



NTNU – Trondheim
Norwegian University of
Science and Technology

Ruteplananalyse for lokaltog.

Casestudie for Trønderbanen

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Project Management

Submission date: June 2013

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NORGES TEKNISK-

NATURVITENSKAPELIGE UNIVERSITET

INSTITUTT FOR BYGG, ANLEGG OG TRANSPORT

Oppgavens tittel: Ruteplananalyse for lokaltog. Casestudie for Trønderbanen Timetable analysis for local trains. Case study of Trønderbanen	Dato: 10/06/2013		
	Antall sider (inkl. bilag): 120		
	Masteroppgave	X	Prosjektoppgave
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Faglærer/veileder: Nils Olsson			
Eventuelle eksterne faglige kontakter/veiledere: Hansen Halvor Schrøder (NSB)			

The purpose of this master thesis is to find alternative timetables for Trønderbanen with a mixed traffic of long distant, cargo and local trains. The limitations during the calculation process are more or less the limitation that the inputs of the program and the case study set. Calculating and comparing timetables that run a clock face procedure with hourly intervals sets another constraint. The other parameters of the system are considered to be the same as today. The analyzed line consists of the single line parts from Sjøberg to Trondheim S and Stjørdal to Steinkjer and the future infrastructure that includes a double track from Trondheim S to Stjørdal and the electrification of the whole examined line. The special focus both in theory and praxis was given to where the slack time has to be placed to avoid the spreading of delays. The method used is the timetable theory and Viriato, a powerful integrated tool for timetable scheduling, made by SMA. NSB and JBV supplied all the necessary infrastructure and data needed in order to make these calculations. SINTEF (Teknologi og Samfunn) supplied the license to the software as part of PUSAM project. The background is Traffic Theory that helped to evaluate the produced Railway Timetables. The best scenario was evaluated according to the running times specific infrastructure alterations have been suggested. This scenario assigns buffer times to stations.

Stikkord: placement of slack, Trønderbanen, Viriato, timetable theory, cargo, freight, passenger trains, NSB, SINTEF Teknologi og Samfunn, PUSAM

DEDICATION OF THE REPORT

This master thesis is dedicated to my professor Konstantinos Liberis that inspired my love for railways.

I. FORORD

Rapporten oppsummerer arbeidet gjort i det siste semesteret av Prosjektledelse ved NTNU, i Trondheim, våren 2013. Oppgaven er gitt ved Institutt for Bygg, Anlegg og Transport, med Nils Olsson, NTNU, som faglærer og Hansen Halvor Schrøder, NSB AS. Persontog Plan, som veileder.

Temaet for rapporten er ruteplananalyse for lokaltog og casestudien er Trønderbanen. Dette er en direkte videreføring av mitt arbeid med prosjektoppgaven "Timetable alternatives for Trønderbanen" gjennomført høsten 2012. Flere personer har bidratt i forbindelse med arbeidet med denne masteroppgaven og jeg ønsker å takke disse. En spesiell takk rettes til Nils Olsson og Hansen Halvor Schrøder for god veiledning underveis i arbeidet med masteroppgaven.

Trondheim, 10 juni 2013

I. PREFACE

The current master thesis summarizes the work done in the last semester of Project Management at NTNU in Trondheim during the spring of 2013. The task is given by the Department of Building, Construction and Transport, with Nils Olsson, from NTNU, and Halvor Hansen Schroder from NSB's planning department, as my supervisors.

The theme of the report is the route for local analysis and case study Trønderbanen. This is a direct continuation of my work on the project "Timetable alternatives for Trønderbanen" in autumn 2012. Several people have contributed in this thesis and I would like to thank them. Mainly my supervisors, Nils Olsson and Hansen Halvor Schroder for the good guidance during the thesis work.

Trondheim, 10 juni 2013

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LIST OF ACRONYMS

BP= Blockpost

H= maximum velocity (km\h)

HP= stop

JBV= Jernbaneverket is the Norwegian government's agency for railway services.

K= constant coefficient dependent on the type of the train

K= (number of sets) is the maximum capacity in the time period

K= velocity for titling trains (km/h)

NSB= Norwegian State Railways

P = important infrastructure points or Plus velocity (km/h)

SMA= SMA und Partner AG is an independent company specialized in transportation

STA= station

T =(min) the frequency or tourist velocity (km/h)

V= speed (km/h)

ΔV = additional coefficient

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SUMMARY

Because of the planned electrification of the Trondheim-Steinkjer, it is necessary to look at different route concepts Trønderbanen. Electric trains have better acceleration performance than current diesel ones, which would result in a theoretical travel time savings of 7 to 10 minutes in the line between Trondheim and Steinkjer. As the route is single-track, the current route model is restricted by the crossing points, and there is little room to achieve real runtime savings.

Trønderbanen is very important for both Trondheim and the regions that are linked to it through the specific rail-path, the infrastructure and pathways are characterized by being old and with relatively low average speed. The sharp curves and gradients limit the speed that can be reached.

Large parts of the line have low geometric standards and a standard rate as low as 80 km / h (independent of the stop pattern). Parts of the trail are further landslide and erosion prone, with significant operating and unsecured level crossings. The path is currently preclude public access to outdoor recreation areas (especially sea), which it is described by the traffic sign that indicates hazard and it is called "wild crossings". (Forslag til Planprogram "dobbeltspor Trondheim S - Stjørdal av 25.mars 2013.)

The part of the line between Trondheim S and Stjørdal is fully exploited when it comes to capacity and it is not possible to put more trains in the line without compromising runtime and / or punctuality. This part of the line also affects Stjørdal – Steinkjer as well as the long distance trains and freight for Nordlandsbanen.

This specific part between Trondheim S and Stjørdal is described by Jernbaneverket as a 'bottleneck' for both lines of Nordlandbanen and Trøndersbanen. The current capacity of the line cannot be increased if the line is going to remain as currently. The task is

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therefore to develop and compare different route concepts in Trønderbanen to provide an indication of which improvements can be achieved and to identify other necessary measures in order to accomplish this.

Due to the wished electrification of the examined line a re-scheduling of routes is essential. The procedure of producing timetables for the specific line (Steinkjer-Søberg) has been conducted by Viriato, a specialized software. Sintef Teknologi og samfunn owns the licence to the software as it has a special agreement with NSB as a part of PUSAM project (punktlighetsforbedring og kostnader av forsinkelser i jernbanetraffikk).

The evaluation criteria /factors that have been chosen in order to evaluate the scenarios are the following: The achieved crossings, the driving times, the number of train sets that need to be used. To get the number of train sets printing of the graph has been chosen because of its simplicity.

Some other factors have been examined also and these are: the demand based on the population, the timetable times around zero, the stability of the timetable, the historical value of each station, the number of crossings. Recovery times, the employees' point of view and comparison with the current timetable have also been examined. The procedure has been traced by the planning department of NSB and with the use of data provided by Jernbaneverket.

The theoretical part of this report is focused on primarily on punctuality and routing to maximize the probability of avoiding delay and / or prevent them from being scattered. Timetable theory is being presented with a special focus on placing of buffer times. That is another important issue that is being discussed and completes the theoretical background of the current report.

1. INTRODUCTION

1.1 Background

Traffic management in railway networks and timetables are two linked elements when it comes to railway operation. Even though the planning procedure deviates from its execution because of unforeseen factors, the scheduling remains a very important part for the operation of the transportation system. Timetabling is a very important tool that can be used in this sense from the level of planning until the level of communicating information to the customers.

This can be implemented in two ways: manually and with IT –tools. To achieve the continuous improvement in the planning procedure an updating is required regularly. It is difficult to make a material plan without a timetable and it is difficult to schedule maintenance and running without both personnel and without plans (Olsson, N. O. E. and M. Veiseth , 2011). For over than 150 years the scheduling was being implemented manually. It was the typical way of planning until the 1990s when computer-based methods were introduced (Pachl, 2008). Advanced tools for construction design have been introduced over the past decades. However, judging from the punctuality levels that they are not the highest ones, (apart from Japan), one can say that this tool has shortened the procedure of planning but has advanced its performance. The low degree of robustness and exactness is the main cause for this disappointing measurement (Pachl, 2008).

The method used in this project to calculate train diagrams is based on the use of Viriato, a powerful IT-tool. The aim of this project is to produce and to evaluate alternative timetables for Trønderbanen. The current line operates with diesel engine trains. The planned electrification of the Steinkjer-Sjøberg is a need to look at different route concepts Trønderbanen. The current path model is locked at the existing crossing points, and there is little room to achieve real savings when it comes to running times.

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Trønderbanen is very important for both Trondheim and the regions that are linked to it through the specific rail-path, the infrastructure and pathways are characterized by being old and with relatively low average speed. The sharp curves and gradients limit the speed that can be reached. The part of the line between Trondheim S and Stjørdal is fully exploited when it comes to capacity and it is not possible to put more trains in the line without compromising runtime and / or punctuality. This part of the line also affects Stjørdal – Steinkjer as well as the long distance trains and freight for Nordlandsbanen.

The analyzed line consists of parts of the current infrastructure (meaning the geometrical features of the line). These are the parts from Sjøberg to Trondheim S (single track) and Stjørdal to Steinkjer (single track). Trondheim S- Stjørdal is wished to be converted from a single line track to a double line track.

1.2 Initiation of this study

A good time scheduling is an essential factor for making a railway network attractive. With a misfortune of a weak scheduling process, the railway may lose ground over other means of transportation. Ultimately, neglecting to give significant importance to this field is equal to deriving the railway network from evolving, thus reducing the demand. That is the reason why it is important to make the network more attractive. The first step is the planned electrification of the line between Steinkjer-Sjøberg so as to use a specific type of trains (Flirt) that can achieve a maximum velocity of 160 km/h.

The scope of the project has been defined in a meeting that took place in the beginning of January 2013 with the supervisor of this report, Nils Olsson and the writer of this report. By having a constant contact with NSB the scope was stated more clearly through another meeting that took place at the end of the same month. The initial version of it was divided into two parts: a theoretical and a practical one. The practical was focused mainly in punctuality and the location of slacks during the planning procedure in order to avoid the spreading of delays. The practical one was to use Viriato in order to examine different scenarios (after the electrification of the line and the double line between Stjørdal and Trondheim) and crossing patterns capacity between. Several in person meetings took place in Oslo with NSB during the current report.

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The tool used to produce the timetables is Viriato and has been provided after the financing of SINTEF as part of PUSAM. The main content of the present report is a comparison of the different timetables alternatives that have been produced by taking some parameters into account and at the same time making a number of essential and logical assumptions.

1.3 Study purpose

The purpose of the report is to choose through a detailed examination of various factors which scenario is the optimal one for the line Sjøberg to Trondheim S, Trondheim S-Stjørdal and Stjørdal to Steinkjer after its electrification, the use of certain type of passenger trains and the replacement of the single track between Trondheim S and Stjørdal with a double one.

By making several other assumptions and taking a number of parameters for granted, while creating timetables for a specific future version of an already existing line (Steinkjer-Sjøberg) the optimum alternative is intended to be found. The task is, therefore, to develop and compare different routing concepts to provide an indication of the improvement that can be achieved (like travel time, frequency, structure) and to identify other appropriate action (like construction of double track / crossing) that must be done to achieve this. This is being made by the use of several criteria that are used during the evaluation. The evaluation procedure can lead to important conclusions that can improve the current or enhance the performance of the future railway network. The above procedure has been done in cooperation with NSB. The planning department of NSB is committed to reducing the incidence of planning inadequate elements in order to achieve high and consistent standards of everyday performance.

The accuracy of the given data that has been used in order to produce the timetables is checked. NSB provided the data during the specialization project. All the calculations have been made with this version of database. JBV provided the database also for the specific line. A comparison of these two databases ensured the accuracy of the used input.

1.4 Limitations

The limitations during the calculation process are more or less the limitation that the inputs of the program have. The infrastructure, the rolling stock and the available materials to be used are some of those. The number of the produced diagrams seems limitless at the beginning but after increasing the number of the trains that run in the line, the crossing pattern puts an important restriction that makes the planning procedure very specific. As a result, the final produced diagrams are very specific.

The scope of the current project also puts another limitation to the project itself.

1.5 Report structure

Each chapter describes the procedure that has been followed. The structure of the report is the following.

- In chapter two the materials and methods that have been used are being described. These include the scope, the research questions and the literature study.
- The theoretical framework that was the result of the previous process is presented to the next chapter (chapter 3). The answer to the two first research questions is also summarized and presented here.
- In chapter four, an overview of the case study is being presented.
- In chapter 5 Viriato is being demonstrated from the scope of NSB. This part also includes the inputs-assumptions that have been made.
- The produced results are being presented in the following chapter (chapter 6) the discussion is being conducted. The discussion is based on the methods presented at the chapter 2).
- The final chapter is about concluding the results of the report and setting the framework for further work. (chapter7)

2. METHODOLOGY

2.1 General methodology

In order to write the present report, the methodology had to be specified before the initiation of the process. The definition of the research questions was the first step that was taken. The nature of the research questions defined the method to be followed.

The analysis involves both quantitative and qualitative techniques.

The study is divided in two parts: one theoretical and one practical. In the practical part of the report the purpose was to use the software to produce the desired timetables having set some hypothesis.

Table 1-report structure

Theoretical part	Practical part
<ul style="list-style-type: none">• quantitative methods	<ul style="list-style-type: none">• qualitative methods

Predictions according to this have been contacted. The questions are mainly 'What' and 'How much'.

For the theoretical part, quantitative methods have been used in order to answer the question. The questions are mainly 'Why' and 'How'.

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Table 2- Qualitative vs. Quantitative research methods characteristics (Thomas, 2003)
(Saunders, 2011)

QUALITATIVE	QUANTITATIVE
Understand and interpret the social interactions embed in a phenomenon or event	Test of hypothesis, cause/effect reasoning, make predictions
Small group of elements under study not randomly selected	Large and randomly chosen group under study
Study of the whole event and not just single variables	Study of specific variables
Data: impressions, images, objects, etc.	Data: numbers, statistic metrics
Data gathering: interviews, questionnaires, observation, field notes, reflections, etc.	Data gathering: measurements using structured and validated data collection methods
Not generalizable findings	Generalizable findings
Focus in quality, behavior and complexity	Focus in quantity, scales and trends
Answer the questions 'why' and 'how'	Answer the questions 'what' and 'how much'

2.2 Defining the scope

As the present master thesis is a continuation of the specialization project that has been written the previous semester, the scope was relevant to it. A main contributor was SINTEF Teknologi og samfunn and PUSAM (Punktlighetsforbedring og kostnader av forsinkelser i jernbanetrafikk).

Thus, the scope has been defined under PUSAM and NSB perspective. According to Sintef's webpage PUSAM project has as its general purpose to develop methodologies and tools that can demonstrate quality defects in rail transport and quantify the effects of time and cost in the whole procedure.

A decision support system that will help to improve conditions for rail transport in Norway is the aim of the PUSAM project. The system shall support rating of improvement, prioritizing cost-effective infrastructure investment and maintenance, as well as planning and management of traffic. JBV, which owns the rail infrastructure in Norway, is responsible for the project that has also as participants: CargoNet, NSB, Airport Express, SINTEF, Institute of Transport Economics and NTNU. The terminal date

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was the end of 2012 but the license of Viriato is valid until March 2014. The project is financed by the Norwegian Research Council and the participating organizations.

Under this particular frame the master thesis' scope has been defined in a meeting that took place in the beginning of January 2013 with the supervisor of this report, Nils Olsson and the writer of this report. By having a constant contact with NSB the scope was stated more clearly through another meeting that took place at the end of the same month. The initial version of it was divided into two parts: a theoretical and a practical one. The practical was focused mainly in punctuality and the location of slacks during the planning procedure in order to avoid the spreading of delays. The practical one was to use Viriato in order to examine different scenarios (after the electrification of the line and the double line between Stjørdal and Trondheim) and crossing patterns capacity between. Several in person meetings took place in Oslo with NSB during the writing of the current report. A further systematic communication through e mails has been established to achieve the maximum result.

2.3 Research questions

As the purpose is to analyze the possible timetables for Trønderbanen, the theoretical background for the analysis. The theoretical part is directed towards punctuality and routing to maximize the probability of avoiding delay and / or prevent them scattered, placement of slack, and other topics about punctuality, taken into consideration during the planning process. The (route) planning focuses on Trønderbanen and includes commuter, regional and freight trains. Planning illustrates both the opportunities with existing and potential future infrastructure.

The following main points have been considered:

1. Principles of how punctuality can be integrated into the route planning process.
2. Route planning for local trains in Trønderbanen taking into account other kind of traffic.
- 3 Assessment of the relationship between infrastructure and possible timetables.

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In co-operation with the supervisors, it was agreed that on the following research questions:

1. Where the slack should be placed during the scheduling procedure in order to avoid delays and / or prevent them scattered?
2. How the routing should be planned in order to maximize the probability of avoiding delays?
3. What can reduce the stop pattern in the case study?

2.4 Literature study

2.4.1 Choosing the information sources

To develop the methodology for approaching the whole matter the first step was to search through the numerous available resources. Those could be found in different databases. This repetition on the one hand implies that the used resources are the best ones, but on the other hand, this could mean that the approach of the matter is one dimensional. This is the reason why a more systematic approach was used.

The tools have been split in some categories to ensure that every single theoretical aspect of the matter is taken into consideration.

Internet was a large contributor during this procedure but also EndNote X6 was used to classify resources.

As the matter is a very technical one, the sources were very limited. The theoretical approach is more or less the same.

The tool used to evaluate the found data was (ROAR) Reliability-Objectivity-Accuracy-Relevance as VIKO suggests.

The followed steps that have been followed as a part of the methodology approach are:

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Figure 1- steps for literature methodology

- Step 1:

Starting from the already known references, Pachl was used. Pachl is the guru in this area and this is not a subjective view. To ensure objectivity different specialists (professors for NTNU and NTUA) have been asked about who is the “best” reference for this particular topic and they both answered the same. As a result, through the web page of Pachl, different books were found that they are relevant to the specialization project. In general a web page is not as reliable source as some other one, but when it comes to this particular case the reliability is very high. Considering the fact that this particular writer is recognized by the vast majority of the scientific world, the initial source is very reliable, objective accuracy and relevance.

- Step 2:

Trying to brake the issue into several elements/words, a certain number of keywords was defined. These words were used in some search engines/tools.

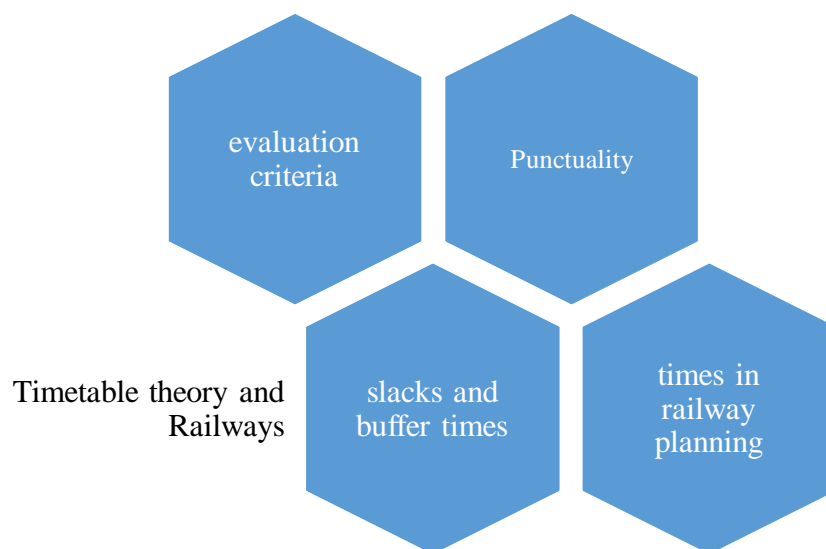


Figure 2-keywords used during the bibliography research

2.4.2 Tools used in bibliography research

The mentioned tools were:

- On line libraries
- On line universities' libraries have been used initially but they have given the same results as the following ways.
- BIBSYS (NTNU Transportation database): This tool was the one that has been used initially in order to detect which sources are accessible either in the form of hard copies or this of pdf format. After detecting the sources and found out which ones were not accessible, other libraries of other universities were used in order to obtain them.
- Science direct

Other internet sources:

- Google scholar: It was the main web-engine machine that was used to find the pdf forms of some documents after detecting them through the library's search tools.
- NSB, JBV, SMA: As NSB is the company which provided the database, an initial exploration of its site was taken for granted. Not a lot of information were given there. Contacts were much more helpful. The same applies to SMA ,the company that distributes VIRIATO
- Organizations: Transportation Research Board: Some articles were found here that they were quite relevant to the project.

Conference and journal websites

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- Railway gazette: a journal covering a wide range of topics related to railways.

Another important part of the methodology was, in order to ensure ROAR to double check the resources. The evaluation of the resources was made by using the following scale.

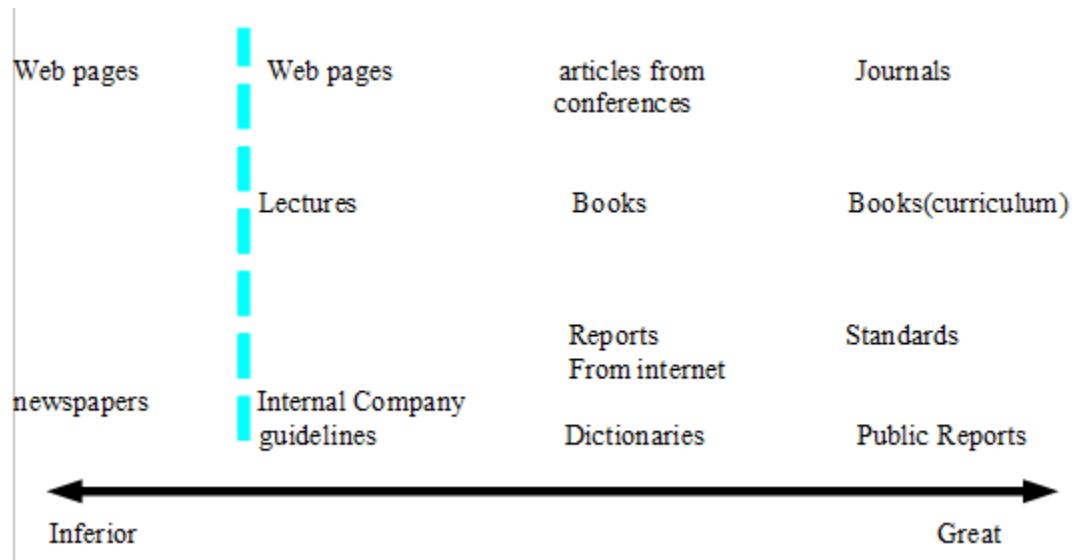


Figure 3 – Evaluation of resources according to N.Olsson

3. THEORETICAL FRAMEWORK

3.1 Structure of theory

The theoretical part of this report is focused on primarily on punctuality and routing to maximize the probability of avoiding delay and / or prevent them scattered. Timetable theory is being presented with a special focus on placing of buffer times. That is another important issue that is being discussed and completes the theoretical background of the current report.

The analysis is being presented as it appears in the following shape:

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Figure 4- Procedure followed in order to answer the first two research questions

3.2 Introduction-Railways and management: A system approach

Railways is a complex system V.A Profilidis (2006). A good synergy of all components is necessary and application of the system approach is required to achieve the desired level of functioning. Railway managers should focus on the real problem which is: 'What is the transport need to be satisfied and what can be the target aimed at?' All alternatives must be examined.

Each activity must be evaluated and examined in relation to its environment, internal or external. Adaptability is very important when it comes to railways. Constant changes take place and the system has to adjust itself in order to function to the new environment. During this procedure two kind of decisions can be taken:

- Decisions in a strategic level: Decisions relevant to the fundamental railway management, for example volume of passengers.

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- Decisions in a tactical level: new technologies, changes in every level. This kind of decisions consist of the following steps that are being depicted in the figure.

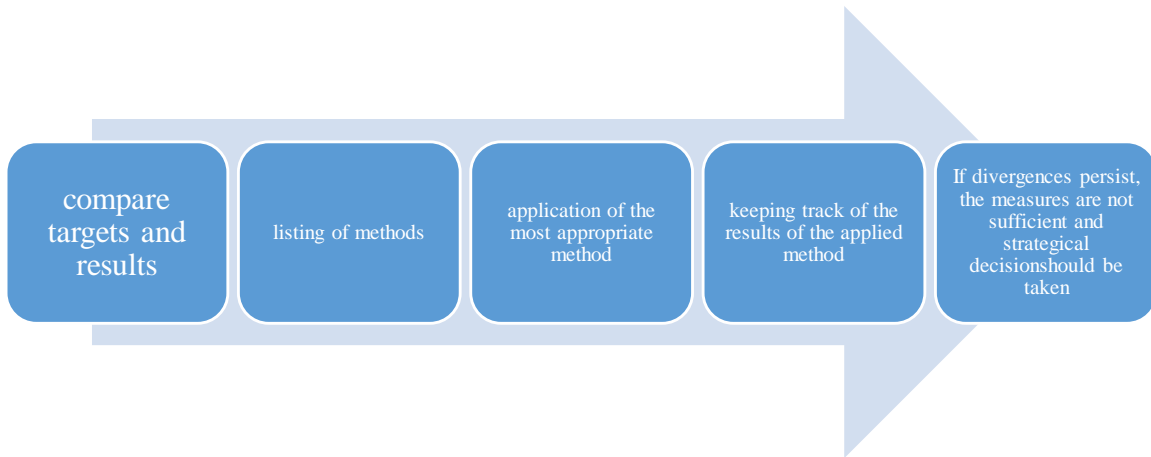


Figure 5- Steps in the tactical level of decision making according to V.A Profilidis(2006)

Problem Definition	What needs should be satisfied?
	What targets should be met?
	What are the evaluation criteria?
Analysis	Listing of the external constrains
	Production of alternative solutions
	Evaluation according to the priorities
Results	What is the best solution?
	Application of the solution
	Evaluation of the best solution

Figure 6- System approach in decision making V.A Profilidis(2006)

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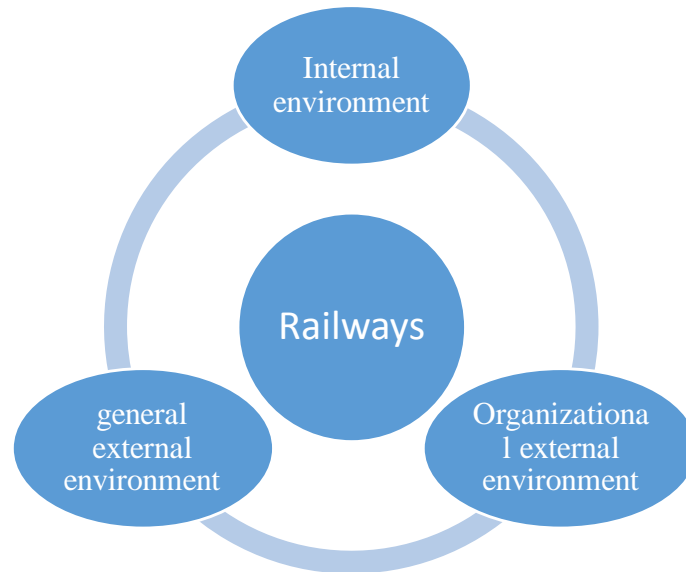


Figure 7- Railways and external and internal environment V.A Profilidis(2006)

As external environment we define the legislation, the culture, the economy, the politics, the physical resources. As organizational external environment we define the state, the banks, the clients, the competition and the technology. As internal we define the personnel, the financial resources and the organization.

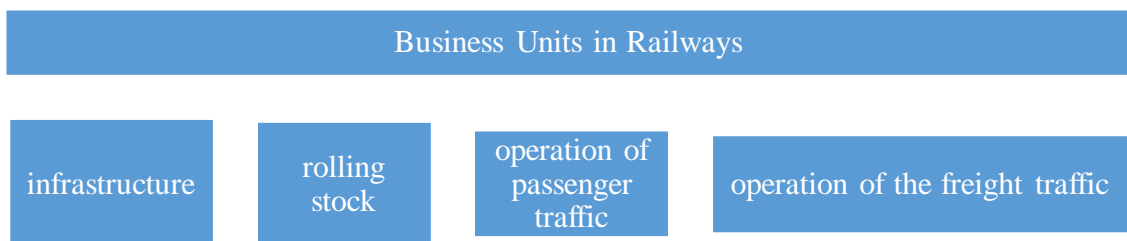


Figure 8 - Business units in the railway industry

The criteria for the quality control should be clear and not only based in the empirical assessment. Railways should adopt The ISO (International Standards Organization) or some similar certification. The efficiency can be improved by continuous quality control. In the past, many lines were constructed without any financial or any kind of consideration apart from the political one. The old practices are out of fashion. Before constructing a line clear answers to the following questions should be given:

Why this facility is needed?

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What it is going to change?

There is always the danger, without a sufficient plan, to end up with low traffic and high expenses.

Long term planning	medium term planning	yearly planning
<ul style="list-style-type: none">• 10-15 years• sector strategies	<ul style="list-style-type: none">• 3-5 years• funding, requirements, policies	<ul style="list-style-type: none">• 1 year• includes schedule planning

Figure 9-levels of planning V.A Profilidis(2006)

To make a successful planning procedure, someone has to understand the existing situation, forecast problems and evolutions and after that to define the actions to be taken, allocate the resources and identify the mechanisms of monitoring.

One plan can work in the short term (for example high season) but may be inefficient and expensive in the long term.

Planning should be characterized by flexibility, adaptability and efficiency.

The operators of the line give a request to the infrastructure management. This order is linked to the desired timetable. As operators can be numerous in one line, this order may meet problems in praxis. Cargo, long distant trains and local trains use the line at the same time some hours during the day. As a result they may be conflicts in which may the line is going to be utilised especially if it is as single track line.

The train timetabling problem (TTP) as defined by Fischetti (2009), consists of finding an effective train schedule on a given railway network. The schedule needs to satisfy some operational constraints given by capacities of the network and security measures. Moreover, it is required to exploit efficiently the resources of the railway infrastructure. In addition the produced timetable has to be robust against disturbances. To achieve this buffer times are being added.

3.3 The planning procedure

To understand the purpose of the planning procedure one has to be aware of its several functions. It coordinates train times for proper utilization of infrastructure while it ensures predictability in rail traffic and produces information to the travelers and forms the basis to infrastructure management and control (Pachl, 2008).

Three types of different formats exist when it comes to the produced results of planning.

- Tables for customers
- graphic tables
- tables for the personnel

The basic tool that most railways use to depict the planning is train diagrams. They depict a relation between time and distance in a time axis and in a station axis. Train movements are drawn as train paths, with train number written on them. 'A train path describes the usage of the infrastructure for a train movement on a track and in time. They can also be modeled as a sum of blocking times that have no dependency with the type of signaling used on the line and on the train (traction and braking characteristics). In Norway the line is being depicted in the Y-axis. Stations and stops are being depicted here. In other countries the depiction takes place in the X-axis (Pachl, 2008).

A timetable should at least be able to comply with safety regulations while at the same time being able to be theoretically executable (and that is it being without internal conflicts between trains) and practical and executable that is it facilitate punctual trains under normal conditions for rollback capability in the event of irregularities. In addition it has to comply with the market's demands. Unlike all the other means of transportation, railways have one degree of freedom .There are a number of factors that have to be taken into account while contacting the scheduling. The infrastructure and the laws regarding the personnel are some of them. The strategic planning is usually top-down. This type of planning is linked to a long term perspective and is linked to the

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strategic planning of the whole organization. On the other hand a more detailed planning requires a bottom-up approach. This kind of planning is about maintenance, materials and personnel but in a more short-term perspective. (Olsson, N. O. E. and M. Veiseth 2011).

3.3.1. Scheduling Methods

Scheduling can be implemented in two ways: manually and with IT –tools. To achieve the continuous improvement in the planning procedure an updating is required regularly. It is difficult to make a material plan without a timetable and it is difficult to schedule maintenance and running without both personnel and without plans (Olsson, N. O. E. and M. Veiseth, 2011).

For over than 150 years the scheduling was being implemented manually. It was the typical way of planning until the 1990s when computer-based methods were introduced (Pachl, 2008).

In manual scheduling the procedure that is being followed consists of the following steps:

- 1) The train path is being constructed as a polygon from station to station.

- 2) The times (running times which contain regular recovery times) are taken from tables. Special recovery times are being added. This step because of the complicated calculation includes the use of computers. Otherwise ride checks are being used.

- 3) The minimum line headways are being determined. A supplementary time is added to the running time. In Europe this is 1 min. A buffer time is also added which is 3 min.

The principles that are being used in this case is that the signaling type defines the dwell time. At a station with a signal at the exit of it the dwell time is attributed to the block section in approach while at a station with signaling in the entrance and the exit it can

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also attributed to the section beyond. While waiting at a signal the train cannot use this time for leaving and boarding passengers.

In computer based methods the principles are either the same as those used in manual scheduling or pre-defined matrices with line headways are being used.

The negative with this is that in some complicated occasions some conflicts may not be detected by the system. On the other hand, due to the significant reduction of effort in comparison to manual scheduling, this kind of planning is very successful. It requires experience to detect any flaws of the computer results.

The main principle behind scheduling with the use of computers is the calculation of blocking time stairways. Capacity research and scheduling are really similar when it comes to calculations. The only difference is that the detection of the conflicts is complicated. Where it happens buffer times have to be added. Most of the suppliers of IT tools of simulation have placed an add-on to make this possible and attractive to the market.

To use the computer based planning a very detailed version of the infrastructure is necessary. This has to contain the track layout and all the restrictions that come together with it including speed limits. Up to this point, the infrastructure manager is able to solve scheduling conflicts by moving the curves. In the near future multiple suggestions for solving these conflicts are going to be available based on the background theory probably as an add-on to the already existing soft-wares (Pachl, 2008).

For creating and testing the timetable, planners can use simulation tools, like RailSys and OpenTrack or Viriato by SMA.

According to Caimi (2009) timetable generation is usually done in two steps: the customer needs has to be met in the first step (train service intention since at this point it is not known whether this offer is feasible). A train service intention consists of train lines and frequencies specifying the customer-relevant information according to the same writer, such as stop stations, interconnection possibilities, arrival and departure platforms at stations and rolling stock. In a second step, the feasibility of this service

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intention is checked by generating a feasible schedule. If this is possible, a schedule is provided as proof of feasibility, otherwise both steps have to be repeated until a feasible service intention is found.

Caimi (2009) also points out the importance of a detailed timetable procedure. The decomposition of the whole network into condensation zones and compensation zones is being proposed not only from him but from several other researchers such as Pacht (2008) and Anne Christine Torp Handstanger (2009).

Infrastructure data and the basics of planning procedure have to be clarified before explain the above procedure.

3.3.2. Infrastructure data

An accurate infrastructure model is the fundamental basis for the planning process. According to Pacht (2008), the modelling of railway infrastructure is the basis for all the components of the planning procedure.

Infrastructure data can be created manually or electronically and has to be checked according to its quality, maintenance and its intellectual property.

Data quality is a very important issue according to Pacht (2008). Using incorrect or inconsistent information may cause serious problems in the planning process in the long term.

Equally important is the maintenance of the computer based infrastructure models. All alterations of the infrastructure have to be integrated into the model.

Last but not least, intellectual property of the raw data and the developed computer based infrastructure models. According to Pacht (2008) questions like “Who has legal access to the raw data and to the computer based infrastructure models?” and “Is it possible to transfer either raw data or modelled infrastructure to third parties?” must be answered.

3.4. Basics for scheduling

3.4.1. Clock-face Timetables

A periodic or fixed (regular) interval or clock-face timetable has the following principle: it contains even intervals between the trains. This is widely used in Europe for commercial reasons.

On a single line in this case the running time from one meeting point to another is the half of the fixed scheduled meeting point. The constraint in this case is if two stations have a close distance, the running or dwell time has to be extended to this amount. Another major constrain is the number of the meeting points. The number of train sets is calculated by a simply dividing the cycle time to the fixed interval that is scheduled between the trains. There are three strategies using in scheduling in the case of clock-face schedules: 1) non symmetrical clock-face timetables, symmetrical and integrated ones (Pachl, 2008).

Trains from opposite directions meet twice into the time interval that has been fixed. As a consequence the timetable is always symmetrical from the one direction. If all the routes have the same symmetry time this is called a symmetric timetable.

3.4.2. Cyclic timetables

In many European countries, passenger trains are operated according to a cyclic or a periodic timetable. This means that on each line trains run every 30, 60 or 120 minutes. Furthermore, if the passenger trains are operated according to a cyclic timetable, then the time slots for freight trains are often cyclic as well. However; not all planned time slots for freight trains may be actually used in the operations.

An advantage of a cyclic timetable is that passengers can easily keep departure times in mind.

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Furthermore, it is relatively easy to set up a large number of transfer possibilities for passengers. However, a drawback is that a cyclic timetable cannot easily offer a large number of direct connections, since a cyclic timetable is not flexible in itself. Another drawback is the potential inefficiency of a completely cyclic timetable; trains may have to be operated even at times with only a small number of passengers. Therefore, in practice there are usually exceptions to the completely cyclic timetable. For example, there may be some additional trains during rush hours, and frequencies may be reduced during late evening hours.

Some European countries do not have any cyclic or regular elements in their timetables.

3.4.3. Train separation

A very important aspect of train scheduling is train separation. There are certain rules that have to be followed in order to secure the safety. Two vehicles can follow each other in a minimum distance which is equal to the difference of their braking distances plus a safety distance. The separation by sight is only applicable in low velocities. The main principles to be followed for safe train separation are the following ones:

- The section ahead must be clear.
- The overlap behind the next signal must be clear.
- Stop signals must ensure that the train ahead is going to be protected from the following train and opposing movements.

What is really important is to examine the way movement is being transmitted from track to train and how the line behind the train is released (Pachl, 2008).

3.4.4. Capacity

The capacity in railway infrastructure is defined as the total number of possible paths in a specific time window, considering the actual path mix or known developments respectively and the infrastructure management's own assumptions, in nodes,

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individual lines or part of the network and with market-oriented quality. (UIC Fiche 405 OR, 2004)

Practically it defines the maximum number of trains which may run on a railway section part in a certain time period, with a certain level of service. It is dependent on technical parameters. Those can be the geometry of the infrastructure, the speed limits, the type of the signaling system and prioritization of the train traffic.

From timetabling point of view capacity has certain requirements that are obvious in the figure. (UIC Fiche 405 OR, 2004)

Timetable planning
requested number of train paths
requested mix of traffic and speed
existing conditions of infrastructure
time supplements for expected disruptions
time supplements for maintenance
connecting services in stations
requests out of regular interval timetables (system times, train stops, ...)

Figure 10-Capacity from the timetable planning point of view (UIC Fiche 405 OR, 2004)

The dynamic relationship between the main parameters that define capacity is depicted in the “Capacity Balance” (UIC Fiche 405 OR, 2004).

These parameters are the number of trains, the average speed, heterogeneity and stability.

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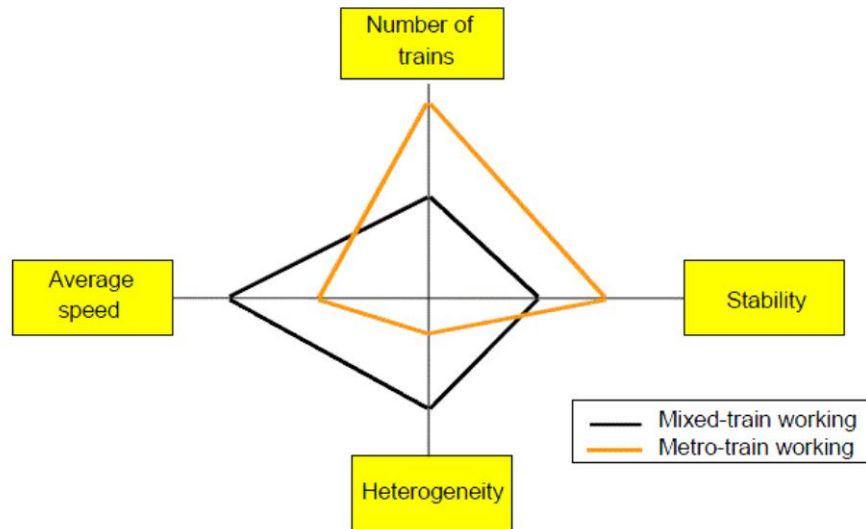


Figure 11-Capacity balance (UIC Fiche 405 OR, 2004)

The important side-conclusions that can be excluded from this diagram are:

The level of service lowers as the number of trains increases when the average speed increases, the breaking distance increases also, causing a reduction in capacity.

From reliability and timetable's stability point of view, recovery times must be taken into account as well as buffer times. Consequently, this causes a reduction to capacity of the network.

When different types of train use the network heterogeneity increases unlike practical capacity that decreases.

The theoretical capacity of a line can be calculated by the following formula:

$$K=T/t \text{ (1)}$$

where:

K (number of sets) is the maximum capacity in the time period T (min) and the frequency.

The theoretical maximum capacity refers to the capacity of trains of the same performance when they take full advantage of their abilities.

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While the theoretical capacity is the one when the actual planning is taking into account and the practical capacity is the one that is practically achieved.

3.5. Times in scheduling

3.5.1. Blocking time and interlockings

Interlocking is the way the signals are connected electrically in a way that movements are being contacted in a safe way. The types of interlocking are 1) interlocking without consecutive signals or 2) interlocking with consecutive signals.

Lines consist of block sections to ensure safety. A train is not permitted to enter the block section ahead if this is occupied by another train. This time of occupation is called block time (Pachl, 2008).

3.5.2. Scheduled Running Time

The scheduled running time includes the following sub-times: the pure running time between the stops that are in the schedule, the dwell time in the stops, the recovery time and the scheduled waiting time.

The pure recovery time is the minimum possible running time between two stops while the recovery time can be divided to the regular recovery time and to the special recovery time. The first one is 3-7 % in Europe. There are some occasions when the recovering time is included to the dwell time and not to the running time (Pachl, 2008).

To increase the robustness of a timetable as it has been described previously, certain slack times are generally added to the minimum process time of every train and the minimum headway time between every pair of trains (Jianxin Yuan and Ingo A. Hansen 2008). The slack times here are named as running time supplement and buffer time, respectively. The time supplement enables a train to compensate for a small delay, while the buffer time prevents a small delay from being scattered to other trains.

3.5.3. Headways and buffer times

To create a sufficient headway is a crucial element of successful planning. The headways can either be assigned to the stations or to the sections in between (Pachl, 2008).

There are four types of headways (Potthoff, 1980). The cases are the following ones: two trains depart in the same line (depart-depart headway), two trains arrive in the same line (arrive-arrive headway), two opposing trains with the one arriving and the other one departing in the same line (arrive-depart headway) and two opposing trains with the one departing and the other one arriving in the same line (depart-arrive headway).

As Hansen (2008) points out, the running time supplements and buffer times inserted in a timetable assure some degree of robustness of the timetable but on the other hand larger time supplements and buffer times result in longer planned travel times for passengers, higher operating cost for train operators and less efficient capacity utilization for infrastructure managers. A detailed allocation of these slack times is a challenging issue in timetabling process. In practice, it is common to design first a number of feasible timetables and then evaluate the reliability.

The buffer time is the smallest slot between the blocking time stairways of two trains and it depends on several factors. When the second train has a priority, the buffer time is larger (Pachl, 2008).

Planning sufficient headway between train paths is an essential requirement of scheduling. There are two main logics when it comes to assigning headways. They can either be assigned to the stations that limit a section or to the station between two stations (Pachl, 2008).

Assigning headways to stations is the more traditional principle that is very common in scheduling.

The point where time applies is usually not a signal but the station line of the train diagram. This principle leads to different headways at both sides of a section. If the

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minimum headways for the different train combinations are put into a sheet, each section has two sheets for the two sections limiting that section. If headways are assigned to a section between two stations there are no different types of headways. The headway is always the difference between the times two successive trains of either direction enter the section.

However, the average headway at one station equals the average headway at the station at the other end of the section (Pachl, 2008).

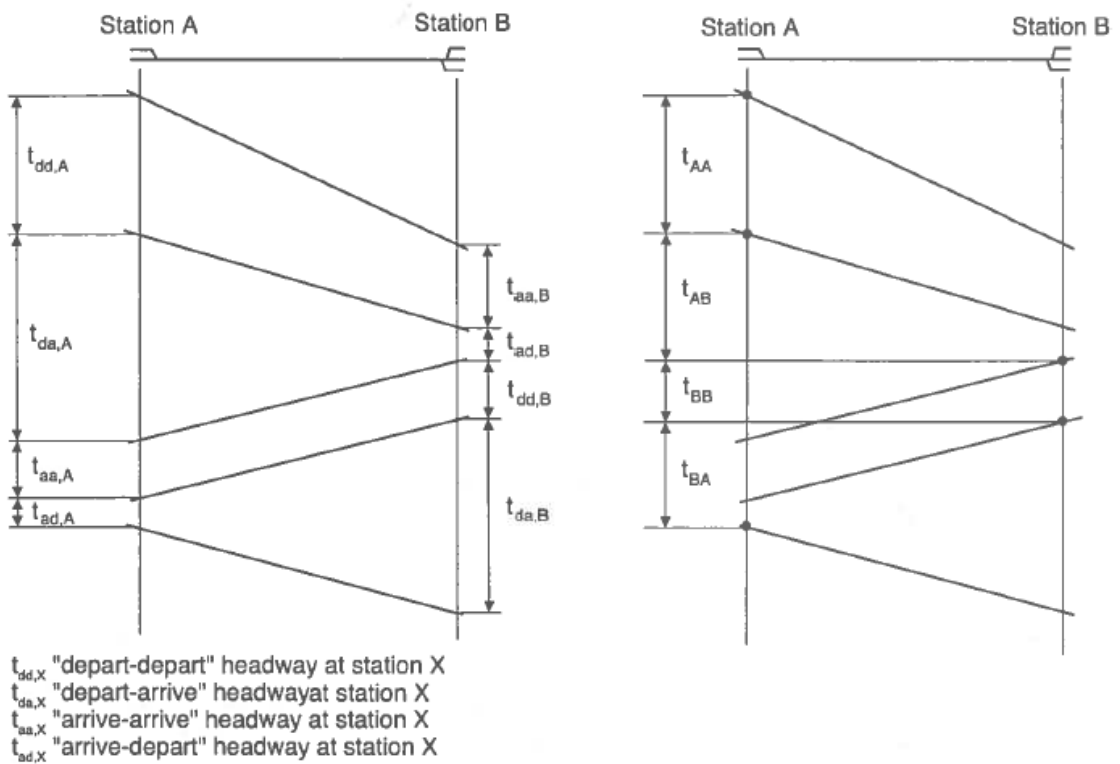


Figure 12- Depiction of headways according to Pachl (2008)

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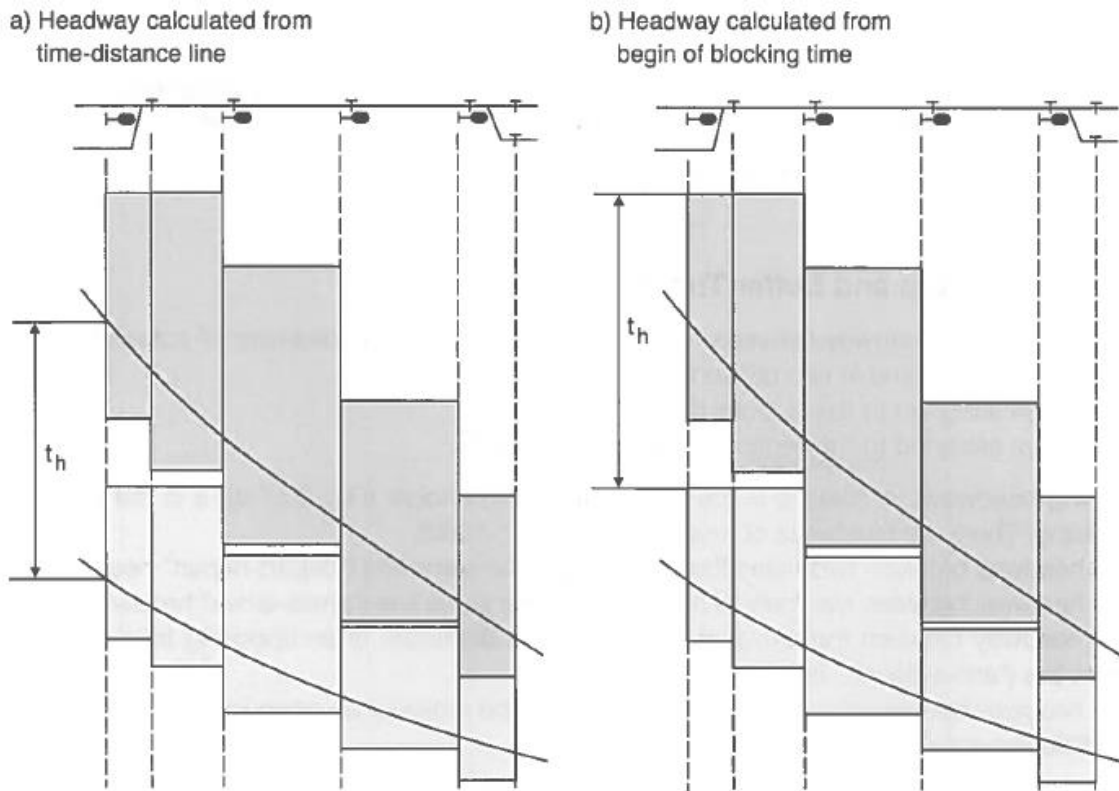


Figure 13-calculation of headways according to Pachl (2008)

According to Pachl (2008), the last years this principle has become quite popular for analysis of line capacity. The advantage is that the minimum headways for all train combinations of a section can be described by just one sheet. This advantage is also interesting for scheduling systems that use minimum headway sheets as input data. This allows calculation of the headways in two different ways. The headway can either be calculated from the times the trains pass a specified point when entering the section or from the beginning of the blocking time of the first block section between the two stations. The second principle is very valuable for capacity research. For scheduling, calculation of the headways from the passage at specified points is more appropriate.

The scheduled headway between two trains must consist of the minimum line headway plus the required buffer time to compensate small delays. The buffer time is the smallest slot between the blocking time stairways of two trains. Many railways refer to the buffer time as recovery margin which is not the same with the recovery time.

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The recovery time enables a train to make up a small delay while the buffer time prevents a small delay from being transmitted to other trains. On the other hand, the recovery time extends the running time of a train while the buffer times reduce the number of trains that may be scheduled (Pachl 2008).

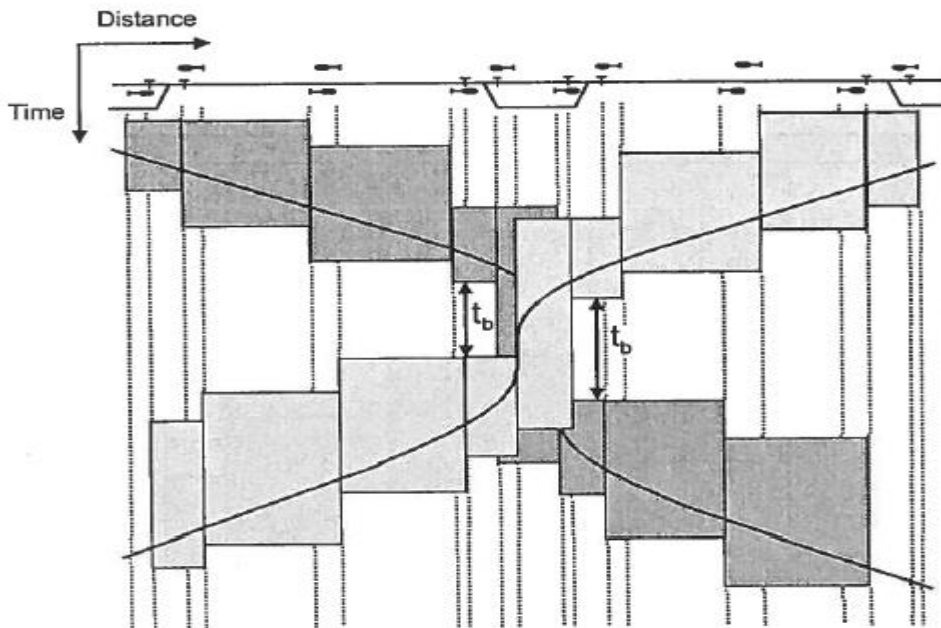


Figure 14-Buffer times according to Pachl (2008)

The amount of buffer times depends on the required level of the wanted service. Usually the buffer time is determined depending on the kind of the line headway. Most railways use the following basic rules (Pachl, 2008):

- large buffer times when the second train has a higher priority than the first train
- small buffer time when the first train has a higher priority than the second train
- Average buffer time when both trains have the same priority.

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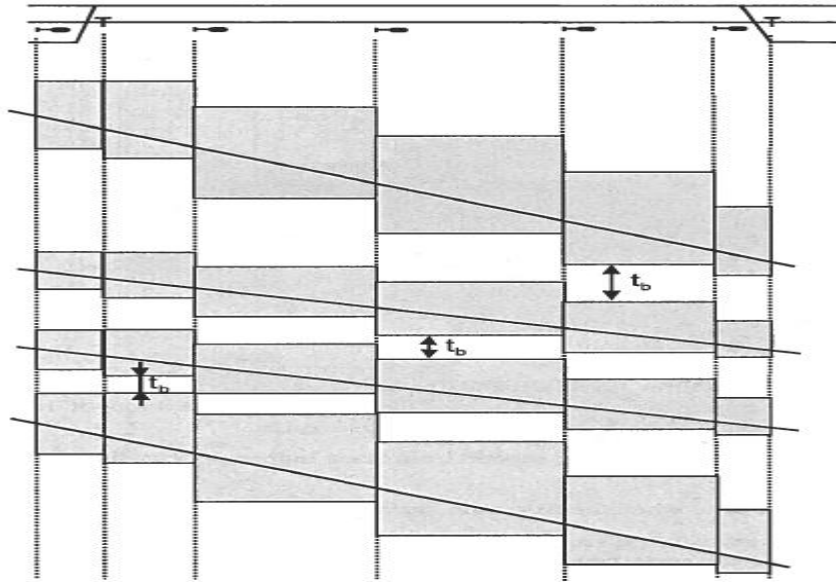


Figure 15-Headways

Today, most railways still allocate buffer time in a deterministic way i.e. to have fixed minimum buffer times to be added to the different kinds of train combinations. Current research activities try to develop procedures for a stochastic modelling of buffer time allocations (Hansen 2004).

Swiss railways already use the principle that in terminal areas with a very high density of traffic, train paths may be planned without buffer if sufficient recovery time for making up delay is added to the running time between terminals (Herrmann 2006).

An exact allocation of a buffer time to each train path in accordance with the rules above only makes sense in an accurately scheduled operation where the train sequence seldom changes (Pachl, 2008). According to the same writer, on lines where train often run out of their schedules or with a lot of extra trains, the traffic may be scheduled without buffer times for every single train. This is especially typical for freight trains and for connecting lines inside of large terminal areas. On such lines, the buffer that is required for a good quality of operation could be better provided by the rule that a certain number of trains must be followed by a clear buffer path.

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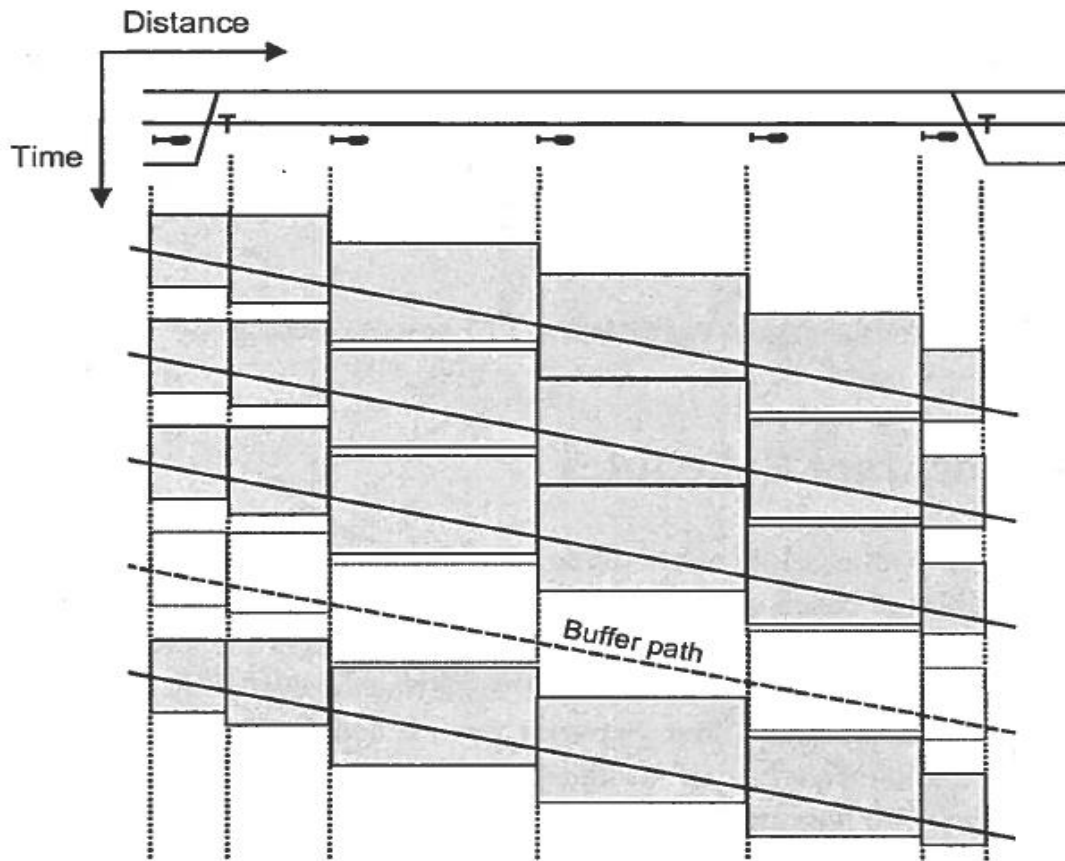


Figure 16-Buffer paths

Beneath the train path buffer times, buffer times are also required at connecting stations where scheduled transfer connections between trains exist and where crew or equipment changes from one train to another. To avoid the transmission of delay at such points, a buffer time must be added to the time that is required for the transfer.

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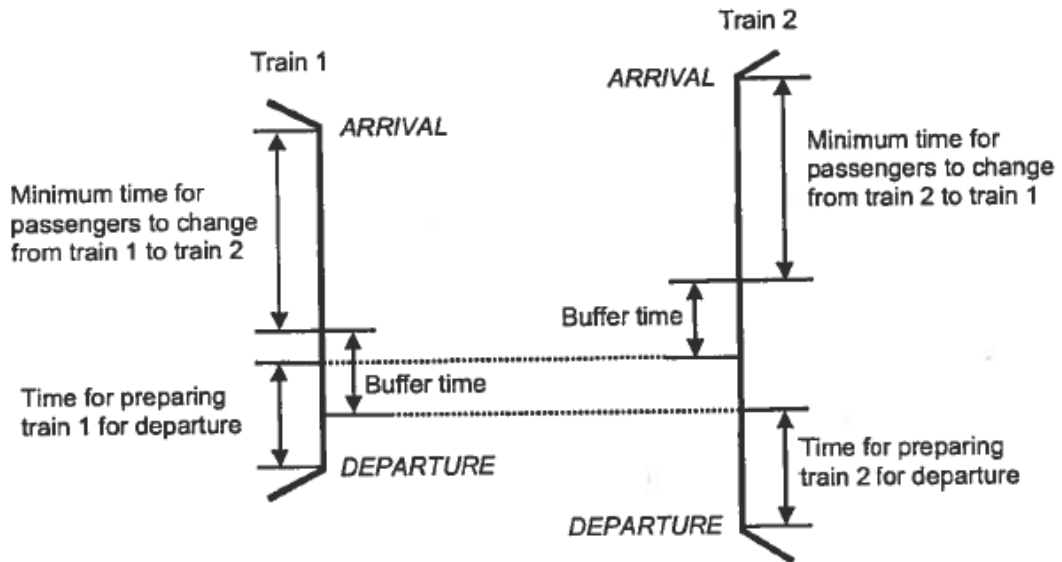


Figure 17-Minimum times for passengers according to Pachl (2008)

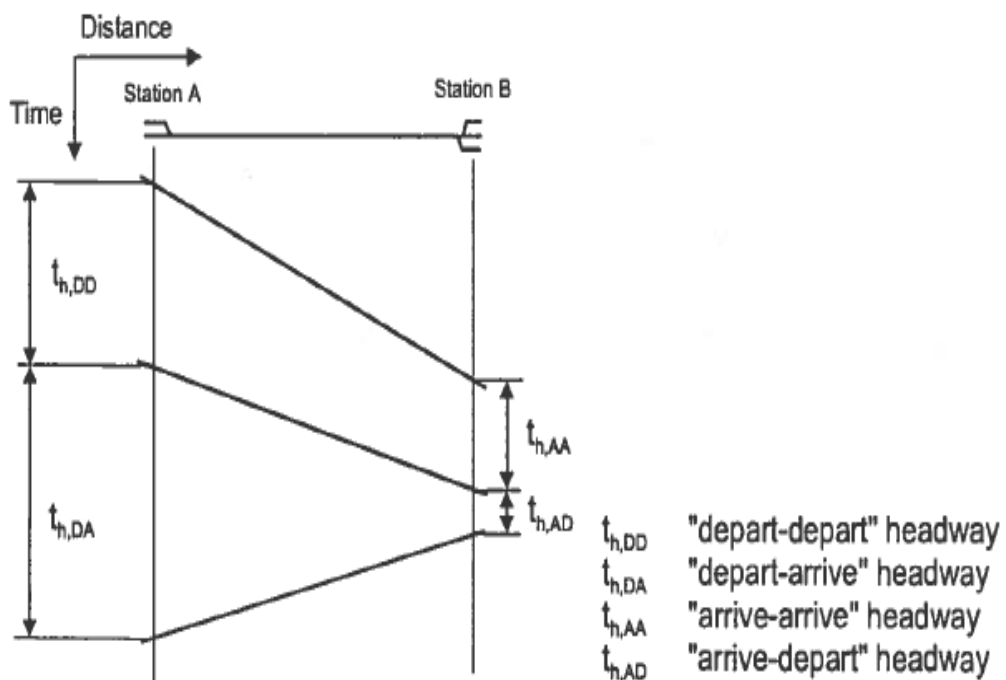


Figure 18- the four different kinds of headways according to Pachl (2008)

Anne Christine Torp Handstanger (2009) uses in her Phd thesis a mathematical analytical model that makes use of exponentially distributed buffer times between the trains of higher priority in the schedule. In the same report it is being claimed there is stochastic demand for train paths. Headways (referred here as spacing times) of different sizes

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exist. There also might be spaces long enough for irregular freight traffic to be included into the timetable. In less traffic dense periods of the day, this might be a possible solution to fill up the schedule with ad-hoc freight trains. Maximizing the freight capacity by taking advantage of the possible paths is the purpose of the referred study. This possibility of integrating freight trains into the schedule depends on the number of trains in total and the infrastructure characteristics, but also how far the schedule chosen is from stochastic operation. A cyclic timetable operation as has been described previously is not as flexible as timetables with stochastic operation. The constant spacing time between the trains in a cyclic timetable, and with high train density this will make it difficult to fit in slow and long freight trains.

For a stochastic modelling of the transfer, Goverde (2005) gives a detailed procedure while Jianxin Yuan and Ingo A. Hansen (2008) point out several stochastic optimization timetable models that explicitly incorporate reliability and punctuality of scheduled trains. These include Carey (1994) and Vromans (2005) and are being used to optimize the allocation of time supplements.

According to Jianxin Yuan and Ingo A. Hansen (2008), the total size and particular allocation of the buffer times between consecutive trains at railway bottlenecks have rarely been studied. It is also pointed out that those optimization methods, do not take into account the acceleration and deceleration of trains on delays and punctuality in case of conflicts.

Yuan (2006) developed a probabilistic a delay propagation model which enables an accurate estimation of delay propagation and punctuality of trains. In their paper Jianxin Yuan and Ingo A. Hansen (2008) use a model for optimally allocating the buffer times between consecutive trains at a railway junction in an analytical manner.

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The amount of the buffer time according to Pacht (2008) is 1 -3 minutes. NSB uses in praxis minimum 2 minutes. The constraints that a signaling system sets to the planning procedure affect also headways and buffer times according to Jianxin Yuan and Ingo A. Hansen (2008).

Buffer times between successive trains at a railway bottleneck are determined by taking into account both the efficient use of infrastructure capacity and robustness of the proposed schedule. Yuan and Hansen analyzed the effect of frequency of trains passing through a critical bottleneck in the area of the Dutch railway station. According to Jianxin Yuan and Ingo A. Hansen (2008) the knock-on delays of trains on a railway bottleneck depend on the primary delays of trains. The same writers point out that ‘if the primary delay of a train is expected to be larger, a longer buffer is allocated between. However, increasing the buffer time between a pair of trains reducing buffer times elsewhere in a periodic schedule. Therefore, the buffer times between each pair of trains is scheduled to be allocated appropriately’. The type of affected trains is very important parameter also for the procedure.

Jianxin Yuan and Ingo A. Hansen (2008) consider a number of trains passing a rail junction as it is being depicted in the following figure, in period T.



Figure 19- model for the mathematical approach of Jianxin Yuan and Ingo A. Hansen (2008)

Jianxin Yuan and Ingo A. Hansen suggest a mathematical approach of the optimal allocation of buffer times which is:

$$\text{Minimize } c = \sum_{i=1}^n w_i \bar{L}_i(b_i)$$

$$\text{Subject to } \sum_{i=1}^n b_i = B$$

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Where:

W is a weight factor for train i b represents the scheduled buffer time of train from the preceding one in a timetable period T . L implies that the mean knock-on delay transmitted to train i is influenced mainly by the buffer time b .

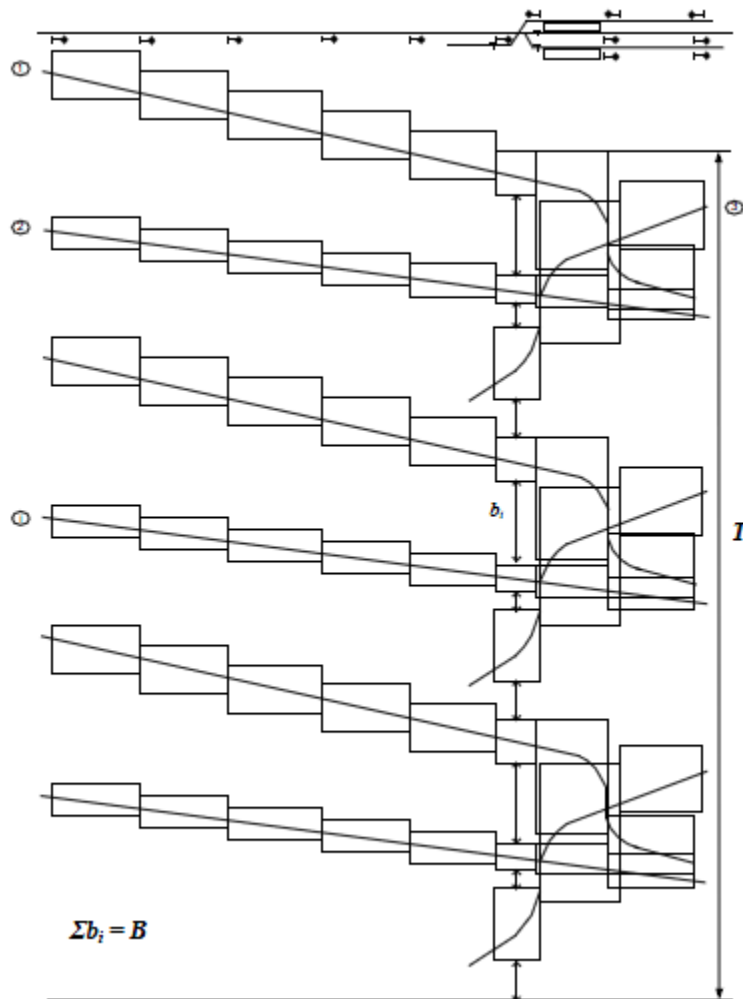


Figure 20- Allocation of the buffer times between each pair of succeeding trains according to Jianxin Yuan and Ingo A. Hansen (2008)

A railway scheduling model based on a decomposition of the railway network into condensation and compensation zones is being introduced by Traffic here is less dense in compensation zones which connect the condensation zones and slack time can be added to train runs in order to increase stability of the timetable. (Caimi, 2009). In this paper it is being also suggested a decomposition of the problem geographically into

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condensation and compensation zones. Different policies for generating train schedules are then applied to the two zones according to their properties. Time reserves are removed from the condensation zones and moved to the compensation zones, where more capacity is available.

Kroon, Marti, Helmrich, Vromans, and Dekker (2008), point out a stochastic optimization model that allocates the time supplements and the buffer times in a given timetable to achieve maximum robustness. The average delay in this procedure is minimized.

Fischetti (2009) proposes an allocation of buffer time that is just proportional to the train duration.

3.6. Evaluation criteria of timetabling

3.6.1. Stability and Robustness in timetable planning

Stability is the capacity of the system to make restitution for delays and, in general disturbances in the system and to go back to the initial condition. (Hansen and Pachel, 2008).

One objective is to create a timetable that is as robust as possible. That means that the timetable can deal as well as possible with relatively small disturbances in the real-time operations. Robustness is the ability of the system to battle the parameter and the operational alterations (Hansen and Pachel, 2008).

Thus, robustness of a timetable may lead to a high punctuality in the real-time operations. For references on robustness, see Jen (2004) and Sastry and Bodson (1989).

To assure a high quality of a timetable, the robustness needs to be evaluated. Carey (1999) introduces a number of ex ante heuristic reliability measures based on headway times and knock-on delays. To evaluate the robustness of timetables accurately, the

Timetable analysis for local trains. Case study of Trønderbanen

knock-on delays of trains need to be estimated on a real basis according to Jianxin Yuan and Ingo A. Hansen (2008).

A recommended approach on finding robustness (Fischetti, 2008) comprises of two steps (1) finding an optimum timetable and (2) finding a robust schedule by the assumption of fixed train orders in passing the block sections. Another approach (Babar Khan and Zhou, 2010) in a double-track comprises of the following stages. Departure/arrival times from/to stations and deviation from the initial plan is being calculated. The sim in this particular occasion is have smaller total travel times and deviations with the assumption of high-speed trains' over the medium-speed ones. An approach that involves a stochastic model to assign time supplements to block section travelling times, considering only one train was issued by (Fischetti and Monaci, 2009) that they evolved the model to periodic train schedule.

From the managerial point of view (Vansteenwegen and Oudheusden, 2006), (D'Angelo, 2009) and (Odijk, 2006) bring out a new definition of timetable robustness. The main concept is based on the fact that for every timetable there is one and only sequence. Thus, a timetable class contains many different timetables, the timetables are called robust. This type of timetable classes has the property that slight disturbances to the input data can be dealt with by modifying the timetable within its class. A new probability distribution has been defined that gives higher probability to robust timetable classes. (Shafia, 2010) made an application of this approach to the train timetabling problem and (Shafia, 2011) to the job shop scheduling problem.

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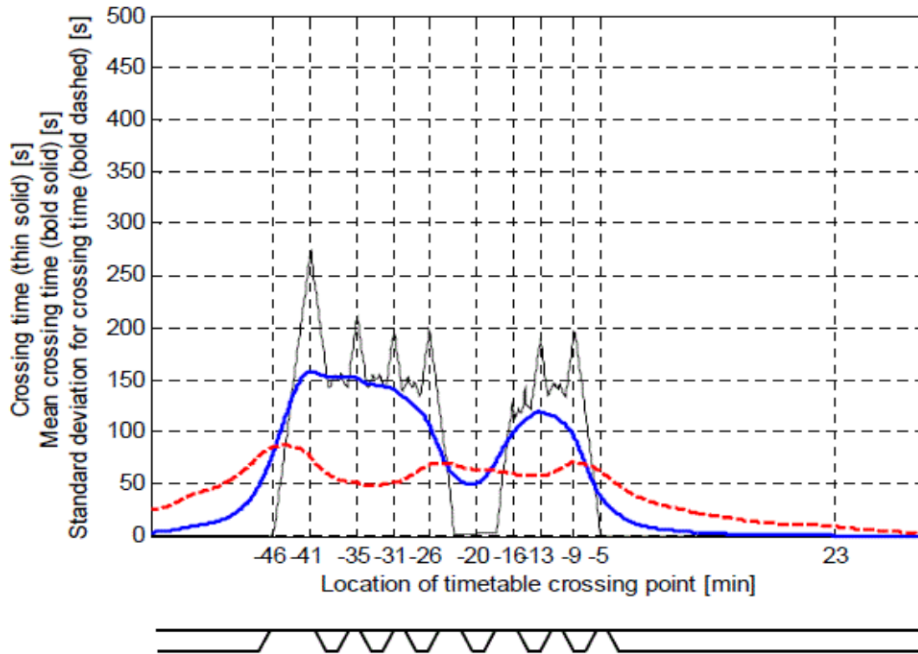


Figure 21-Location of crossings in relation to crossing time (Lindfeldt,2010)

Lindfeldt (2010) introduced a diagram that gives the crossing time and the standard deviation from it in dependence on the point that the crossings are being made. Crossings at the beginning of a double line give larger deviations from planned times and as a result affect the stability of the produced timetable.

3.6.2. Reliability in timetables

Reliability in timetabling procedure is dependent on several factors; the most crucial one is the quality of the timetable itself. This level of quality can be measured by defining the maximum values either for the total delay or those of the waiting times. Assessing reliability is relevant to assessing stability and robustness (Hansen and Pachl, 2008). Railway system is prone to stochastic effects on operation (e.g. running and dwell times), which reduce the theoretical capacity. To balance it, recovery times and buffer times may be added to reduce stochastic effects on traffic: the higher these times are, the lower the capacity and the higher the reliability will be. A comparison between maximum capacity and reliability is necessary to obtain a trade-off value for the user

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(who prefers maximum reliability with frequent services) and the railway infrastructure manager (who is interested in maximizing the number of available train paths). To measure reliability someone can measure average delay of the trains like in the following figure shows (Abril, 2008).

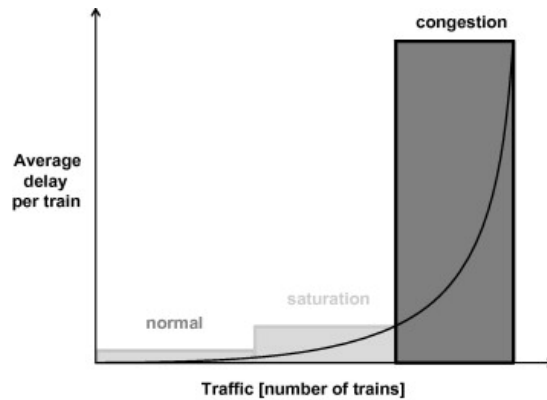


Figure 22- measurement of reliability (Abril,2008).

Reliability and punctuality are linked when it comes to the planning procedure. Train delays affect those two factors.

3.6.3. Punctuality

Punctuality describes the accuracy and reliability of trains (Salkonen, Paavilainen, 2010). Measurements of railway traffic quality has been taken by the international railway organizations UIC (International Union of Railways), CER (Community of European Railway and Infrastructure Companies) and CIT (International Rail Transport Committee).

Quality and punctuality has only been in use for the last 20 years. This is not a long period. Punctuality measurements are needed for several purposes. There are three main applications for information about punctuality (Skagerstad and Carrie, 2004).

- 1 to provide information
- 2 to control and contribute to decision making
- 3 to improve the current situation through project planning

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The production of punctuality data is based on regulation or law and calculation of punctuality is a pretty raw and rough process (Carey, 1999). Several methods are used for punctuality, and from these methods heuristic and ad hoc methods are the most general. An example of a heuristic method would be to determine the percentage value of trains arriving on track in relation to a given threshold. Simulation methods are time-consuming, while analytical methods are suitable only for simple systems. (Carey, 1999 Paavilainen, Salkonen, 2010) Measurements of punctuality are taken from perceived information, the cases in which measurements can be performed afterwards.

It is possible to measure punctuality in all intersections that have scheduled arrival or departure times, not just at your destination. (Olsson, 2004 Haugland). It can also be calculated (Salkonen, Paavilainen, 2010), as a percentage of passengers arriving on time at the station as the sum of the delay minutes experienced by passengers that passenger satisfaction regarding punctuality or the handling of delays .

Punctuality and reliability have a common goal (Rietveld, 2001) is the probability P that the train arrives x minutes late. In bibliography several other can be found, where punctuality is defined as 'the likelihood of an early departure', 'The mean difference between the expected arrival time and scheduled arrival time', ' average delay of an arrival given that one arrives late', 'average delay of an arrival given that one arrives more than x minutes late'.

Punctuality is a critical measure of the quality of the planned rail delivery. To retain existing and attract more passengers, the scheduled train services be reliable. To achieve this, it is necessary not only to strengthen the daily management of power trains but also to improve the robustness of the scheduled timetable. To increase the robustness of a timetable, slack times must be placed. The times are slack named running time supplements and buffer time, respectively. Currently supplement enables the train to compensate for the small delay, the buffer thus prevents a small delay to be added to the second train. The running time supplements and buffer times in the timetable set assure a certain degree of robustness in the schedule. But the more time supplements and buffer times resulting in a shorter planned journey for passengers, the higher operating costs for rail operators and less efficient utilization of infrastructure managers.

3.6.4. Successful planning procedure

Some decisions have to be taken in order to begin the procedure of scheduling. Setting priorities and goals is essential for a successful result. An important decision is the frequency (in this report taken to be an hourly one). In order to simplify marketing and information given to the customers the basic pattern should operate from start to close of service. A half-hour service is oriented to serve urban areas.

The interface between the two types of line has to be taken into account. The planned double line gives the freedom to the system to increase capacity. This automatically will have an effect to the single part of the line. Increasing capacity in the double line, and with the assumption that the circle of the train (from one point A to another point B and afterwards back to point A), will increase the number of crossings in the single line. As a result priorities have to be set in the planning procedure.

Appropriate recovery gaps between the times during scheduling are important. A very fancy schedule that it is not feasible in praxis can harm the image of the operator. Thus, punctuality is essential. The passenger when he is about to use a transportation mean with a fixed travelling time, he is willing to spend this time. Any positive deviation from the plan is regarded as an unwanted one.

In addition, a total transportation plan that combines other means also is essential to optimize the procedure.

To evaluate results and proceed to decision making the following factors can be evaluated. Those include income, costs, description of output (frequency, materials and manpower, quality of rolling stock, service etc). A description of the expected market impacts linked to the overall goals and plans and the risk profile and uncertainty is essential also.

The basic elements are:

- The most important nodes of the network have to be known

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- Timetables should be consistent throughout the day and every day.
- Investment should be directed at bringing key

What has to be kept in mind is that perfection cannot be achieved in a real railway network. The task of infrastructure managements and engineers is to improve on the best compromise, often under multiple constraints.

According to Pahl and Hansen (2008) in order to make a good planning the following success factors should be met:

- good overview of all aspects of infrastructure (tracks, stations etc)
- detailed overview of the design and function of signaling systems
- overview of the capacity of the network based on modern methods
- good runtime calculations
- established standards for energy-efficient power trains
- active use of robustness with special focus on crossings and bottlenecks
- use of unlike types of simulation
- monitoring and analysis of punctuality information and other traffic information

3.7. The planning problems

Planning problems in a railway system are solved traditionally based on the experience and the craftsmanship of the railway planners (V.A Profilidis2006). Several evaluation models, such as analytical models and simulation models, have been developed for supporting the solution process. However, these models cannot generate solutions themselves: they can only evaluate solutions that were generated in another way.

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When increasing the density of the timetable, scheduling trains becomes more and more difficult as the chosen schedule not only has to meet safety restrictions, but also must minimize propagation of delays (Caimi, 2009).

3.7.1. The problem: Train delays

The reliability of urban passenger trains is a critical performance measure for passenger satisfaction and ultimately market share. A delay to one train in a peak period can have a severe effect on the schedule adherence of other trains. Higgins and Kozan (1998).

A delay of a train in a peak period can have a serious effect on the schedule for other tog. Higgins and Kozan (1998) presents an analytical based model to quantify the expected positive delay for passenger trains and track in an urban rail network. The model is especially direct delay to trains, knock-on delays to other trains, and delays at scheduled connections. A solution of the resulting system of equations is found using an iterative refinement algorithm.

In the same paper apart from placing buffer times in order to avoid delays the following strategies are being proposed:

1. Building of new track or sidings, which reduces the large delay due to bottlenecks;
2. Altering track alignments to increase train speeds;
3. A more advanced train control system to decrease minimum headway and thus increase track capacity
4. New systems to allow more efficient or safer entry and exit of passengers from trains.

3.7.2. The problem: Routing trains

Routing trains through railway stations is an integral part of railway timetabling, particularly in dense systems. Without this, there is no effective timetable!(Pachl, 2008)

Railway stations are the main source of delays in dense railway systems. Therefore, focusing on the

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robust routing of trains there is highly relevant in terms of punctuality. Robustness here again means insensitivity of the railway system to small disturbances in the real-time operations.

Pachl point out Zwaneveld et al. (1996, 2001) and the model is based on the concept of conflict graphs. A similar approach is used by Billionet (2003).

In addition, Caimi (2005) present a heuristic algorithm for finding delay tolerant routings based on an iterative fixed point method while Carey and Carville (2003) 'describe a heuristic algorithm for modifying a draft timetable at a station that gives rise to a conflict-free routing' Pachl (2008). Carey and Crawford (2007) take this one step further. Analytic models based on queuing theory for minimising the scheduled waiting times are described by Wakob (1985) and Wendler (2007).

Carey and Crawford (2007) extend the algorithm to several stations along a railway corridor.

3.8. Summary – answer to the first two research questions.

The Chapter 2 was mainly focused on punctuality and routing to maximize the probability of avoiding delay and / or prevent them scattered. The following research questions have been answered:

Where the slack should be placed during the scheduling procedure in order to avoid delays and / or prevent them scattered?

The buffer time is the smallest slot between the blocking time stairways of two trains and it depends on several factors. When the second train has a priority, the buffer time is larger (Pachl, 2008). Planning sufficient headway between train paths is an essential requirement of scheduling. There are two main logics when it comes to assigning headways. They can either be assigned to the stations that limit a section or to the station between two stations (Pachl, 2008).

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Assigning headways to stations is the more traditional principle is very common in scheduling.

Today, most railways still allocate buffer time in a deterministic way i.e. to have fixed minimum buffer times to be added to the different kinds of train combinations. Current research activities try to develop procedures for a stochastic modelling of buffer time allocations (Hansen 2004).

Swiss railways already use the principle that in terminal areas with a very high density of traffic, train paths may be planned without buffer if sufficient recovery time for making up delay is added to the running time between terminals (Herrmann 2006).

An exact allocation of a buffer time to each train path in accordance with the rules above only makes sense in an accurately scheduled operation where the train sequence seldom changes (Pachl,2008).

Anne Christine Torp Handstanger (2009) uses in her Phd thesis a mathematical analytical model that makes use of exponentially distributed buffer times between the trains of higher priority in the schedule.

For a stochastic modelling of the transfer Goverde 2005 gives a detailed procedure while Jianxin Yuan and Ingo A. Hansen (2008) point out several stochastic optimization timetable models that explicitly incorporate reliability and punctuality of scheduled trains. These include Carey (1994) and Vromans (2005) and are being used to optimize the allocation of time supplements.

In their paper Jianxin Yuan and Ingo A. Hansen (2008) use a model for optimally allocating the buffer times between consecutive trains at a railway junction in an analytical manner.(Caimi, 2009). In this paper it is being also suggested a decomposition of the problem geographically into condensation and compensation zones. Different policies for generating train schedules are then applied to the two zones according to

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their properties. Time reserves are removed from the condensation zones and moved to the compensation zones, where more capacity is available.

Kroon, Marti, Helmrich, Vromans, and Dekker (2008), point out a stochastic optimization model that allocates the time supplements and the buffer times in a given timetable to achieve maximum robustness.

How the routing should be planned in order to maximize the probability of avoiding delays?

Routing trains through railway stations is an integral part of railway timetabling, particularly in dense systems. Without this, there is no effective timetable!(Pachl, 2008)

Railway stations are the main source of delays in dense railway systems. Therefore, focusing on the robust routing of trains there is highly relevant in terms of punctuality. Robustness here again means insensitivity of the railway system to small disturbances in the real-time operations.

Pachl underlines Zwaneveld et al. (1996, 2001) and the model is based on the concept of conflict graphs. A similar approach is used by Billionet (2003).

In addition, Caimi (2005) presents a heuristic algorithm for finding delay tolerant routings based on an iterative fixed point method while Carey and Carville (2003) 'describe a heuristic algorithm for modifying a draft timetable at a station that gives rise to a conflict-free routing' Pachl (2008). Carey and Crawford (2007) take this one step further. Analytic models based on queuing theory for minimising the scheduled waiting times are described by Wakob (1985) and Wendler (2007).

Carey and Crawford (2007) extend the algorithm to several stations along a railway corridor.

3.9 Summary-basis for the evaluation

Important aspects of timetabling procedure are:

- Robustness (has to be less than 1 so as for the primary delays to be less than the secondary ones)
- Reliability
- Stability
- Punctuality
- Feasibility
- Traffic composition (referred as heterogeneity in capacity chapter)
- Allocation of buffer times and headways
- Time and place of crossings (factor of robustness)
- Number of train sets (capacity factor)
- Total travelling time
- Average speed (capacity factor)

Most of the above factors are being used in order to make the evaluation in chapter 6.

4. CASE STUDY: TRØNDERBANEN

4.1 The history of the line

Nordlandsbanen, the line between Hell and Steinkjer was given to traffic in 1905. In 1962 the section that leads to Bodø became also a reality. Since then, the railway line between Trondheim and Stjørdal has been modernized, but by following the traditional first rail-path.

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Trønderbanen was NSB's project name on the coordination of passenger services on railway lines between Oppdal, Røros, Trondheim and Steinkjer. It occurred as a concept when rail services in the two counties of Trøndelag was reorganized in the 1990s.

The term Trønderbanen was created by Gunhild Myren from Sandvollan in Inderøy, when she won a naming contest in 1993. Trønder Railway was one of the truly successful rail initiatives in Norway, with departures at fixed times almost every hour throughout the day between Trondheim and Steinkjer. In 2003 brought about the path. 1.1 million passengers. From the 1st of January 2004 joined NSB using the name Trønderbanen of rail services north and south of Trondheim. The reason was that the business unit in Trondheim was dissolved and decisions were now taken in Oslo.

Trønderbanen uses the following lines:

Dovrebanen, Meråkerbanen, Nordlandsbanen, Rørosbanen and sidelines Stavne Railway



Figure 23-Trondheim-Steinkjer

Currently the line is single track but there is a plan to electrify it. Between Trondheim and Stjørdal the plan is to make a double track. With this way to capacity is going to be increased on the congested corridor. The timetabling will be made operationally complex by the link with the classic line. The objectives for electrifying the line include also economic and social benefits.

The examined line includes: Sjøberg to Trondheim S (single track) Trondheim S- Stjørdal (double track) and Stjørdal to Steinkjer (single track).

Timetable analysis for local trains. Case study of Trønderbanen

From 2008, the term "Trønderbanen" has been a NSB-term and represents the part between Storen – Steinkjer.

4.2 The current problematic situation of the line- the background for the case study

Eventhough Trønderbanen is very important for both Trondheim and the regions that are linked to it through the specific rail-path, the infrastructure and pathways are characterized by being old and with relatively low average speed. The sharp curves and gradients limit the speed that can be reached.

Large parts of the line have low geometric standards and a standard rate as low as 80 km / h (independent of the stop pattern). Parts of the trail are further landslide and erosion prone, with significant operating and unsecured level crossings. The path is currently preclude public access to outdoor recreation areas (especially sea), which it is described by the traffic sign that indicates hazard and it is called "wild crossings". (Forslag til Planprogram "dobbeltspor Trondheim S - Stjørdal av 25.mars 2013.)

The part of the line between Trondheim S and Stjørdal is fully exploited when it comes to capacity and it is not possible to put more trains in the line without compromising runtime and / or punctuality. This part of the line also affects Stjørdal – Steinkjer as well as the long distance trains and freight for Nordlandsbanen.

This specific part between Trondheim S and Stjørdal is described by Jernbaneverket as a 'bottleneck' for both lines of Nordlandbanen and Trøndersbanen. The current capacity of the line cannot be increased if the line is going to remain as currently. As mentioned in the consequence study (KVU) of JBV the capacity of the specific lie in 2008 was over than 100% and further said: "In recent years, Trønderbanen experienced a stagnation in passenger demand growth. This is due to lack of capacity in the rail network to increase the frequency during peak times, and that travel time is too long compared to alternative car. " (Konseptvalgutredning (KVU) for transportløsning veg/bane Trondheim – Steinkjer og Kvalitetssikring 1 (KS1) av 24.09.2012)

4.3 The suggested solution

The railway should be able to take their share of the overall traffic growth. There is also a stated political objective that a larger proportion of freight to be transferred to rail. This requires more and longer freight trains between Trondheim and Bodø. ". Forslag til Planprogram "dobbeltspor Trondheim S - Stjørdal av 25.mars 2013.

The plan of turning the line into a double one can contribute to increase the capacity. In addition, the electrification of the line will facilitate this goal. This automatically means that more passenger trains and more freight trains can use the line.



Figure 24-I konsept 1 Moderniseringskonseptet i Konseptvalgutredning (KVU) for transportløsning veg/bane Trondheim – Steinkjer

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The social benefits of a double track on the route Trondheim S - Stjørdal were discussed in the Conceptual Study (KVU) in August 2011. This consisted of a combined road and railway transport solution between Trondheim and Steinkjer.

Electric trains have better acceleration performance than current diesel ones, which would result in a theoretical travel time savings of 7 to 10 minutes in the line between Trondheim and Steinkjer. As the route is single-track, the current route model is restricted by the crossing points, and there is little room to achieve real runtime savings. In addition, the measure of electrifying the line increases the capacity for freight on the Nordlandbanen and reduces the risk of accidents. ". Forslag til Planprogram "dobbeltspor Trondheim S - Stjørdal av 25.mars 2013. The planned construction is based on a tight program and it is due to begin in the early 2018.

5. THE TIMETABLE TOOL

5.1. Viriato

To answer to the rest of the research questions Viriato has been used. The purpose was to use the software to produce the desired timetables having set some hypothesis. For this part of the report quantitative methods have been used. Some hypothesis have been made and predictions according to this have been contacted. Viriato is a powerful integrated timetable planning tool introduced by SMA (1996) that allows users to produce the optimal timetables. It is widely been used by NSB and it serves the following purposes:

Strategic – Using detailed data to develop initial travel time estimates, rough timetables and rostering plans that optimize vehicle use. It helps planners identify optimal timetables by allowing them to easily compare alternatives.

Capacity – As timetable implementation approaches, Viriato can work with detailed data to refine and share timetables between stakeholders.

Timetable analysis for local trains. Case study of Trønderbanen

Operations – Daily timetables can be prepared for use by train operators and infrastructure managers. The Viriato consists of the graphic timetable, travel time analysis, conflict detection, network diagrams, platform occupation charts and customer timetables.

Large amounts of detailed data can be used to prepare precise plans to make the network's capacity maximum. Viriato is a complete timetable planning application that helps timetable planners quickly, accurately and transparently develop optimal timetables for all levels of operations (SMA website).

5.1.1 Constructing the timetable in Viriato

The initial step to be taken during the planning procedure is to decide on a specific arrival or departure time, e.g. the first train is going to leave from the stop at 6.00am and the last one at 24.00pm from a specific direction. The procedure repeats itself from the opposite direction. The path of that train would be the first one to create and it would be fixed. In Viriato there is a possibility to calculate timetables for a family of trains, meaning trains that have same characteristics and leave in regular times (clock face diagrams). The next step would be to define the headway (or interval) between trains. Taking into account the demand the infrastructure manager take some important decisions that have to do with the frequency, the number of the crossings and other important characteristics of the timetable. Timings sometimes have to be adjusted to achieve the desired crossings in the single line.

5.1.2 How NSB uses Viriato

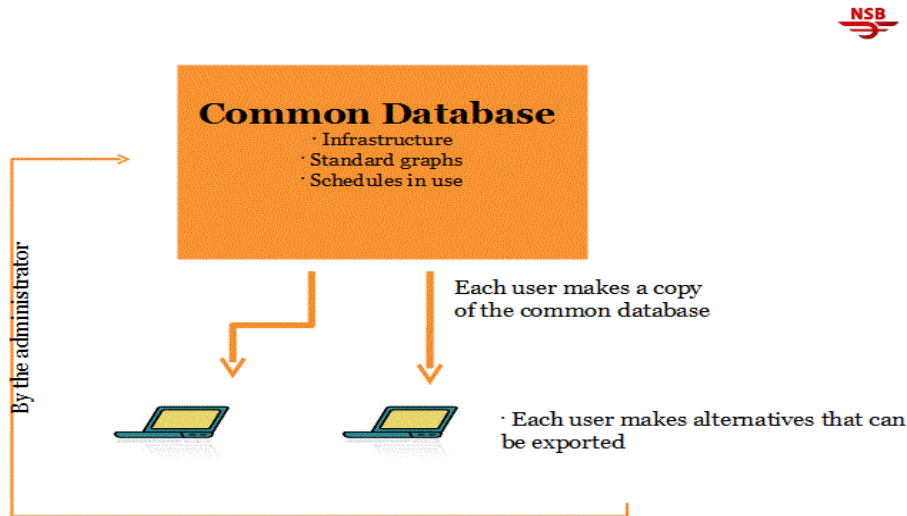


Figure 25- flow of information in the internal network of NSB while scheduling

NSB has a common database. Each user has to make an individual copy of this database and to create alternatives. When this procedure is completed the administrator can export these alterations to the common database. The initial input during the alteration procedure is the infrastructure to be examined. The infrastructure management has to keep pace of the changes that have been made in the infrastructure data. For this reason JBV (November 2012) provided the infrastructure also that happens to be the same with the one that NSB had provided earlier this year.

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Database Settings Infrastructure Rolling Stock Trains Timetable Netgraph Reports Window ?

Section Definition

Section ID: 14NEW Description: dobbelspør trondheim+stjørdal future of Nordlandsbanen-S Valid from: Valid until: Status: Last Change: 2012-12-07 10:19 Remarks:

Attributes Tracks Headway Times

Node ID	Node Name	Km 1	Km 2	# Tracks	Km from Start	Inlem. Distance	Direction	Attribut 1	Attribut 1.1	Attribut 2	Attribut 3	Attribut 4	Valid from	Valid until	Status
TND	Trondheim_S	0.000			0.000		B								
NNN	Lademoen	0.960		2	0.960	0.960	B								
LDM	Lilleby	1.770		2	1.770	0.810	B								
LEA	Leangen	3.490		2	3.490	1.720	B								
ROT	Rotvoll	4.450		2	4.450	0.960	B								
BHM	Børheim	7.420		2	7.420	2.970	B								
SJØ	Sjølyst_Bp	10.240		2	10.240	2.820	B								
VHR	Vikhammer	12.690		2	12.690	2.450	B								
HUG	Haugan_Bp	15.670		2	15.670	2.980	B								
MSD	Midteandan	18.550		2	18.550	2.880	B								
KBN1	KBN1	19.900	19.895	2	19.900	1.350	B								
HMV	Hommelvik	23.140		2	23.145	3.245	B								
KBN2	KBN2	24.200	25.827	2	24.205	1.060	B								
HEL	Hell	31.540		2	29.918	5.713	B								
VÆR	Værnes	32.860		2	31.238	1.320	B								
STJ	Stjørdal	34.670		2	33.048	1.810	B								

Node: Ins. Above Remove Section: New Copy Rename Delete Print Save Close
 Ins. Below Search

Figure 27-Definition of infrastructure

To define infrastructure one has to define the relevant sections.

The examined line includes: Søberg to Trondheim S (single track) Trondheim S- Stjørdal (double track)and Stjørdal to Steinkjer (single track).

The section between Steinkjer and Trondheim has and particular ID in the general common data base. The number of this ID is 14.

Currently, the line is single track line. There is a plan to make this line a double track so someone can copy the old node and create a new one with the name 14NEW (Trondheim S- Stjørdal) . There, the alteration that has to be made is to put 2 instead of 1 in the column called # Tracks. The new part replaces a percentage of the part with ID 14.

The infrastructure also has the part with ID 10N (Trondheim to Søberg) intergrated.

To make the speed calculations Viriato uses the Strachl Formula:

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$$R_{(r+a) \text{ vehicle}} = 2.5 + \frac{(V + \Delta V)^2}{K} \quad (\text{kg/ton}) \quad (2)$$

Where:

V= speed (km/h)

ΔV = additional coefficient

K= constant coefficient dependent on the type of the train

Where the additional coefficient can take the following values:

=zero (horizontal line and quit weather)

=12 at (lateral wind, medium intensity)

=20 at (lateral wind, strong intensity)

=30 at (strong wind, high intensity, long duration)

And the constant coefficient can be:

= 4000 (high speed and goods train, homogeneous complete)

= 3000 (medium speed, non-homogeneous train)

= 2000 (different types of vehicles)

= 1000 (empty vehicles)

To make the calculations more accurate the curves, tunnels, the velocity profile and the vertical profile are taken into account.

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Table 4- velocity categories

Code	Category
H	Maximum velocity
P	Plus velocity
K	Speed titling trains
T	"tourist velocity"

When making the running time calculation viriato has to know which type of velocity is being used during the procedure. There are several alternatives as showed in the above table.

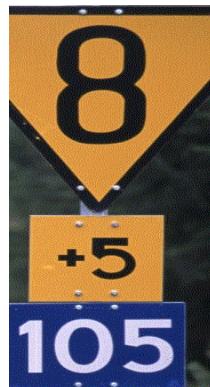


Figure 28-Depiction of the three types of velocities

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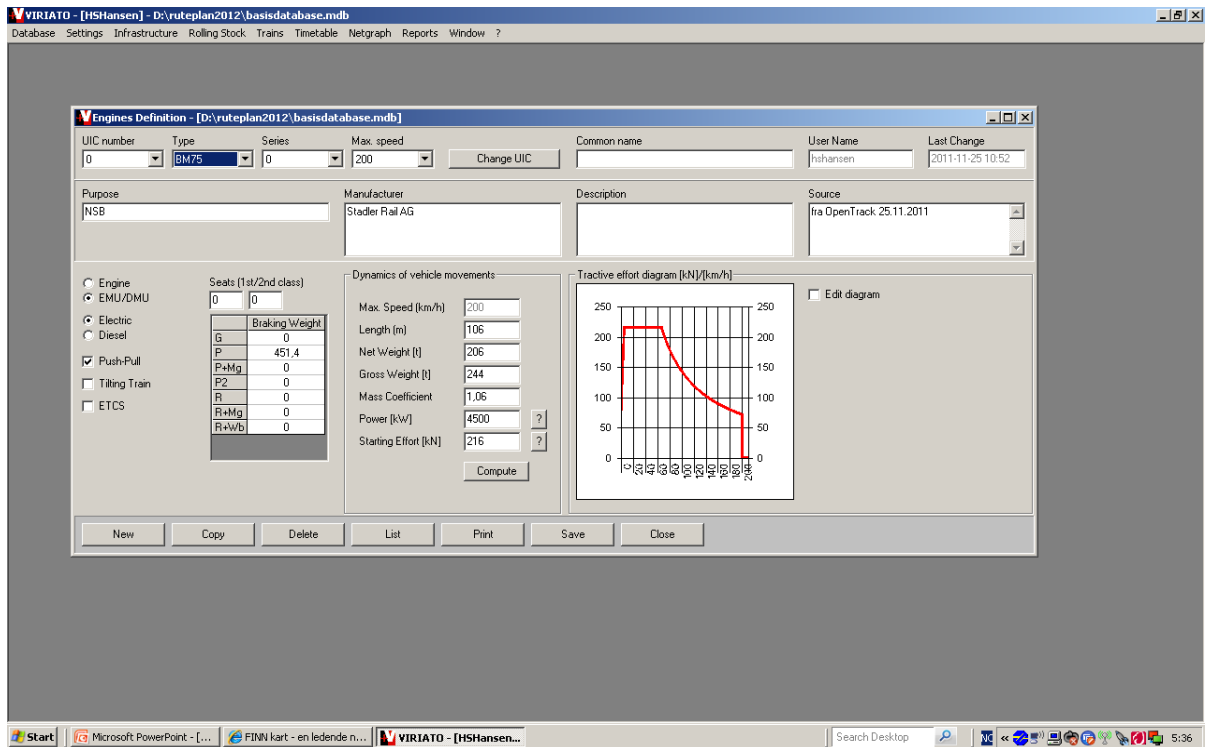


Figure 29- Generation of the traction diagram by Viriato

Viriato calculates the traction diagram by only knowing the type of the train that we use in the planning procedure. In this case this is FLIRT 4-wagon train.

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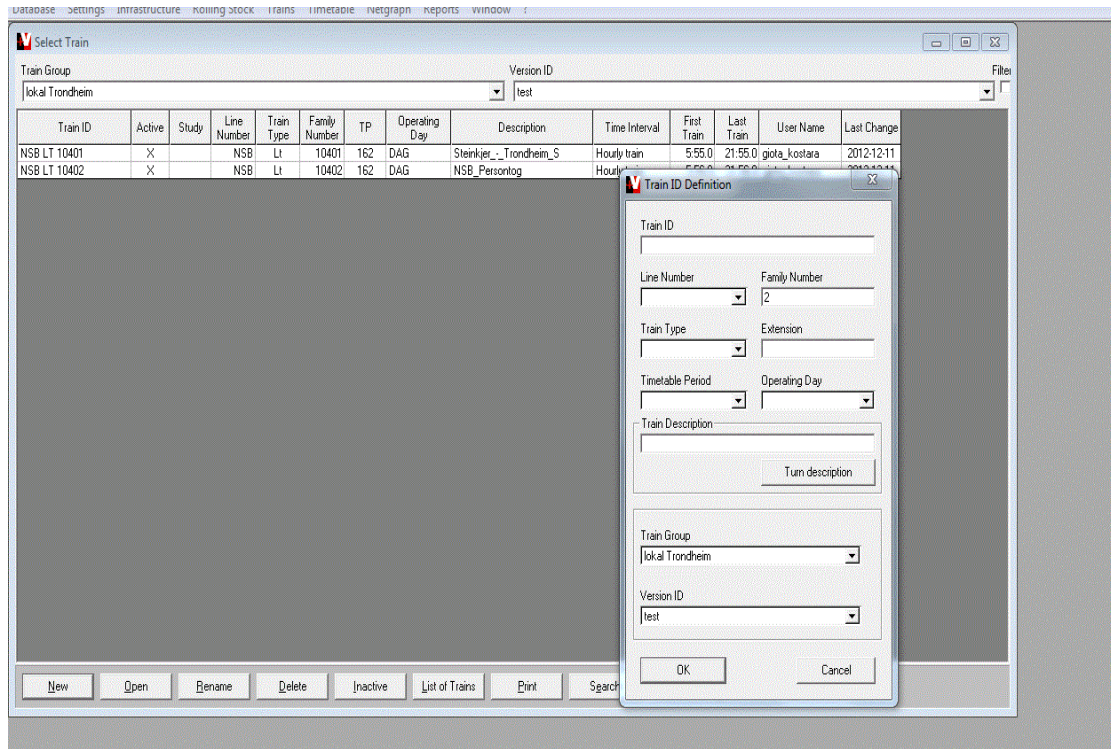


Figure 30-Definition of trains

To issue a new family of trains for each direction the fields that appear in the above diagram have to be filled in. The procedure has to be repeated for both directions.

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The screenshot shows a software interface for timetable analysis. The 'Schedule' tab is active, displaying parameters for a train from Steinkjer to Trondheim S. The parameters include:

- Operating Day/Validity: DAG
- First Train: 05:55.0
- Fixed Node: Trondheim S
- Time Interval: Hourly train
- Last Train: 21:55.0
- Timetable Period: 162
- Source of Running Time: Viriato
- v (km/h): 65
- Total additional running time in %: 10.0

 Below the parameters is a table with the following columns: Section, Sect. Track, Node, Track No., Track Info, ST, Arrival Time, Dep. Time, Run Time, % RTR, RT, aRT, tol% RT, Stop Time, Add Stop, Sup Stop, Remark, and km. The table lists stations from Steinkjer to Værnes with their respective arrival and departure times and running times.

Section	Sect. Track	Node	Track No.	Track Info	ST	Arrival Time	Dep. Time	Run Time	% RTR	RT	aRT	tol% RT	Stop Time	Add Stop	Sup Stop	Remark	km
		Steinkjer					05:55.0						0.5				0.000
14	1	Mære			B	06:02.5	06:03.5	6.8	10	0.7				1.0			10.656
14	1	Sparbu				06:05.1	06:07.1	1.5	10	0.1			0.5	1.5			12.570
14	1	Røra				06:12.3	06:12.8	4.7	10	0.5			0.5				20.030
14	1	Verdal				06:19.6	06:20.1	6.2	10	0.6			0.5				29.270
14	1	Bergsgrav				06:22.5	06:23.0	2.2	10	0.2			0.5				31.800
14	1	Østborg Bp					06:27.2	3.8	10	0.4							36.870
14	1	Røstad				06:29.4	06:29.9	2.0	10	0.2			0.5				40.320
14	1	Levanger				06:31.2	06:33.2	1.2	10	0.1			0.5	1.5			41.600
14	1	Skogn				06:39.3	06:39.8	5.5	10	0.6			0.5				49.490
14	1	Ronglan				06:44.3	06:44.8	4.1	10	0.4			0.5				55.850
14	1	Åsen				06:51.0	06:51.5	5.6	10	0.6			0.5				64.100
14	1	Vudu Bp					06:55.8	3.9	10	0.4							69.440
14	1	Langstein					06:59.5	3.4	10	0.3							74.950
14	1	Hammer Bp					07:03.0	3.2	10	0.3							79.640
14	1	Skatval				07:06.2	07:06.7	2.9	10	0.3			0.5				83.700
14	1	Stjørdal				07:11.7	07:12.2	4.5	10	0.5			0.5				90.830
14NEW	2	Værnes				07:13.8	07:14.3	1.5	10	0.1			0.5				92.640

Figure 31-Putting the schedule parameters

The next phase of the planning has to do with the definition of schedule parameters. Here the first train and the last train have to be decided. At the beginning the stop times are being put. To achieve favorable crossings supplementary stop times have to be added in the special column and lines in the diagram (yellow lines).

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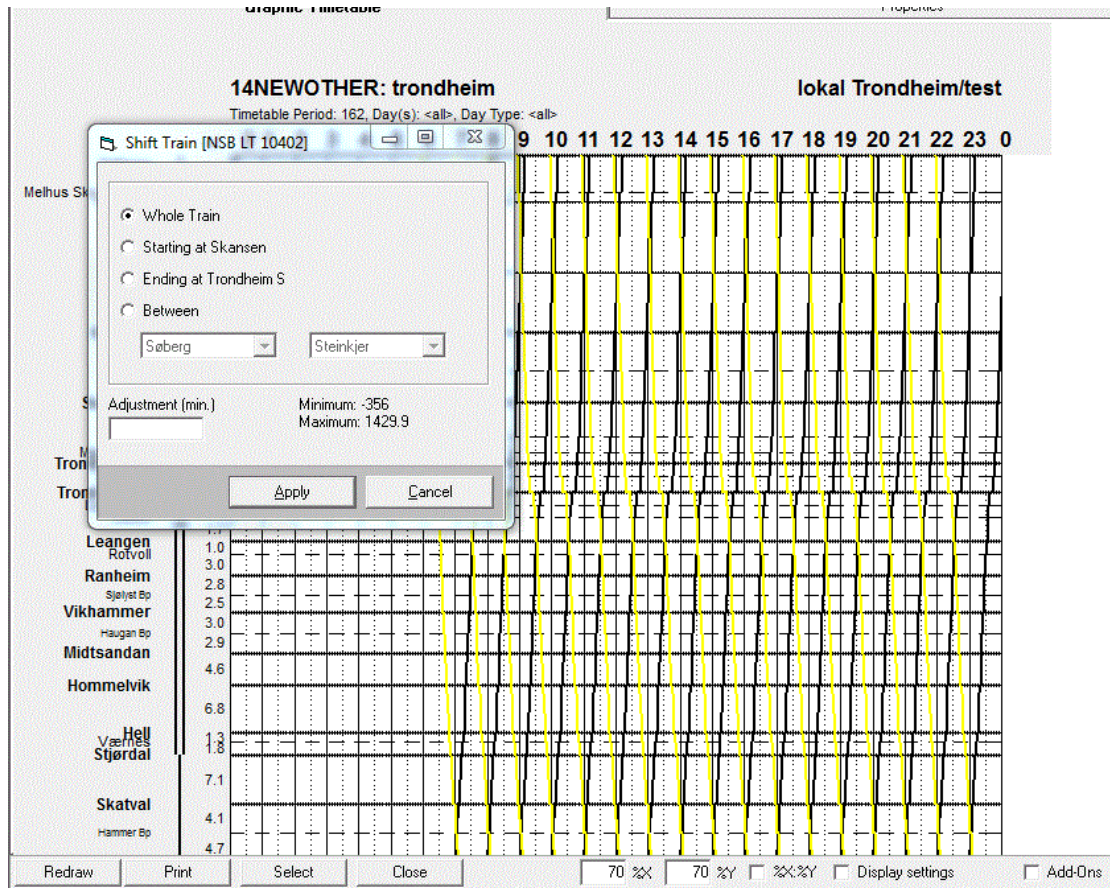


Figure 32-Adjusting the lines

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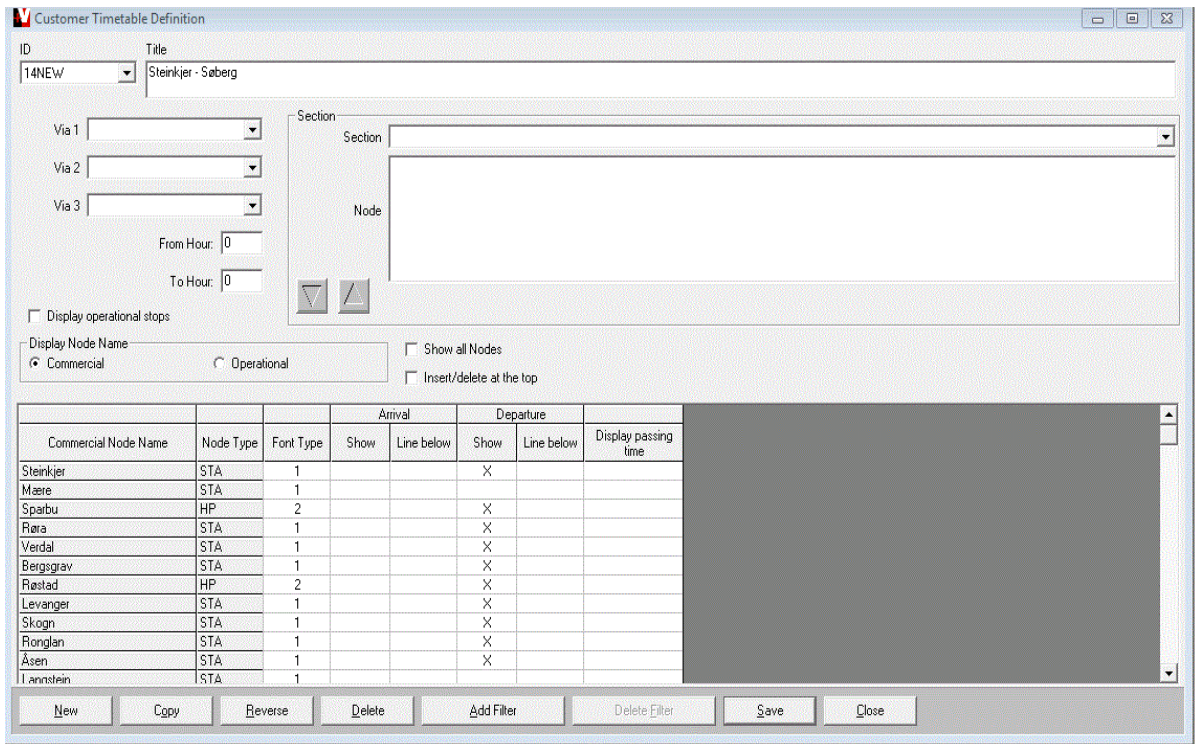


Figure 33-definition of customers' timetable

To get the number of train sets there are different possibilities NSB proposes the following methods:

1. The path of one train set is being drawn. Different color /line types are being added up for each train set until all the services have been covered. Count the number of colors/line types to get the number of train sets. The above method is easily explained by the following figure.

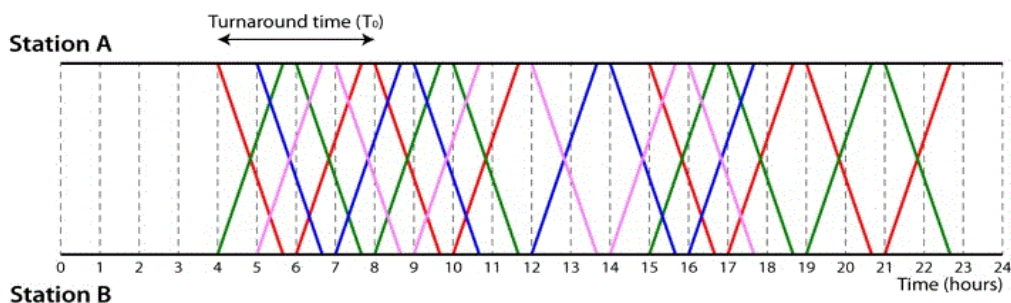


Figure 34-Calculation of the train sets for each scenario

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2. A sum of travel time A to B turnaround time at B + Travel time B to A + Turnaround time A is calculated and divided by the time between each service and get the number of train sets necessary.

3. The number of internal crossings is being counted. If the turnaround time is ok (above minimum) the number of necessary train sets would be the number of crossings + 1.

5.2. Limitations of Viriato: Inputs of the program

Two kind of limitations appear. The limitations that have been placed with the form of hypothesis and those that the program has.

The limitations during the calculation process are more or less the limitation that the inputs of the program have. The infrastructure, the rolling stock and the available materials to be used are some of those. The scope of the current project also puts another limitation to the project itself. The inputs of the program are being presented in the following table.

Another limitation is the way that the program calculates the timetables inside tunnels. In this case, the special resistances are not being calculated. The tunnel is as if it does not exist. During the procedure it is taken as a hypothesis that these resistances do not play an important role to the calculations.

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Table 5-Inputs of the program

Assumption	Comment	Decision
Number of tracks	The future infrastructure between Trondheim and Stjørdal is going to double line track.	-double track Trondheim-Stjørdal (future infrastructure) -single line in the rest track (existing infrastructure)
Tunnel	During the calculations is not taken into account. Theoretically a tunnel will increase the resistance because of the air flow so it will reduce the remaining force for acceleration.	To simplify the model ,tunnels are not taken into account
Inclination		The line is considered to be more or less without inclination.
Length of line	The future infrastructure is going to have the length same length as the current one.	Trondheim-Stjørdal 33.048m
Distances Between stops	distances between the stops and location of the stops is the same as the current infrastructure	The same as now
Type of V		H=P
Max V	The max V that this type of trains can have. Assumption: it can maintain it min for 10 seconds and after that it is going to start push the brake	160 Km/h
Speed profile		2P

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V near stops	The max V that can be reached near a stop	30km/h
Train type		Flirt 4 wagon
Family number		10400/10401
Timetable period		162
Min stop time (retention times)	In big stations is minimum 2min. For suburban residence time should be 30 s at small stations and 1 min at larger stations. In Trondheim area, all stations except Trondheim S that has 30 s station stay. In Trondheim S will likely be a need for time off for personal change of at least 2 min drive stays.	0.5 min
Turnaround time	For turning of trains at the station requires a minimum of about 10 min, time should be 15 minutes or more.	Min 10 min
Frequency		Hourly
RTR%	Most train sets can run in plus speed. As a basis for sketching 10% slack has been used.	8-10
Symmetry Axis	It is xx: 00 that the symmetry axis, ie the train arriving to station X minutes before the hour will be departing X minutes after the hour. This provides symmetry xx: 00 This is a principle that is being followed as much as possible, including uses the new routing model in Eastern symmetry axis xx: 00 for the so-called 10-min system.	

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Crossings	Crossings must be done at stations and one of the trains must always arrive first. This must be left at the station and wait for a certain number of minutes before the next train can run into the station. The scheduled time for the crossing are generally longer than the actual crossing locking time (determined by the signaling system) and are usually for 3 minutes.	2 min is also acceptable
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5.3. Other inputs: Rolling stock

The passenger trains that have been used in this report are the Electric Low-floor Multiple unit FLIRT that will provide a high-speed service.



Figure 35-4 part electrical train of the FLIRT family

NSB has purchased 50 5-part electrical trains of the FLIRT family from Stadler.(NSB site)26 of these have been equipped as Long Local version for the S-Bahn traffic in the Oslo area, with travelling times of up to 90 minutes. The other 24 trains are equipped as Short Regional, and will be used in the area of Southern Norway for connections with travelling times of up to 3 hours. The trains that have been ordered are a development

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of the well-proven FLIRT family, with a special focus on customer friendliness for families, the elderly and the disabled. They are also characterized by an advanced thermal and acoustic insulation and fulfill the high requirements needed for winter operation in Norway.



Figure 36-types of FLIRT

The traffic composition used in this report is being presented in the following table.

Table 6- trains used in this report

Train type	Name in viriato	Max speed	Weight	Length	Speed profile type
Local trains					
Cargo Trains	CD312	90 km/h	1077t	600	1-H
Long distant trains	Di4 with flinke	120 km/h	298t	200m	1-H

6. OUTPUTS AND DISCUSSION

6.1. Scenarios from the specialization project

In the specialization project that was written during the winter of 2012 the produced alternatives were four. The inputs were the same that have been described in the relevant chapter, In this stage of the study the trains that have been used were FLIRT type and the line was as it was described in the chapter INPUTS. But why four alternatives? The scenarios that can be produced as a result of the described procedure seem to be numerous. A simple adjustment of the family of trains that run in each direction, followed by a modification of waiting times in certain stops where the crossing is being done can produce many scenarios. However there are some restrictions that have to be taken into account and these are the inputs of the program. The four scenarios are:

6.1.1 Scenario A

In this scenario the crossings have been made in Røra ,Ronglan and Stjørdal. From Stjørdal the line starts to be double line. As a result the examined crossings are planned to be made in Røra and Ronglan.

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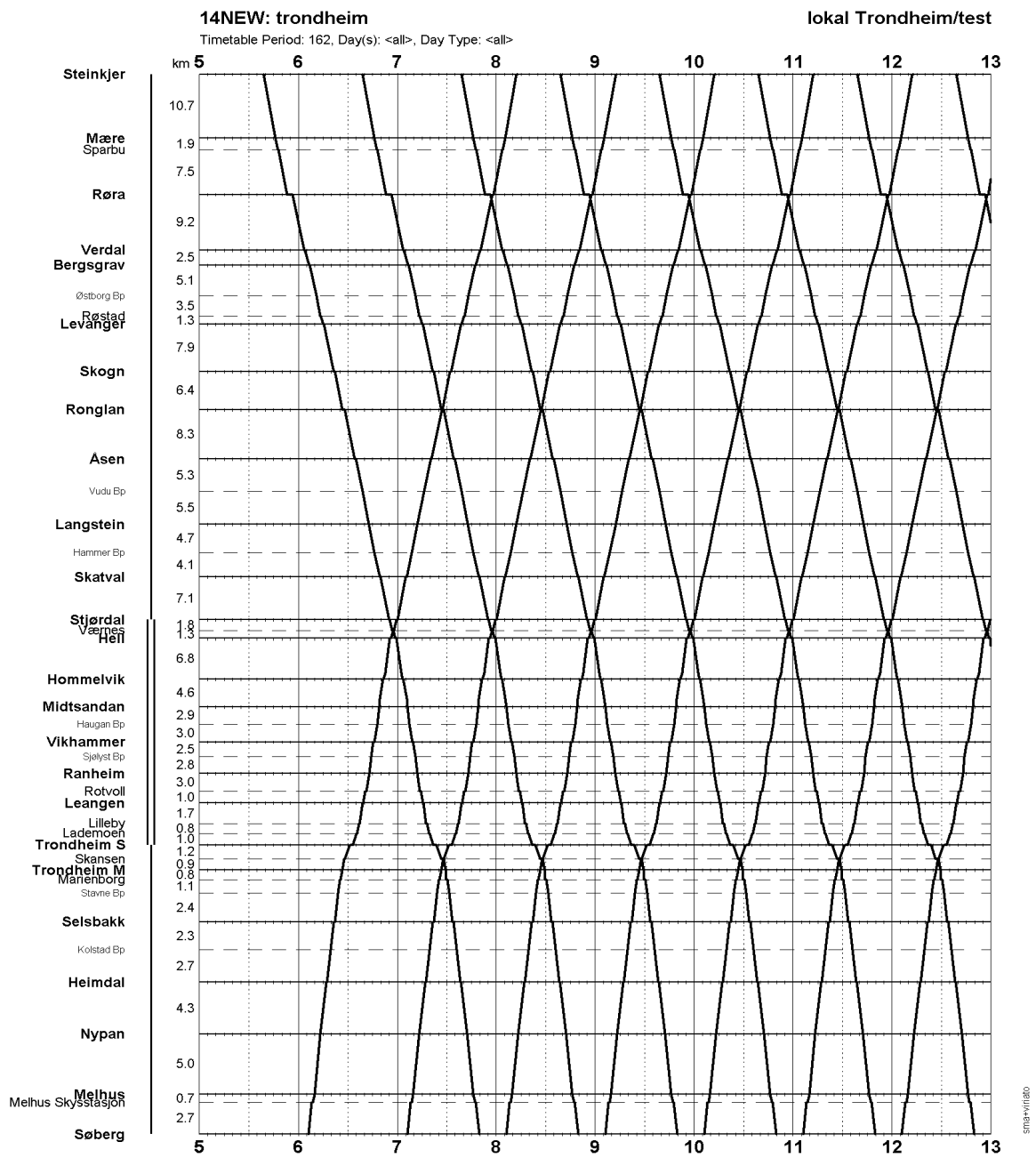


Figure 37- Scenario A

6.1.2 Scenario B

In this scenario the crossings are planned in Bergsgrav-Åsen-Selsbakk.

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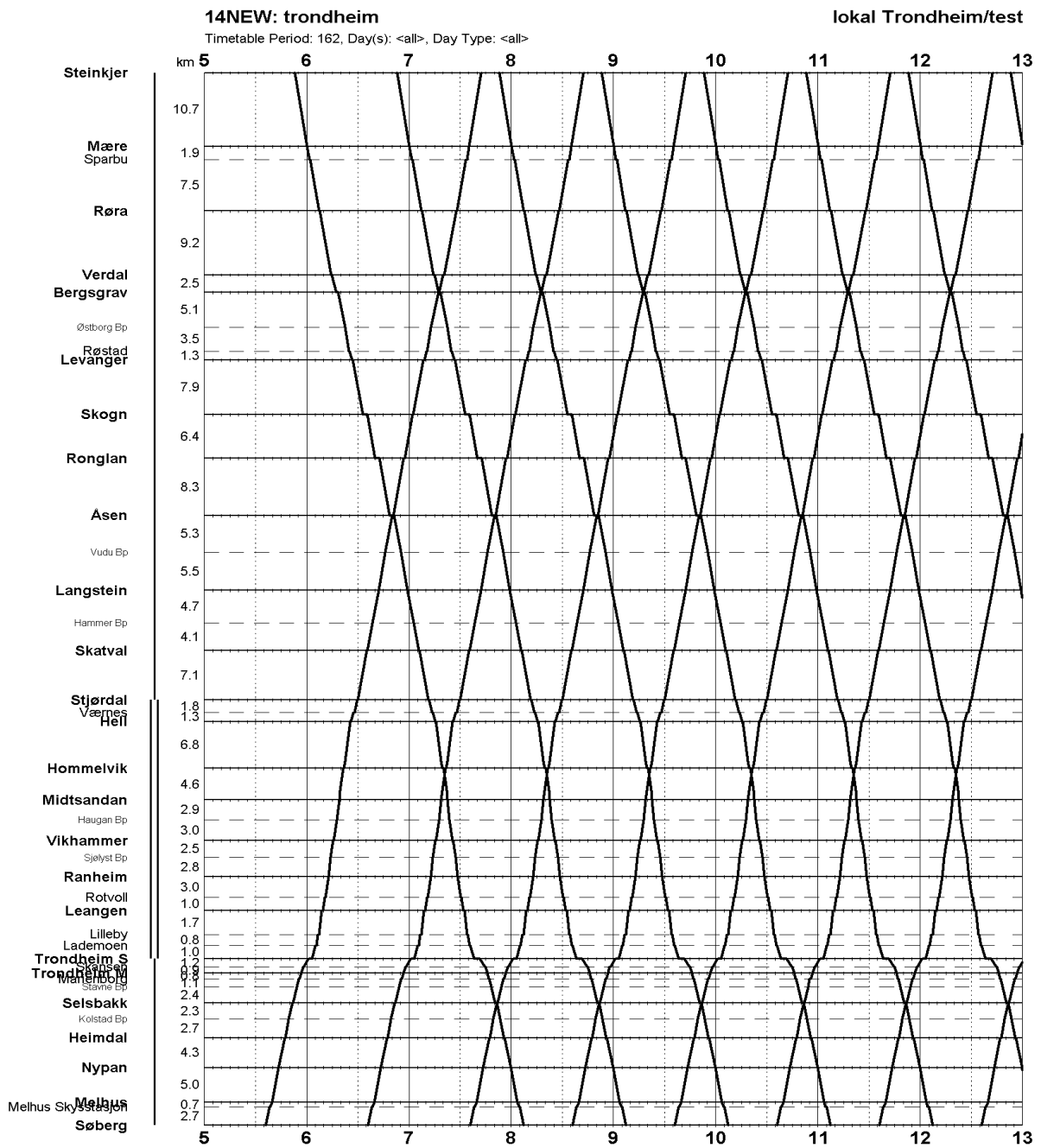


Figure 38-scenario B

6.1.3 Scenario C

Here the crossings are planned in Verdal-Åsen-Selsbakk.

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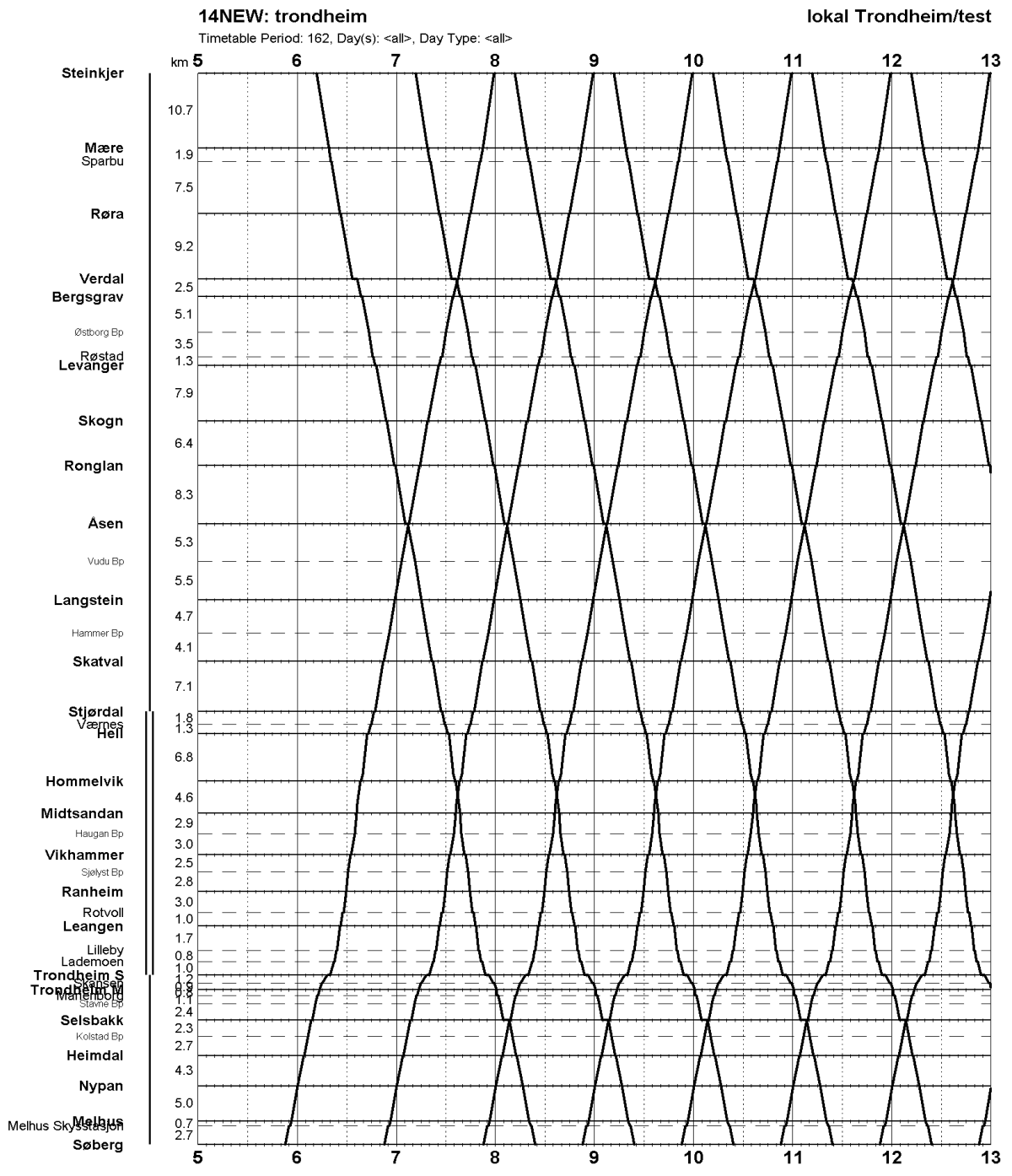


Figure 39- Scenario C

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6.1.4. Scenario D

The crossings in this scenario are planned in Mære-Levanger-Hammer Bp-Nypan.

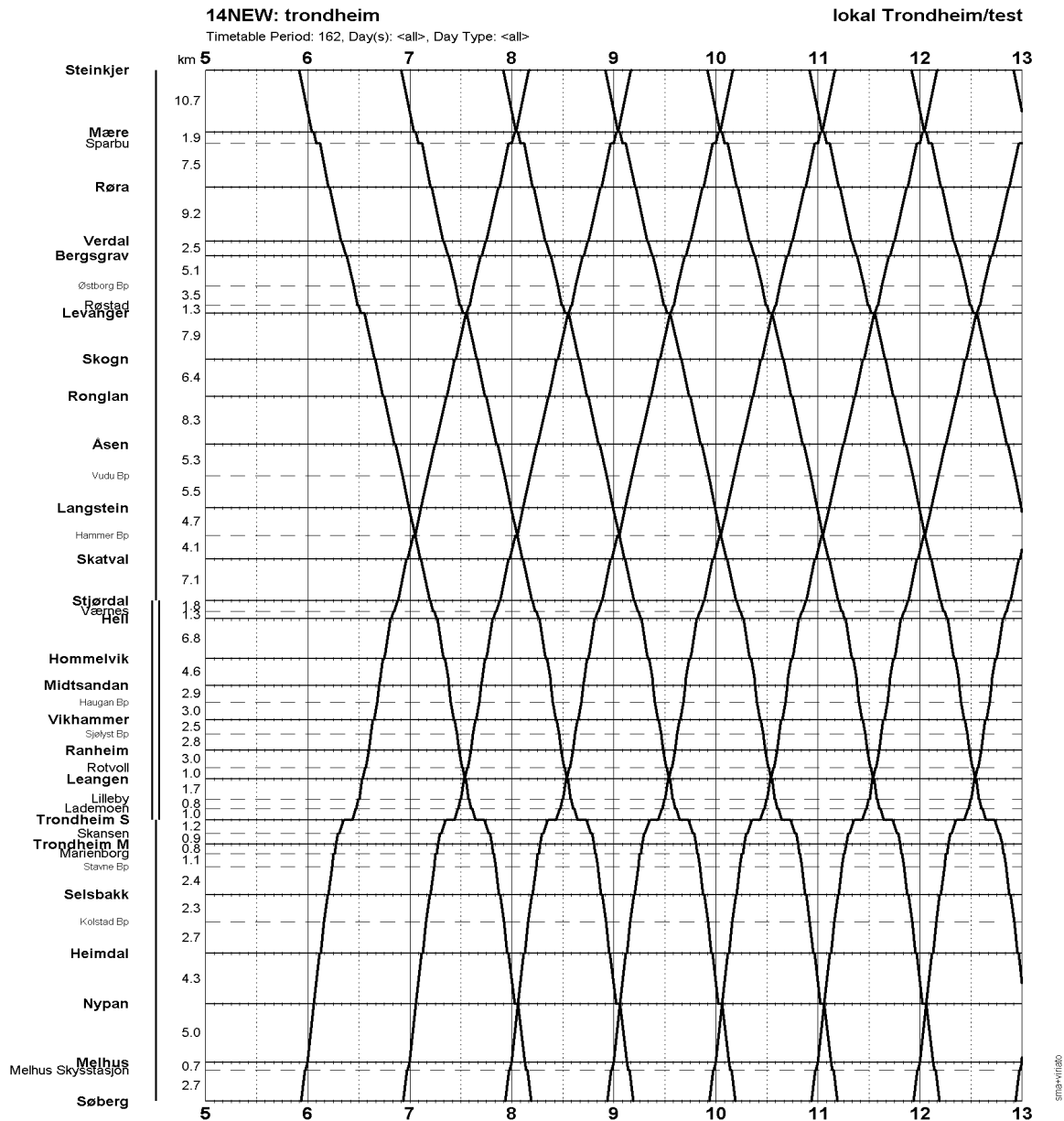


Figure 40- Scenario D

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6.2. Comparison of the scenarios from the specialization project

The evaluation criteria /factors that have been chosen in order to evaluate the scenarios are the following: The achieved crossings, the driving times, the number of train sets that need to be used. To get the number of train sets printing of the graph has been chosen because of its simplicity.

Table 7- comparison of results of the specialization project

Concept	A	B	C	D
Frequency	Hourly trains	Hourly trains	Hourly trains	Hourly trains
First train/direction	5.39/6.06	5.37/5.52	6.11/5.52	5.55/5.56
last train/direction	21.39/22.06	21.37/21.52	22.11/21.52	21.55/21.56
Crossings at:	Røra-Ronglan-Stjørdal	Bergsgrav-Åsen-Selsbakk	Verdal-Åsen-Selsbakk	Mære-Levanger-Hammer Bp-Nypan
Driving times	102.1min-101.6min	102.1min-101.6min	102.1min-101.6min	103.3min-103min
Number of sets	5	5	5	6
evaluation	Demand in Røra-Ronglan-Stjørdal has to evaluated.	Demand in Bergsgrav-Åsen-Selsbakk has to evaluated.	Good departure times from the employees perspective.	Worst scenario (requires a new crossing loop in Hammer Bp, has the largest traveling time and needs one more set of trains)

It is obvious from the comparison of the three scenarios that the worst one is the scenario D. It requires a new crossing loop in Hammer Bp, has the largest traveling time and needs one more set of trains. The positive about this scenario is the departure time of the first and the last train. It is near 6.00am which is the time when the drivers start working.

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From the cost point of view is also the worst scenario. One more set of trains requires more personnel and the alteration in the line also costs.

The scenarios A, B, C are very similar scenarios. The number of departures, the train kms and the number of train sets are the same in the first three scenarios. The driving times are also the same.

The evaluation criteria that has been left to be examined in order to decide which timetable is the optimal between these three alternatives are the departure times of the first and the last train in each timetable and the place of the crossings.

To evaluate them we have to know the demand, the number of the passengers /stop that they need to get out /in of the train so as to decide where it is better to put the crossing.

In that case we have to evaluate the demand in Røra, Ronglan, Stjørdal, Bergsgrav, Åsen, Selsbakk, Verdal that are the places where the crossing has been planned in the three first scenarios.

Røra has a population of less than 500 people (Statistisk sentralbyrå, 1. januar 2012) while Ronglan is a small village that The European route E6 highway goes through it. This is a very important element to be taken into account during planning. From the social and the financial point of view. On the other hand, almost 22.000 people live in Stjørdal. A crossing that would increase probably the waiting time at this station is balanced from the great demand in comparison to the other alternatives. Bergsgrav serves Vinne which is a village and Åsen has a very small population also. Selsbakk and Verdal have 900 and 15000 people respectively. From this point of view the best alternatives are those that include a crossing in Verdal and ofcourse Stjørdal. This alternatives are A and C.

From the stability point of view (Lindfeldt, 2010) the crossings are better to be made inside the double line and not where it starts. From this point of view if someone decides to put a crossing in Stjørdal that belongs at the beginning of the double track this is going to increase considerably the probability to have unexpected delays. In this case the worse scenario is scenario A.

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From the historical point of view it is important to examine the stations-stops that have the least demand, the ones with the less population to be served. The reason behind that is that a crossing in a station with a great demand is always in the plan. Preserving stations that have a historical sense can be attractive to the user. Maintenance cost is another factor that has to be evaluated also. In Bergsgrav there has been a station since 1938 and Selsbakk station is there from 1919. Åsen station was built in 1902 by architect Paul Due and was built with a surrounding park. The current building is from 1944, but it is no longer used by the railway and it is now an art gallery (JBV). Paul Due also built the same year (1902) the station in Ronglan. From this point of view the crossings are better in Ronglan and Åsen. A, B and C alternatives include this crossings. Alternatives B and C that include a crossing in Åsen that can be an attraction because of the gallery and the track is the optimal ones from this point of view.

The departure times of the first /last train in each scenario is also an important evaluation criterion. In that case, from the employees' point of view the best scenario is C. Again to define thoroughly this criterion a more inside knowledge of the demand is required. From the managerial point of view is important to know what time the majority of the passengers want to arrive to their destination. This cannot be determined by the population. The passenger may want to move from one point of the network to the other but to belong to the departure point. This parameter is also going to define the frequency of the service which in the present study was considered to be an hourly one.

From the number of crossings point of view the best scenario is Scenario A that requires two crossings in the single line (Stjørdal is in the future double line) while Scenario B on the other hand has three crossings. This does not affect the traveling time but it is better to reduce crossings in the single line. So, in that sense scenario A is the best one.

Comparing to the current timetable one can easily identify some hidden factors that maybe have not been taken into account. It is interesting to see where the planned stops have been planned. Røra, Ronglan, Bergsgrav, Åsen, Selsbakk, Verdal are the stops that the train does not stop some specific hours. From this point of view and taking into account the fact that the current project refers only to hourly services in the entire line

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someone cannot make a safe conclusion out of this. Only the assumption that the future plan is going to use the same stops as the current one.

Another important aspect is the times. For example a high-speed train that arrives at 10.32 and leaves at 10.33 is not the favorable case. The times should be around the zero point. From this point of you the best scenarios are A and C.

Recovery or turnaround times are another important aspect. No obvious conclusion can be made according to this. Recovery times in every scenario is obvious from the produced diagrams that are more than 10 min which is the minimum.

Table 8– further comparison of scenarios A, B, C, D

	A	B	C
Demand based on the population	Best scenario		Best scenario
Times around zero	Best scenario		Best scenario
Stability	Worst scenario		
Historical point of view		Best scenario	Best scenario
Employee’s point of view			Best scenario
Number of crossings	Best scenario		
Recovery times	No obvious conclusion can be made according to this.		
Comparison with the current timetable	No conclusion to be made apart from the obvious one (planning has been conducted		

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	according to the demand)		
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From the clarification of the above factors and the understanding of their effects the interactions that each of them has to each is the second element that has to be clarified. This, automatically broadens the procedure of the planning. The merit of hourly timetables is taken as a given (and is very widely in Europe). Practically this may not always be feasible because of geographic and unforeseen factors, but the focus helps to identify good solutions and may highlight areas that could enable a specific improvement to be made. In the above table the scenario D has been excluded because from the very beginning it was obvious that it was the worse one. By the examined factors the best scenario is scenario C.

What has to be kept in mind is that perfection cannot be achieved in a real railway network. The task of infrastructure managements and engineers is to improve on the best compromise, often under multiple constraints. The constraints set limitations to the produced result. A combined set of criteria have to be examined after setting the goal of the planning procedure.

6.3. Conclusion of the specialization project

After examining a specific set of criteria that are stated it is obvious that the worst scenario is that with the larger duration and the most required alterations in the specific line (scenario D). It also the one with the most expected cost. The rest of the scenarios have some positives and negatives aspects.

From the employees point of view scenario C is the best one (later departure time).To evaluate thoroughly the rest of the scenarios it would be interesting if not necessary to have an evaluation of the demand in every potential stop so as to cover it and to make scheduling by setting this important priority.

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Scenario A is the best scenario from the number of crossing point of view, but this is balanced by the fact that its third crossing is made in the beginning of the double line which is negative from the robustness' point of view.

Scenario C gathers the most positive aspects when it comes to the examined criteria.

6.4. Starting point: the best crossing patterns from the specialization project

From the four alternatives only 3 possible crossing patterns are chosen. Those are A, C and D. These patterns are the result of possible passing loops on the single track line between Stjordal and Steinkjer. For this work it is assumed that this line does not undergo major changes. The three possible crossing patterns will then decide which route models that will be possible. From this point of the report and afterwards the names of the scenarios have been changed. The new names that are going to be used in the report appear in the following table.

Table 9- New scenario names

Old name for scenario (from the specialization project)	New name for scenario (to be used from now on this report)
A	A
C	B
D	C

6.5 Improving scenario C

In scenario C (previous scenario D) instead of having the crossing in Hammers Bp a new crossing in Langstein has been added. The assumptions remain the same as with the other crossing patterns. This is being done in order to avoid major changes in the infrastructure. The new improved version of scenario C is being presented in the following figure.

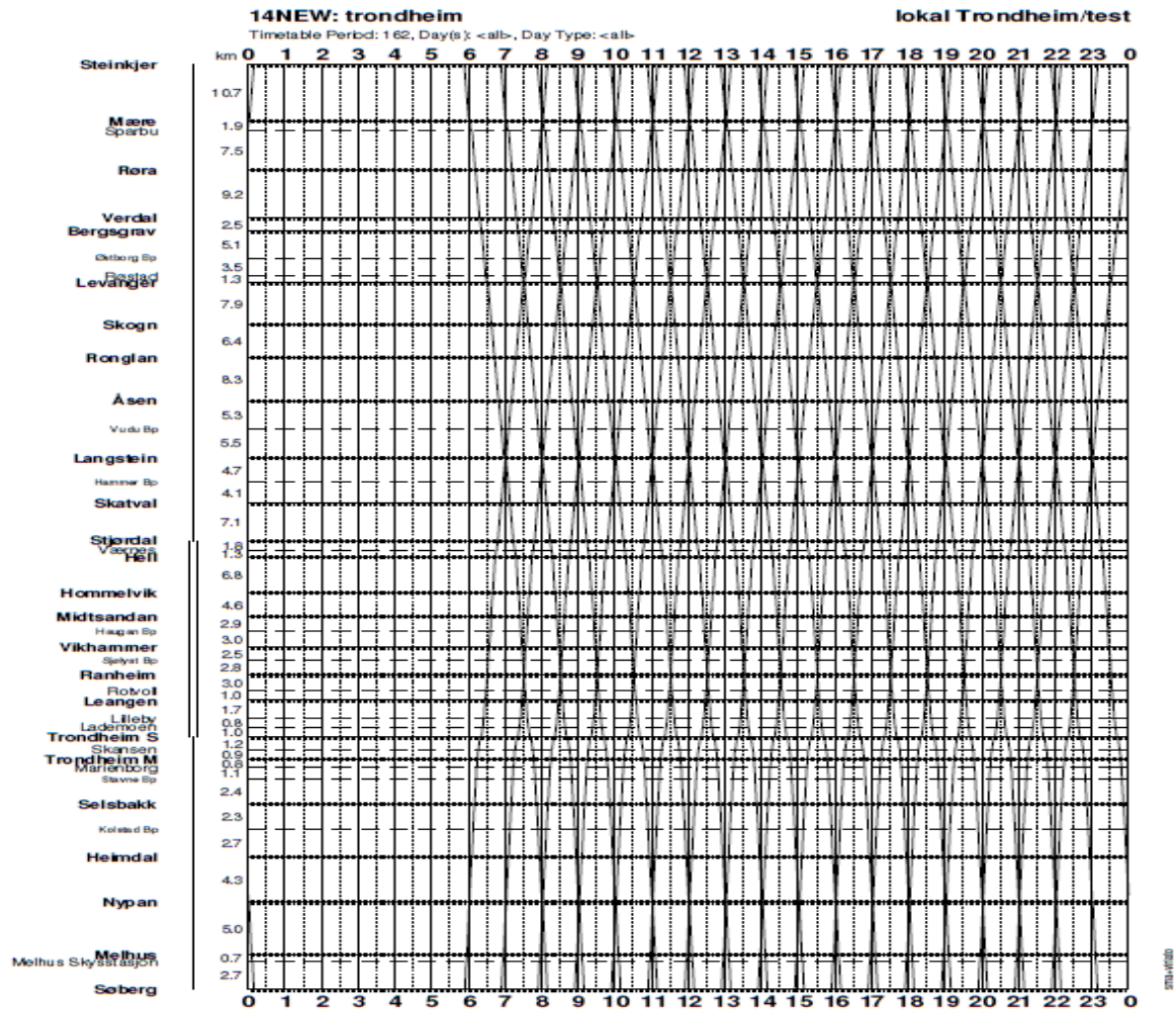


Figure 41-Improved scenario C

6.5.1. What can reduce the stopping pattern?

The aim here is to test whether it is possible to obtain other stopping patterns if some stops are going to be removed.

The three different scenarios have been tested:

- 0 Stop Pattern as today, without Ronglan
- 1 Loss of Ronglan, Berggrav, Skatval, Røstad and Sparbu
- 2 Only stop Levanger and Verdal.

6.5.2. Addition of half time service

The aim is to see how the crossing pattern (on the section Stjørdal-Steinkjer) from step one fit to a half hour service consisting of a service Steinkjer-Melhus (outer service) and

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Stjørdal-Melhus (inner service). With this situation, both an inner and an outer service, some smaller stations will only be served by the inner service, such that the outer service can get a reduced travel time.

The trains Melhus-Steinkjer will then stop at:

- The same stations as the crossing pattern from the previous step on the section Stjørdal-Steinkjer
- Stjørdal-Værnes-Hommelvik-Leangen-Trondheim, on the section Stjørdal-Trondheim
- Marienborg-Bjørndalen-Heimdal-Melhus skystasjon, on the section Trondheim-Melhus

The trains Melhus-Stjørdal will then stop at

- Stjørdal-Værnes-Hell-Hommelvik-Vikhammer-Grilstad-Ranheim-Leangen-Lilleby-Lademoen-Trondheim, on the section Stjørdal-Trondheim
- Skansen-Marienborg-Bjørndalen-Heimdal-Melhus skystasjon, on the section Trondheim-Melhus

For each of the crossing patterns from the previous step and the initial ones the following have been done:

1. The crossing pattern fixed between Stjørdal and Steinkjer (the outer service) is being kept fixed
2. The stopping pattern of the outer service between Stjørdal and Melhus is being adopted, this will give reduced travel time to Trondheim and a new crossing pattern south of Trondheim
3. A service Melhus-Stjørdal (the inner service) with the stopping pattern as described above is being added, and it has been placed approximately on the opposite 30-min than

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the outer service. As the running time of this service is longer than the outer service, it is not possible to have it exactly on the opposite half hour on the whole section Melhus-Stjørdal.

Grirlstad and Bjørdalen are two new stops that have been entered in the database. The crossings in the scenarios remain the same.

6.5.3 Addition of long distance trains and cargo trains

The produced feasible diagrams that have been produced, after the procedure that has been described above, appear below.

The scenarios have been named scenario A, B, C. These names are not to be mixed with the initial scenarios that have been used in the report.

6.6 RESULTS

The results obtained with the above procedure appear in the traffic diagrams below. In the one axis the nodes appear (stations and stops) and in the other the time. A time window between 10 and 14.00 has been chosen to make the depiction easier. The crossing pattern repeats itself the rest hours as the diagrams are clock phase periodical ones.

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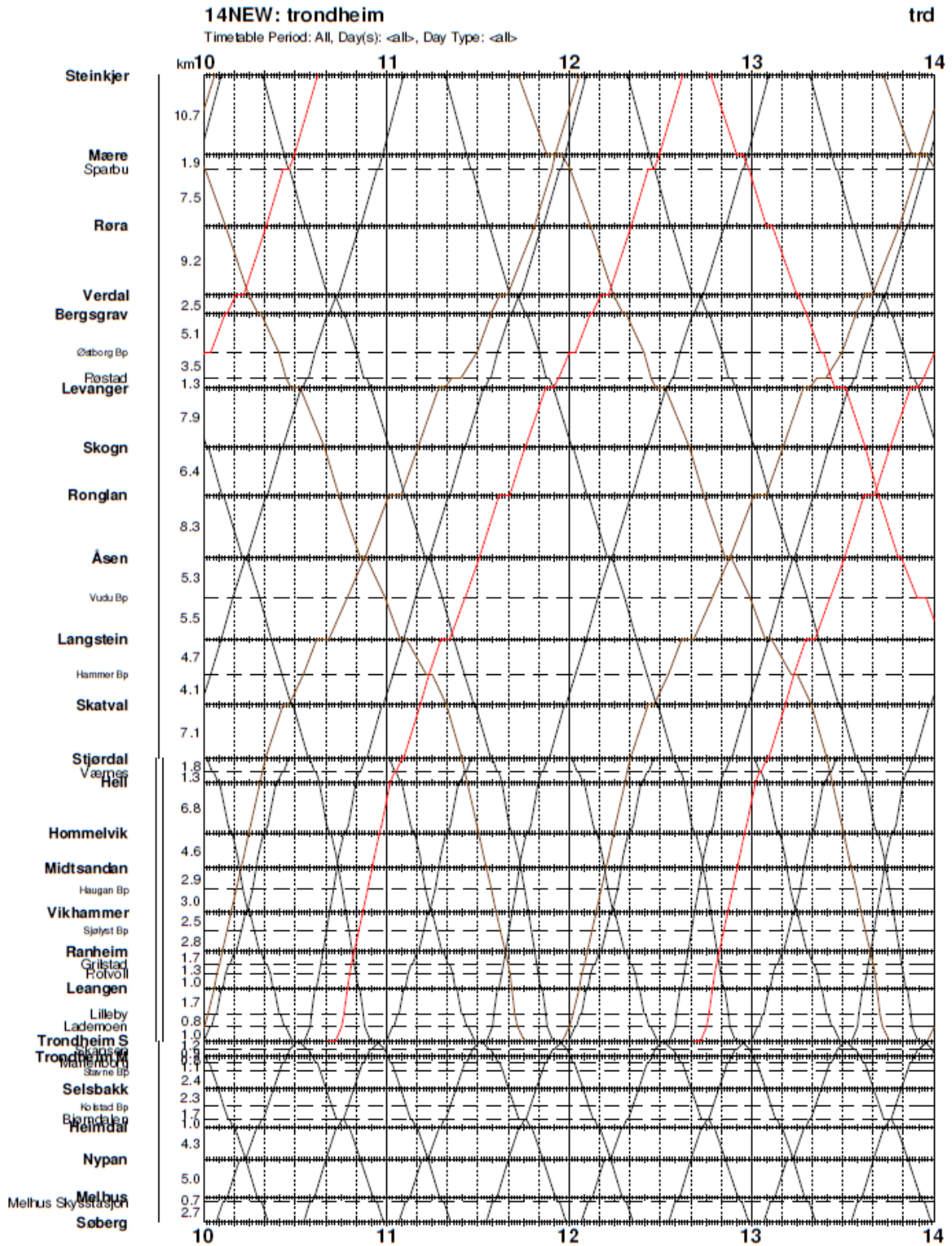


Figure 42-Scenario A

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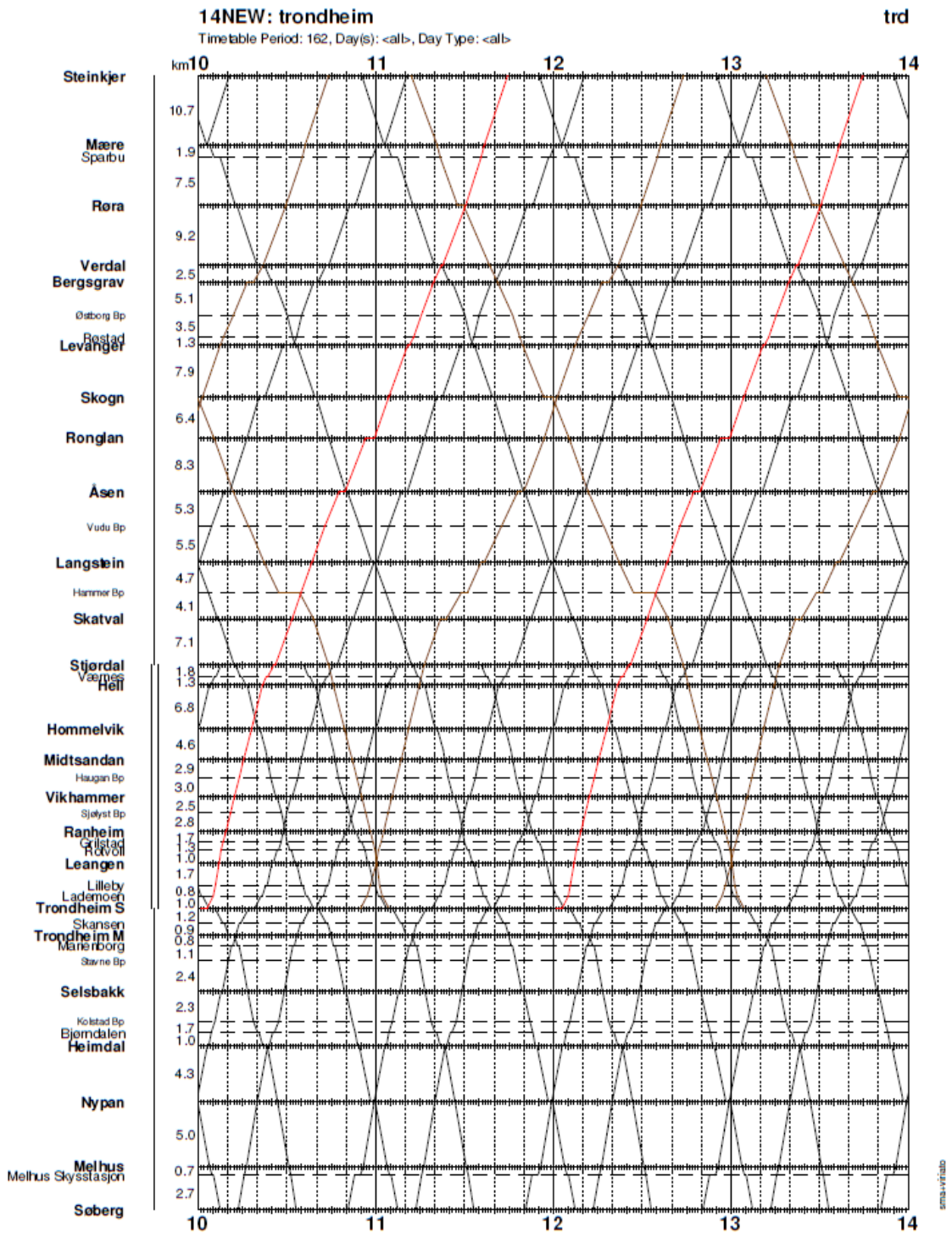


Figure 43-Scenario B

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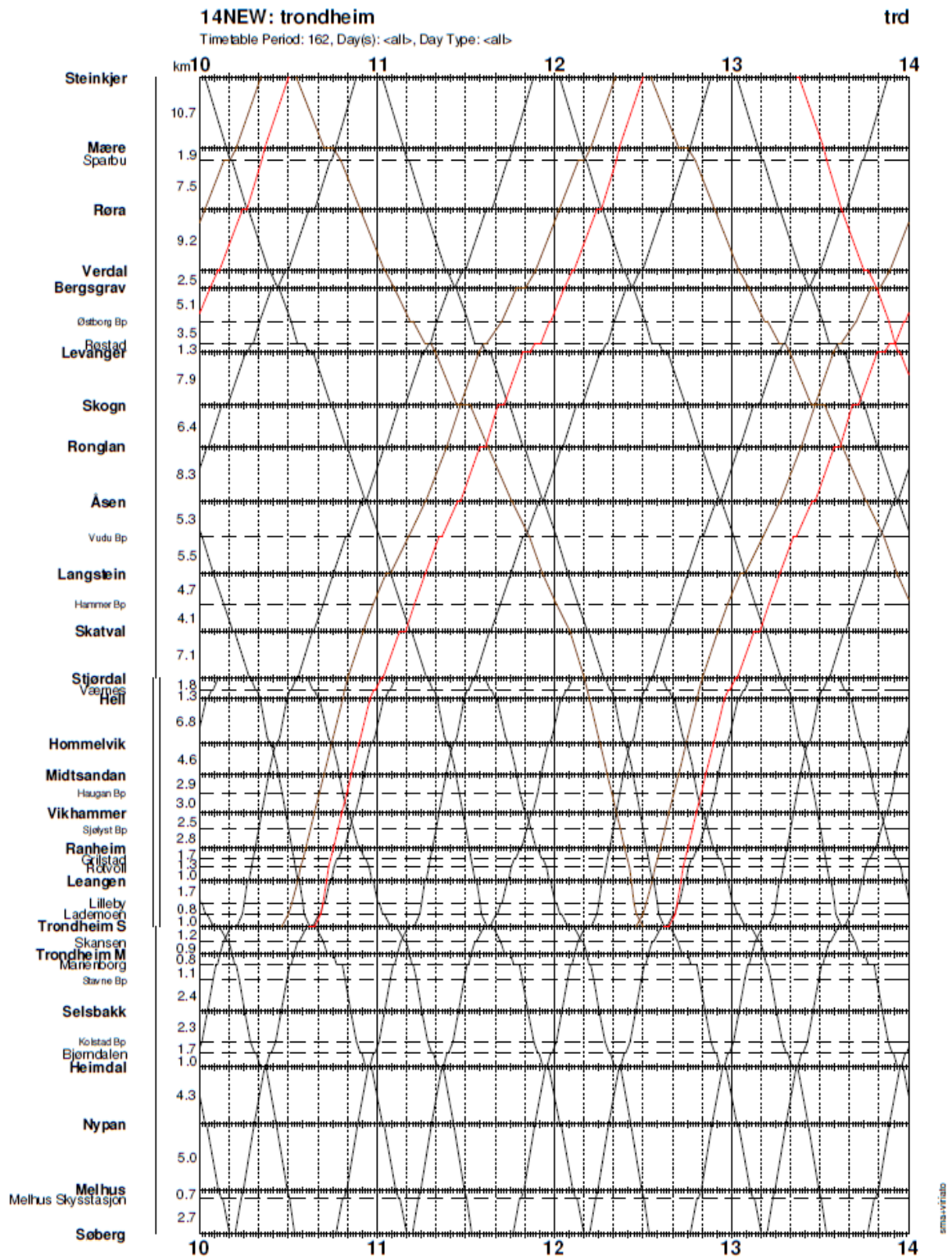


Figure 44-Scenario C

6.7 DISCUSSION

The methodology for designing a timetable starts with analysis and of all the involved factors the factors. It is obvious from the theory part that the following have to be carefully examined:

- The need to make any alterations that are going to cost a lot of money, in a line where is not “needed”. The optimal transportation system in any case is the so-called “door-to-door”. It is every passenger’s wish to be transferred from his starting point to his destination point. This has to be examined from the demand aspect. Taking for granted that the infrastructure manager cannot fulfill everyone’s wish the aspect from which the alterations are going to be made has to be defined. This will also give an answer to the question: “Do we need to make alterations in this line?”
- The optimal use of track capacity. This is relevant as other factors have to be taken into account. For example, you may have an alternative plan A and an alternative B, and the second one to give increase capacity to the network but to the degree that is impossible (due to other limitations that have not be taken into account). To compare two alternative plans, one has to be aware not only of the scope that this comparison is being made but also of the constraints of the line that sometimes are not obvious from the first glance.
- Defining the frequencies for each route. To do that someone has to be aware of the demand. The demand is also relevant to the number of the population. This demand is also a criterion to evaluate alternative timetables. A crossing made in a station with a great demand, from example Trondheim, is more attractive that a crossing made in a stop with low demand or a block post.
- How the transportation means are being connected is also important. A highway parallel to a train track can be a competitor. While designing and evaluating it is important to have a clear image of the transportation map. This is also relevant to the demand. On the other hand is a challenge to make the railway more

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“attractive” to the user by various means with the help of marketing and the proper use of infrastructure.

- Each line has a specific number of trains to be used. Putting more in planning, even for the sake of increasing the capacity leads to utopia. It is obvious that the optimal situation is this one that every train is being used in the line. The capacity in this case is increased and the stability of the network (Figure 2) is increased especially when homogeneity is big (same type of trains in the line). In this case, as a family of trains has been used in scheduling, the stability and heterogeneity are increased.
- Operational issues that have to do with the shifts are also important if not crucial. The infrastructure manager cannot design and evaluate factors without taking into account the laws of the employees and the shifts.
- The railway policy from a social or economic aspect. That is defined from the government, the relevant departments and the stakeholders.

It is easier to quantify all the essential points that can make clear which is the optimum scenario.

The scenarios have the following characteristics:

Table 10- Final scenarios

	Scenario A	Scenario B	Scenario C
Steinkjer-Søberg Total travel time	2h 2 min	2 h 12 min	2h 8 min
Søberg-Steinkjer Total travel time	2h 1 min	2h 18 min	2 h 7 min
Crossings between	Verdal, Levanger, Åsen, Skatval, Nypan	Mære, Verdal, Levanger, Åsen, Langstein, Heimdal	Mære, Røra, Åsen, Langstein, Skatval, Heimdal

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Steinkjer-Søberg			
Crossings between Søberg-Steinkjer	Åsen, Levanger, Verdal	Langstein, Levanger, Mære	Heimdal, Åsen, Vudu Bp, Røstad, Røra, Mære
Number of train sets for Steinkjer-Søberg	5	6	5
Søberg-Stjørdal Total travel time	55 min	53 min	54 min
Stjørdal-Søberg Total travel time	58 min	57 min	55 min
Number of train sets for Søberg-Stjørdal	3	3	4
Crossings at	Bjørndalen	Heimdal	Heimdal
More Crossings needed for this scenario	Rødstad-Ronglan-Verdal-Hammer Bp	Skøgn-Hammer Bp- Røra	Skogn, Ronglan, Rødstad
Best Scenario	X		

The choice of the best scenario was being conducted by the comparison of the number of sets and the driving times.

The best scenario according to the above table is scenario A. In this scenario the designed crossings are in:

- Verdalen,
- Levanger,
- Åsen,

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- Skatval,
- Nypan
- Bjørdalen
- Rødstad
- Ronglan

Table 11- Situation according to the JBV network statement 2013

Crossing	km	Number of spor	Length (m) of spor	Length of the platform (m)	Height of the platform (m)	Crossing Loop
VERDAL	96,2	1-2	283-345	318/111	0,60/0,57	yes
LEVANGER	83,9	1-3	496-613	323/109	0,55/0,57	yes
ÅSEN	61,4	1-2	690-690	54/36	0,62/0,25	yes
SKATVAL	41,9	1-2	700-700	111/110	0,42/0,54	yes
NYPAN	537,1	1-2	308			yes
RØDSTAD	85,2	1		61	0,56	no
RONGLAN	69,7	1	309	114	0,36	no

In order to get the best scenario modifications in the line have to take place.

To evaluate the robustness of the timetables the amount primary/ secondary delays has been evaluated. This has to be less than one. The primary delays have to be smaller than the secondary to increase robustness in timetabling.

Can we just electrify the line without doing any other major changes?

It seems that in order to get the best scenario with the procedure described above the line has to undergo the changes that have been described to the above table.

6.8 Conclusion of the case study

The best scenario according to the above table is scenario A. In this scenario the designed crossings are in: Verdalen, Levanger, Åsen, Skatval, Nypan, Bjørdalen, Rødstad and Ronglan. The line has to undergo some alterations in order to get the suggested scenario. These include extension of the platform to 75m in Åsen, Nypan, Bjørdalen, Rødstad and crossing loop to Rødstad and Ronglan. Just by electrifying the line the suggested scenario cannot be obtained. Electrification gives the possibility to trains with larger maximum velocity to run the line. This as a measure seems positive but on the other hand cannot contribute substantially to the planning procedure. The line, when it is single and with the variety of traffic that runs to it has a locked crossing pattern that prevents trains to take advantage of the maximum capacities.

In order to get the suggested scenario, the alterations that have to be made appear to the table.

Table 12- Changes in the line

VERDAL	None
LEVANGER	None
ÅSEN	Extension of the platform to 75 m
SKATVAL	
NYPAN	Extension of the platform to 75 m
RØDSTAD	Crossing loop, extension of the platform to 75 m
BJØRDALEN	Platform at least 75 m
RONGLAN	Crossing loop

In the best scenario the buffer times have been placed for some trains in the stations and for some other in between in order to achieve the favorable crossings. Placing buffer times between the stations would create crossings that would on the one hand secure the safe operations of the network but on the other hand it would not be as functional as in the case assigning buffer times to the stations. The reason for this is that users (passengers,

drivers) can use the assigned buffer time for functional activities (get in, out of the train etc)

7. CONCLUSION

7.1 Placement of slack

1. Where the slack should be placed during the scheduling procedure in order to avoid delays and / or prevent them scattered?

- The buffer time is the smallest slot between the blocking time stairways of two trains and it depends on several factors. When the second train has a priority, the buffer time is larger (Pachl, 2008). Planning sufficient headway between train paths is an essential requirement of scheduling. There are two main logics when it comes to assigning headways. They can either be assigned to the stations that limit a section or to the station between two stations (Pachl, 2008).
- Assigning headways to stations is the more traditional principle is very common in scheduling.
- Today, most railways still allocate buffer time in a deterministic way i.e. to have fixed minimum buffer times to be added to the different kinds of train combinations. Current research activities try to develop procedures for a stochastic modelling of buffer time allocations (Hansen 2004).
- Swiss railways already use the principle that in terminal areas with a very high density of traffic, train paths may be planned without buffer if sufficient recovery time for making up delay is added to the running time between terminals (Herrmann 2006).

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- An exact allocation of a buffer time to each train path in accordance with the rules above only makes sense in an accurately scheduled operation where the train sequence seldom changes (Pachl, 2008).
 - Anne Christine Torp Handstanger (2009) uses in her Phd thesis a mathematical analytical model that makes use of exponentially distributed buffer times between the trains of higher priority in the schedule.
 - For a stochastic modelling of the transfer, Goverde 2005 gives a detailed procedure while Jianxin Yuan and Ingo A. Hansen (2008) point out several stochastic optimization timetable models that explicitly incorporate reliability and punctuality of scheduled trains. These include Carey (1994) and Vromans (2005) and are being used to optimize the allocation of time supplements.
 - In their paper Jianxin Yuan and Ingo A. Hansen (2008) use a model for optimally allocating the buffer times between consecutive trains at a railway junction in an analytical manner (Caimi, 2009). In this paper it is being also suggested a decomposition of the problem geographically into condensation and compensation zones. Different policies for generating train schedules are then applied to the two zones according to their properties. Time reserves are removed from the condensation zones and moved to the compensation zones, where more capacity is available.
 - Kroon, Marti, Helmrich, Vromans, and Dekker (2008), point out a stochastic optimization model that allocates the time supplements and the buffer times in a given timetable to achieve maximum robustness.
2. How the routing should be planned in order to maximize the probability of avoiding delays?
- Routing trains through railway stations is an integral part of railway timetabling, particularly in dense systems. Without this, there is no effective timetable

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(Pachl, 2008) .Railway stations are the main source of delays in dense railway systems. Therefore, focusing on the robust routing of trains there is highly relevant in terms of punctuality. Robustness here again means insensitivity of the railway system to small disturbances in the real-time operations.

- Pachl underlines Zwaneveld et al. (1996, 2001) and the model is based on the concept of conflict graphs. A similar approach is used by Billionet (2003).
- In addition, Caimi (2005) presents a heuristic algorithm for finding delay tolerant routings based on an iterative fixed point method while Carey and Carville (2003) 'describe a heuristic algorithm for modifying a draft timetable at a station that gives rise to a conflict-free routing' Pachl (2008). Carey and Crawford (2007) take this one step further. Analytic models based on queuing theory for minimising the scheduled waiting times are described by Wakob (1985) and Wendler (2007).
- Carey and Crawford (2007) extend the algorithm to several stations along a railway corridor.

7.2 Best scenario

The best scenario according to the above table is scenario A. In this scenario the designed crossings are in: Verdal, Levanger, Åsen, Skatval, Nypan, Bjørdalen, Rødstad and Ronglan. The line has to undergone some alterations in order to get the suggested scenario. These include extension of the platform to 75m in Åsen, Nypan, Bjørdalen, Rødstad and crossing loop to Rødstad and Ronglan. Just by electrifying the line the suggested scenario cannot be obtained. Electrification gives the possibility to trains with larger maximum velocity to run the line. This as a measure seems positive but on the other hand cannot contribute substantially to the planning procedure. The line, when it is single and with the variety of traffic that runs to it has a locked crossing pattern that prevents trains to take advantage of the maximum capacities. The buffer times have been assigned to stations in this case and that proves the theory part that claims it is

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very common in scheduling. In clock phase periodical diagrams that stochastic routes are not included the number of available crossings in a mixed traffic (cargos, long distant, local trains with a mixture of velocities) are limited. This makes the procedure more difficult and less flexible. Then, the chance to meet the needs of both the market and those that they use the line is limited. Assigning buffer times to the stations is more functional friendly and it is being followed.

7.3 Further work

A different synthesis of trains can be examined. Tunnels and variations from the existing line can be included to make the calculation. The network can be examined as part of a bigger, extended network in order to make conclusions. The demand in each station is also a very important criterion that has to be taken into consideration. A comparison of the costs between construction a double line and electrifying it can be made.

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APPENDICES

vehicle data

Vehicle data	Long Local	Short Regional
Customer	Norwegian State Railways (NSB)	
Lines operated	S-Bahn Oslo	Southern Norway
Gauge	1435 mm	"
Catenary supply voltage	15 kV, 16.7 Hz	"
Axle arrangement	Bo'2'2'Bo'+2'2'Bo'	"
Number of vehicles	26	24
Service start-up	2012–2013	2011–2012
Seating capacity (comfort)	235	216 (44)
Resting seat	36	30
Fold up seats	24	18
Floor height		
Low floor	800 mm	"
High floor	1180 mm	"
Door width	1300 mm	"
Longitudinal strength	1500 kN	"
Overall length	105.5 m	"
Vehicle width	3200 mm	"
Vehicle height	4380 mm	"
Tare weight	216.3 t	218.1 t
Bogie wheelbase		
Power bogie	2500 mm	"
Trailer bogie	2750 mm	"
Powered wheel diameter	920 mm	"
Trailer wheel diameter	920 mm	"
Maximum output at wheel	4500 kW	"
Starting tractive power	240 kN	"
Maximum speed	200 kph	"

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Train ID	Description	Notes
NSB RT 10701	Trondheim S - Bodo	Description
Train Group	Version ID	
flog Nordland	test	<input checked="" type="checkbox"/> Active <input type="checkbox"/> Study

Train Numbers (1) Schedule (2) Filters (3) **Train Basic Data (4)**

Train Configuration

ID	Description
0	D14-m/Inke/0/298/200.0/0/P/119

Copy Conf.
Del. Conf.

Train Formation

Brake Global train configuration

Constr. Speed Push-Pull ready Tilting active

Rolling Stock ID	Series	Length (m)	Max. Speed (km/h)	Gross Weight (ton)	Braking Weight P (t)
D14	m/Inke	34.8	120	152.6	84.2

Rolling Stock : [Internal]

All Filter UIC

Engine(s)	Series	Max.
BM69	0	130
BM70	0	160
BM71	0	210
BM72	0	160
BM73	0	210
BM75	0	200
BM92	0	140

Train basic data for running time calculation

Engine(s)	Total Length (m)	Train Weight (t)	Seats (1st/2nd class)
D14-m/Inke	200.0	298	0 / 0

Coaches Max. Speed Braking %

0 120 119

Comments to run time calculation | Last run time calc: 6/8/2013 10:27:35 PM

Speed Profile Type Train Influence % Add. Time % Add. Load Additional Remarks to the Running Time Calculation

1-H 0 - none Cargo

Database Settings Infrastructure Rolling Stock Trains Timetable Netgraph Reports Window ?

Train ID	Description	Notes
CN GT 10600	CargoNet A/S	Description
Train Group	Version ID	
godstogtrd	test	<input checked="" type="checkbox"/> Active <input type="checkbox"/> Study

Train Numbers (1) Schedule (2) Filters (3) **Train Basic Data (4)**

Train Configuration

ID	Description
0	CD312-0/0/1077/600.0/0/P/76

Copy Conf.
Del. Conf.

Train Formation

Brake Global train configuration

Constr. Speed Push-Pull ready Tilting active

Rolling Stock ID	Series	Length (m)	Max. Speed (km/h)	Gross Weight (ton)	Braking Weight P (t)
CD312	0	23	120	123	150

Rolling Stock : [Internal]

All Filter UIC

Engine(s)	Series	Max.
BM69	0	130
BM70	0	160
BM71	0	210
BM72	0	160
BM73	0	210
BM75	0	200
BM92	0	140

Train basic data for running time calculation

Engine(s)	Total Length (m)	Train Weight (t)	Seats (1st/2nd class)
CD312-0	600.0	1077	0 / 0

Coaches Max. Speed Braking %

0 120 76

Comments to run time calculation | Last run time calc: 6/8/2013 10:37:59 PM

Speed Profile Type Train Influence % Add. Time % Add. Load Additional Remarks to the Running Time Calculation

1-H 0 - none Cargo

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Train Numbers (1)
Schedule (2)
Filters (3)
Train Basic Data (4)

Train Configuration

ID	Description	
0	RABe521-0/0/0/74.1/0/P/185	Copy Conf.
		Del. Conf.

Train Formation

Brake Global train configuration
 Constr. Speed Push-Pull ready
 Tilting active

Rolling Stock ID	Series	Length (m)	Max. Speed (km/h)	Gross Weight (ton)	Braking Weight P (t)
RABe521	0	74.1	160	141	260.9

Rolling Stock - [Internal]

All Filter UIC

Engine(s)	Series	Max. ▲
BM69	0	130
BM70	0	160
BM71	0	210
BM72	0	160
BM73	0	210
BM75	0	200
BM92	0	140

Train basic data for running time calculation

Engine(s)	Total Length (m)	Train Weight (t)	Seats (1st/2nd class)
RABe521-0	74.1	0	0 0
Coaches	Max. Speed	Braking %	
0	160	185	

Comments to run time calculation | Last run time calc: 6/8/2013 7:27:19 PM

Speed Profile Type	Train Influence	% Add. Time	% Add. Load	Additional Remarks to the Running Time Calculation	<input type="checkbox"/> Cargo
2P	0 - none				

Nodes
Train Family
Running Time Calculat

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Calculated passenger timetables for scenario A (best scenario)

14NEW: Steinkjer - Søberg

trd

Timetable Period: 162, Day(s): <all>, Day Type: <all>

Train Type	Lt	Rt	Gt	Rt	Gt	Rt	Gt	Lt	Rt	Lt	Lt	Lt	Rt	Lt
Train Number	10433	10720	10628	10724	10632	10728	10636	10501	10732	10503	10401	10505	10736	10403
Operating Day	DAG	DAG	DAG+	DAG+	DAG+	DAG+	DAG+	DAG	DAG+	DAG	DAG	DAG	DAG+	DAG
km	From:	Bodo	Bodo	Bodo	Bodo	Bodo	Bodo		Bodo				Bodo	
0 Steinkjer	22:19	22:46		0:46		2:46			4:46		6:19		6:46	7:19
13 Sparbu	22:28										6:28			7:28
20 Røra	22:33										6:33			7:33
29 Verdal	22:43	23:15		1:15		3:15			5:15		6:43		7:15	7:43
32 Bergsgrav	22:46		0:18		2:18		4:18				6:46			7:46
40 Røstad	22:53										6:53			7:53
42 Levanger	22:54	23:30	0:31	1:30	2:31	3:30	4:31		5:30		6:54		7:30	7:54
49 Skogn	23:01										7:01			8:01
56 Ronglan	23:06										7:06			8:06
64 Asen	23:14										7:14			8:14
84 Skatval	23:29										7:29			8:29
91 Stjørdal	23:34	0:17		2:17		4:17		6:01	6:17	7:01	7:34	8:01	8:17	8:34
93 Værnes	23:36	0:20		2:20		4:20		6:03	6:20	7:03	7:36	8:03	8:20	8:36
94 Hell								6:05		7:05		8:05		
101 Hommelvik	23:41							6:09		7:09	7:41	8:09		8:41
111 Vikhammer								6:15		7:15		8:15		
118 Grilstad								6:20		7:20		8:20		
119 Rotvoll														
120 Leangen	23:51							6:23		7:23	7:51	8:23		8:51
122 Lilleby								6:25		7:25		8:25		
123 Lademoen								6:26		7:26		8:26		
124 Trondheim S	o 23:54	0:39	1:45	2:39	3:45	4:39	5:45	6:29	6:39	7:29	7:54	8:29	8:39	8:54
Trondheim S	23:56							6:31		7:31	7:56	8:31		8:56
125 Skansen								6:34		7:34		8:34		
127 Marienborg	0:01							6:37		7:37	8:01	8:37		9:01
130 Selsbakk														
134 Bjørndalen	0:08							6:46		7:46	8:08	8:46		9:08
135 Heimdal	0:10							6:47		7:47	8:10	8:47		9:10
145 Melhus Skystasjon	0:18							6:56		7:56	8:18	8:56		9:18
148 Søberg	o 0:21							6:59		7:59	8:21	8:59		9:21
To:														

14NEW: Steinkjer - Søberg

trd

Timetable Period: 162, Day(s): <all>, Day Type: <all>

Train Type	Lt	Lt	Lt	Lt	Lt	Gt	Lt	Lt	Lt	Lt	Gt	Lt	Lt	Rt
Train Number	10507	10405	10509	10407	10511	10600	10409	10513	10411	10515	10604	10413	10517	10700
Operating Day	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG
km	From:					Bodo					Bodo			Bodo
0 Steinkjer			8:19		9:19		10:19		11:19		12:19			12:46
13 Sparbu			8:28		9:28		10:28		11:28		12:28			
20 Røra			8:33		9:33		10:33		11:33		12:33			
29 Verdal			8:43		9:43		10:43		11:43		12:43			13:15
32 Bergsgrav			8:46		9:46	10:18	10:46		11:46		12:46			
40 Røstad			8:53		9:53		10:53		11:53		12:53			
42 Levanger			8:54		9:54	10:31	10:54		11:54		12:54			13:30
49 Skogn			9:01		10:01		11:01		12:01		13:01			
56 Ronglan			9:06		10:06		11:06		12:06		13:06			
64 Asen			9:14		10:14		11:14		12:14		13:14			
84 Skatval			9:29		10:29		11:29		12:29		13:29			
91 Stjørdal	9:01	9:34	10:01	10:34	11:01		11:34	12:01	12:34	13:01	13:34	14:01	14:17	14:17
93 Værnes	9:03	9:36	10:03	10:36	11:03		11:36	12:03	12:36	13:03	13:36	14:03	14:20	14:20
94 Hell	9:05		10:05		11:05			12:05		13:05		14:05		
101 Hommelvik	9:09	9:41	10:09	10:41	11:09		11:41	12:09	12:41	13:09	13:41	14:09		
111 Vikhammer	9:15		10:15		11:15			12:15		13:15		14:15		
118 Grilstad	9:20		10:20		11:20			12:20		13:20		14:20		
119 Rotvoll														
120 Leangen	9:23	9:51	10:23	10:51	11:23		11:51	12:23	12:51	13:23	13:51	14:23		
122 Lilleby	9:25		10:25		11:25			12:25		13:25		14:25		
123 Lademoen	9:26		10:26		11:26			12:26		13:26		14:26		
124 Trondheim S	o 9:29	9:54	10:29	10:54	11:29	11:45	11:54	12:29	12:54	13:29	13:45	13:54	14:29	14:39
Trondheim S	9:31	9:56	10:31	10:56	11:31		11:56	12:31	12:56	13:31	13:56	14:31		
125 Skansen	9:34		10:34		11:34			12:34		13:34		14:34		
127 Marienborg	9:37	10:01	10:37	11:01	11:37		12:01	12:37	13:01	13:37	14:01	14:37		
130 Selsbakk														
134 Bjørndalen	9:46	10:08	10:46	11:08	11:46		12:08	12:46	13:08	13:46	14:08	14:46		
135 Heimdal	9:47	10:10	10:47	11:10	11:47		12:10	12:47	13:10	13:47	14:10	14:47		
145 Melhus Skystasjon	9:56	10:18	10:56	11:18	11:56		12:18	12:56	13:18	13:56	14:18	14:56		
148 Søberg	o 9:59	10:21	10:59	11:21	11:59		12:21	12:59	13:21	13:59	14:21	14:59		
To:														

PANAGIOTA KOSTARA
 Timetable analysis for local trains. Case study of Trønderbanen

14NEW: Steinkjer - Søberg

trd

Timetable Period: 162, Day(s): <all>, Day Type: <all>

Train Type	Lt	Lt	Gt	Lt	Lt	Rt	Lt	Lt	Gt	Lt	Lt	Rt	Lt	Lt
Train Number	10415	10519	10608	10417	10521	10704	10419	10523	10612	10421	10525	10708	10423	10527
Operating Day	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG
km	From: Bodo													
0 Steinkjer	13:19			14:19		14:46	15:19			16:19		16:46	17:19	
13 Spærbu	13:28			14:28			15:28			16:28			17:28	
20 Røra	13:33			14:33			15:33			16:33			17:33	
29 Verdal	13:43			14:43		15:15	15:43			16:43		17:15	17:43	
32 Bergsgrav	13:46		14:18	14:46			15:46		16:18	16:46			17:46	
40 Røstad	13:53			14:53			15:53			16:53			17:53	
42 Levanger	13:54		14:31	14:54		15:30	15:54		16:31	16:54		17:30	17:54	
49 Skogn	14:01			15:01			16:01			17:01			18:01	
56 Ronglan	14:06			15:06			16:06			17:06			18:06	
64 Asen	14:14			15:14			16:14			17:14			18:14	
84 Skatval	14:29			15:29			16:29			17:29			18:29	
91 Stjørdal	14:34	15:01		15:34	16:01	16:17	16:34	17:01		17:34	18:01	18:17	18:34	19:01
93 Værnes	14:36	15:03		15:36	16:03	16:20	16:36	17:03		17:36	18:03	18:20	18:36	19:03
94 Hell		15:05			16:05			17:05		18:05			19:05	
101 Hommelvik	14:41	15:09		15:41	16:09		16:41	17:09		17:41	18:09		18:41	19:09
111 Vikhammer		15:15			16:15			17:15		18:15			19:15	
118 Grilstad		15:20			16:20			17:20		18:20			19:20	
119 Rotvoll														
120 Leangen	14:51	15:23		15:51	16:23		16:51	17:23		17:51	18:23		18:51	19:23
122 Lilleby		15:25			16:25			17:25		18:25			19:25	
123 Lademoen		15:26			16:26			17:26		18:26			19:26	
124 Trondheim S	o 14:54	15:29	15:45	15:54	16:29	16:39	16:54	17:29	17:45	17:54	18:29	18:39	18:54	19:29
Trondheim S		15:31		15:56	16:31		16:56	17:31		17:56	18:31		18:56	19:31
125 Skansen		15:34			16:34			17:34		18:34			19:34	
127 Marienborg	15:01	15:37		16:01	16:37		17:01	17:37		18:01	18:37		19:01	19:37
130 Selsbakk														
134 Bjørndalen	15:08	15:46		16:08	16:46		17:08	17:46		18:08	18:46		19:08	19:46
135 Heimdal	15:10	15:47		16:10	16:47		17:10	17:47		18:10	18:47		19:10	19:47
145 Melhus Skystasjon	15:18	15:56		16:18	16:56		17:18	17:56		18:18	18:56		19:18	19:56
148 Søberg	o 15:21	15:59		16:21	16:59		17:21	17:59		18:21	18:59		19:21	19:59
	to:													

PANAGIOTA KOSTARA
Timetable analysis for local trains. Case study of Trønderbanen

14NEW: Steinkjer - Søberg

trd

Timetable Period: 162, Day(s): <all>, Day Type: <all>

Train Type	Train Number	Operating Day	Gt	Lt	Li	Rt	Lt	Li	Gt	Lt	Li	Rt	Lt	Gt	Li	Rt	
			10616	10425	10529	10712	10427	10531	10620	10429	10533	10716	10431	10624	10433	10720	
			DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	
km	From:		Bode			Bode			Bode			Bode		Bode		Bode	
0	Steinkjer			18:19		18:46	19:19			20:19		20:46	21:19			22:19	22:46
13	Sparbu			18:28			19:28			20:28			21:28			22:28	
20	Røra			18:33			19:33			20:33			21:33			22:33	
29	Verdal			18:43		19:15	19:43			20:43		21:15	21:43			22:43	23:15
32	Bergsgrav		18:18	18:46			19:46		20:18	20:46			21:46	22:18		22:46	
40	Røstad			18:53			19:53			20:53			21:53			22:53	
42	Levanger		18:31	18:54		19:30	19:54		20:31	20:54		21:30	21:54	22:31		22:54	23:30
49	Skogn			19:01			20:01			21:01			22:01			23:01	
56	Ronglan			19:06			20:06			21:06			22:06			23:06	
64	Asen			19:14			20:14			21:14			22:14			23:14	
84	Skatval			19:29			20:29			21:29			22:29			23:29	
91	Stjørdal			19:34	20:01	20:17	20:34	21:01		21:34	22:01	22:17	22:34			23:34	0:17
93	Værnes			19:36	20:03	20:20	20:36	21:03		21:36	22:03	22:20	22:36			23:36	0:20
94	Hell				20:05			21:05			22:05						
101	Hommelvik			19:41	20:09		20:41	21:09		21:41	22:09		22:41		23:41		
111	Vikhammer				20:15			21:15			22:15						
118	Grilstad				20:20			21:20			22:20						
119	Rotvoll																
120	Leangen			19:51	20:23		20:51	21:23		21:51	22:23		22:51		23:51		
122	Lilleby				20:25			21:25			22:25						
123	Lademoen				20:26			21:26			22:26						
124	Trondheim S	o	19:45	19:54	20:29	20:39	20:54	21:29	21:45	21:54	22:29	22:39	22:54	23:45	23:54	0:39	
	Trondheim S			19:56	20:31		20:56	21:31		21:56	22:31		22:56		23:56		
125	Skansen				20:34			21:34			22:34						
127	Marienborg			20:01	20:37		21:01	21:37		22:01	22:37		23:01		0:01		
130	Selsbakk																
134	Bjørndalen			20:08	20:46		21:08	21:46		22:08	22:46		23:08		0:08		
135	Heimdalen			20:10	20:47		21:10	21:47		22:10	22:47		23:10		0:10		
145	Melhus Skystasjon			20:18	20:56		21:18	21:56		22:18	22:56		23:18		0:18		
148	Søberg	o		20:21	20:59		21:21	21:59		22:21	22:59		23:21		0:21		
	To:																

+: Runs according to the operating day of the previous day

14NEW: Søberg - Steinkjer

trd

Timetable Period: 162, Day(s): <all>, Day Type: <all>

Train Type	Train Number	Operating Day	Lt	Rt	Rt	Gt	Gt	Gt	Li	Lt	Rt	Li	Lt	Gt	Li	Li	
			10434	10733	10737	10601	10603	10605	10500	10402	10701	10502	10404	10607	10504	10406	
			DAG	DAG	DAG+	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	
km	From:		Bode			Bode			Bode			Bode		Bode		Bode	
0	Søberg		22:04						5:32	6:04		6:32	7:04			7:32	8:04
3	Melhus Skystasjon		22:06						5:35	6:06		6:35	7:06			7:35	8:06
13	Heimdalen		22:17						5:44	6:17		6:44	7:17			7:44	8:17
14	Bjørndalen		22:19						5:45	6:19		6:45	7:19			7:45	8:19
18	Selsbakk																
21	Marienborg		22:26						5:52	6:26		6:52	7:26			7:52	8:26
23	Skansen								5:55			6:55				7:55	
24	Trondheim S	o	22:31						5:58	6:31		6:58	7:31		7:58	8:31	
	Trondheim S		22:33	22:43	0:43	1:57	3:57	5:57	6:00	6:33	6:43	7:00	7:33	7:57	8:00	8:33	
25	Lademoen								6:02			7:02				8:02	
26	Lilleby								6:04			7:04				8:04	
28	Leangen		22:37						6:06	6:37		7:06	7:37		8:06	8:37	
29	Rotvoll																
30	Grilstad								6:08			7:08				8:08	
37	Vikhammer								6:14			7:14				8:14	
47	Hommelvik		22:46						6:20	6:46		7:20	7:46		8:20	8:46	
54	Hell								6:24			7:24				8:24	
55	Værnes		22:51	23:03	1:03				6:26	6:51	7:03	7:26	7:51		8:26	8:51	
57	Stjørdal		22:53	23:05	1:05				6:28	6:53	7:05	7:28	7:53	8:28	8:53		
64	Skatval		22:59			2:28	4:28	6:28	6:27			7:27	7:59	8:28	8:59		
84	Asen		23:14			2:53	4:53	6:53		7:14		8:14	8:53		9:14	9:20	
92	Ronglan		23:20							7:20		8:20			9:20		
98	Skogn		23:25							7:25		8:25			9:25		
106	Levanger		23:32	23:54	1:54					7:32	7:54	8:32			9:32		
108	Røstad		23:34							7:34		8:34			9:34		
116	Bergsgrav		23:41							7:41		8:41			9:41		
119	Verdal		23:44	0:13	2:13					7:44	8:13	8:44			9:44		
128	Røra		23:51							7:51		8:51			9:51		
135	Sparbu		23:57							7:57		8:57			9:57		
148	Steinkjer	o	0:05	0:37	2:37					8:05	8:37	9:05			10:05		
	To:			Bode	Bode	Bode	Bode	Bode			Bode		Bode				

PANAGIOTA KOSTARA
Timetable analysis for local trains. Case study of Trønderbanen

14NEW: Søberg - Steinkjer

trd

Timetable Period: 162, Day(s): <all>, Day Type: <all>

Train Type	RI	LI	LI	GI	LI	LI	RI	LI	LI	GI	LI	LI	RI	LI
Train Number	10705	10506	10408	10609	10508	10410	10709	10510	10412	10611	10512	10414	10713	10514
Operating Day	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG
km	From:													
0	Søberg	8:32	9:04		9:32	10:04		10:32	11:04		11:32	12:04		12:32
3	Melhus Skystasjon	8:35	9:06		9:35	10:06		10:35	11:06		11:35	12:06		12:35
13	Heimdalen	8:44	9:17		9:44	10:17		10:44	11:17		11:44	12:17		12:44
14	Bjemdalen	8:45	9:19		9:45	10:19		10:45	11:19		11:45	12:19		12:45
18	Selsbakk													
21	Marienborg	8:52	9:26		9:52	10:26		10:52	11:26		11:52	12:26		12:52
23	Skansen	8:55			9:55			10:55			11:55			12:55
24	Trondheim S	8:58	9:31		9:58	10:31		10:58	11:31		11:58	12:31		12:58
24	Trondheim S	o												
25	Lademoen	8:43	9:00	9:33	9:57	10:00	10:33	10:43	11:00	11:33	11:57	12:00	12:33	12:43
26	Lilleby	9:02				10:02		11:02			12:02			13:02
28	Leangen	9:04				10:04		11:04			12:04			13:04
29	Rotvoll	9:06	9:37			10:06	10:37	11:06	11:37		12:06	12:37		13:06
30	Grilstad		9:08			10:08		11:08			12:08			13:08
37	Vikhammer		9:14			10:14		11:14			12:14			13:14
47	Hommelvik		9:20	9:46		10:20	10:46	11:20	11:46		12:20	12:46		13:20
54	Hell		9:24			10:24		11:24			12:24			13:24
55	Værnes	9:03	9:26	9:51		10:26	10:51	11:03	11:26	11:51	12:26	12:51	13:03	13:26
57	Stjørdal	9:05	o9:27	9:53		o10:27	10:53	11:05	o11:27	11:53	o12:27	12:53	13:05	o13:27
64	Skatval			9:59	10:28		10:59		11:59	12:28		12:59		
84	Åsen			10:14	10:53		11:14		12:14	12:53		13:14		
92	Ronglan			10:20			11:20		12:20			13:20		
98	Skogn			10:25			11:25		12:25			13:25		
106	Levanger	9:54		10:32			11:32	11:54	12:32			13:32	13:54	
108	Røstad			10:34			11:34		12:34			13:34		
116	Bergsgrav			10:41			11:41		12:41			13:41		
119	Verdal	10:13		10:44			11:44	12:13	12:44			13:44	14:13	
128	Røra			10:51			11:51		12:51			13:51		
135	Spæbu			10:57			11:57		12:57			13:57		
148	Steinkjer	o	10:37	11:05			12:05	12:37	13:05			14:05	14:37	
	To:	Borb			Borb			Borb			Borb			Borb

PANAGIOTA KOSTARA
Timetable analysis for local trains. Case study of Trønderbanen

14NEW: Søberg - Steinkjer

trd

Timetable Period: 162, Day(s): <all>, Day Type: <all>

Train Type	Lt	Gt	Lt	Lt	Rt	Lt	Lt	Gt	Lt	Lt	Rt	Lt	Lt	Gt
Train Number	10416	10613	10516	10418	10717	10518	10420	10615	10520	10422	10721	10522	10424	10617
Operating Day	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG	DAG
km	From:													
0 Søberg	13:04		13:32	14:04		14:32	15:04		15:32	16:04		16:32	17:04	
3 Melhus Skystasjon	13:06		13:35	14:06		14:35	15:06		15:35	16:06		16:35	17:06	
13 Heimdal	13:17		13:44	14:17		14:44	15:17		15:44	16:17		16:44	17:17	
14 Bjørndalen	13:19		13:45	14:19		14:45	15:19		15:45	16:19		16:45	17:19	
18 Selsbakk														
21 Marienborg	13:26		13:52	14:26		14:52	15:26		15:52	16:26		16:52	17:26	
23 Skansen			13:55			14:55			15:55			16:55		
24 Trondheim S	o 13:31		13:58	14:31		14:58	15:31		15:58	16:31		16:58	17:31	
Trondheim S	13:33	13:57	14:00	14:33	14:43	15:00	15:33	15:57	16:00	16:33	16:43	17:00	17:33	17:57
25 Lademoen			14:02			15:02			16:02			17:02		
26 Lilleby			14:04			15:04			16:04			17:04		
28 Leangen	13:37		14:06	14:37		15:06	15:37		16:06	16:37		17:06	17:37	
29 Rotvoll														
30 Grilstad			14:08			15:08			16:08			17:08		
37 Vikhammer			14:14			15:14			16:14			17:14		
47 Hommelvik	13:46		14:20	14:46		15:20	15:46		16:20	16:46		17:20	17:46	
54 Hell			14:24			15:24			16:24			17:24		
55 Værnes	13:51		14:26	14:51	15:03	15:26	15:51		16:26	16:51	17:03	17:26	17:51	
57 Stjørdal	13:53		o14:27	14:53	15:05	o15:27	15:53		o16:27	16:53	o17:05	o17:27	17:53	
64 Skatval	13:59	14:28		14:59		15:59	16:28	16:59		17:59		18:28	18:59	19:28
84 Asen	14:14	14:53		15:14		16:14	16:53		17:14			18:14	18:53	
92 Ronglan	14:20			15:20		16:20			17:20			18:20		
98 Skogn	14:25			15:25		16:25			17:25			18:25		
106 Levanger	14:32			15:32	15:54	16:32			17:32	17:54		18:32		
108 Røstad	14:34			15:34		16:34			17:34			18:34		
116 Bergsgrav	14:41			15:41		16:41			17:41			18:41		
119 Verdal	14:44			15:44	16:13	16:44			17:44	18:13		18:44		
128 Røra	14:51			15:51		16:51			17:51			18:51		
135 Sparbu	14:57			15:57		16:57			17:57			18:57		
148 Steinkjer	o 15:05			16:05	16:37	17:05			18:05	18:37		19:05		
To:		Bode			Bode			Bode			Bode			Bode

DEFINITIONS

According to Pachel (2008):

Arrival delay: A deviation of the arrival time from the scheduled arrival time at a station.

Blocking time: The time interval in which a section of track is allocated to the exclusive use of one train and therefore blocked to all other trains.

Buffer time: An extra time that is added to the minimum time headway to avoid the transmission of small delays.

Delay: The deviation from either a scheduled event or process time of a train.

Dwell time: The total elapsed time from the time that a train stops in a station until the time it resumes moving.

Dwell time reserve: amount of time which is added to the calculated dwell times in order to compensate for randomness of real dwell times or to obtain departure times to the full minute.

Headway: The space or time interval between two successive trains.

Initial delay: A delay recorded at the cordons of an investigated network when the train enters the network. Also called primary delay.

Knock on delay: A delay caused by other trains due to either short headway times or late transfer connections.

Original delay: A delay generated within the investigated network and not caused by other trains. Also called primary delay.

Primary delay: Initial or original delay

Recovery time: A time supplement that is added to the pure running time to enable a train to make up for small delays.

Running time reserve: Recovery time

Scheduled waiting time: An artificial increase in the overall timing of a train which is caused by the resolution of conflicts during the scheduling process,

Secondary delay: Knock-on delay

Stochastic process: A process described by probability distributions