systems and for example makes a transfer of data from one system to another quite complicated and difficult to perform. Another effect is also that for example dispatchers must use several different systems in order to obtain the needed data. That goes also for timetable and investment planners.

A general and major problem in the operational process of today is that the actual timetable (RTTT[2]) used exists only in the head of the dispatcher or at best also on the "train graph" in front. The RTTT isn´t communicated and almost not possible to communicate to the persons directly involved in the process.

Feedback from operational control

The accumulated proficiency of train dispatchers and train drivers is not fed back to the timetable construction process to any larger extent.

The punctuality data that is stored in the databases may have some small errors due to a couple of sources of error. One (and the main) source of error is that the automate registration of trains passing, leaving, or arriving at stations is measured when the trains passes selected track circuits and not when the train stops, starts, or passes the station centre. The other source of error is that the time measured isn´t marked with what date it is.

One thing that is mentioned as a draw back with the current organisation is that there are no meetings where the new yearly timetable is "delivered" from the TT process to the operational process. Where "delivered" includes that important information concerning the new timetable is clearly communicated to the operational staff.

There are some general problems concerning the feedback reported:

-When there are badly planned trains in the original timetable and therefore an urgent need to make appropriate changes there is often a lack of energy in the organisation and the whole process is experienced as quite sluggish.

-If it is a specific problem every day on a particular line or station it often takes months before the corrections of the timetable are finalised.

-There are even trains that, in the same way, year after year are badly planned, without any corrections are being made.

One passenger RU says that it is difficult to change the timetable for a "problematic train" because all changes are done as a part of the ad hoc process. If changes are done "ad hoc" the train get a low priority and the travel time for a fast passenger train could increase with hours. Therefore normally no changes are done during the year!

The Quality department of the main passenger RU produces a lot of statistics concerning the punctuality. But unfortunately is the ability to produce more in-depth analyses and reports limited. The same seems to go for Trafikverket.

RECOMMENDATIONS

Based on what is described above, the future work concerning the integration of timetabling and operational control in Sweden, in the short term, should be focused on development of the involved models, methods and systems and at the same time raising the quality of used data.

[2] Real-Time Time Table

In order to have a modern railway in Sweden it is important that the involved actors actively work with the main problems described above and tries to:

Quality of the Timetable

- Enhance the quality of the models and data used in the timetabling process.
    - The original plans must be in detail, and be realisable.
    - Include detailed track usage: track length, position for and speed through points and lines.
    - Include signalling systems functionality: signal box functionality, position of signals and distant signals, etc.
    - Include functionality of the ATP-systems: distance for route set timing, etc.
    - Calculate minimal (shortest possible) running times as a basis for adding margins for robustness and resilience
- Instate the validation of used data, models, timetables etc. as a standard.
- Introduce structured ways of working with so-called buffer times, running time supplements, and other allowances etc. in the timetabling process.
    - Create algorithms for calculation and fine-tuning of margins – magnitude and allocation - within the scope of timetable objectives.
    - Validation is again of greatest importance.
- Start considering the very large seasonal variations in temperature, precipitation (snow) etc. in the timetabling process.
- The plan as a whole should have specified values for quality measures:
    - capacity utilisation
    - robustness and resilience
    - comfort
    - cost of wear and tear, i.e. maintenance
    - energy consumption

Timetabling and its tools

- Introduce <u>modern</u> and <u>appropriate</u> tools for running time calculations, simulations and "optimisation" of the timetables.
- Work consistently with the introduction of uniform and appropriate information structures in all involved IT systems.

Rules and regulations

- Create operational rules concerning the dynamic prioritisation between trains that supports an overall effective operational control process.
- Adapt as far as possible rules and regulations to an overall effective operational control process.
    - And of course also the organisation.

Operational control and the usability of the timetable

- Make sure that the timetables do contain all information needed by dispatchers and train drivers in the operational process.

    - Make calculated minimal running times and deadlines - and other requirements by request of the railway undertakers - available in the operational process.
- Force the train operating companies to run the trains according to the plan.
    - And to make necessary updates of the train characteristics relevant for the re-planning process.
- Develop standardised semi-automatic functions for evaluation of accomplishments.

Feedback

- Involve the accumulated proficiency of train dispatchers and train drivers in the timetable construction process.
- Eliminate the existing imprecisions in the measuring of punctuality.
- Make sure that it is possible to analyse the punctuality with the actually used timetables and the actual performance of the trains.

General

- Make sure that all information systems are accessible and usable from a train traffic point of view.
- Avoid “elephantiasis” when developing and introducing new methods and systems.

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