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Evaluation of the Effects in Railway Renewal Projects

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PREFACE

This master thesis has been written to fulfill the requirements of the Master of Science (MSc) program in Project Management at the Department of Production and Quality Engineering (IPK) at Norwegian University of Science and Technology (NTNU), Trondheim, Norway. This research work has been carried out under the PRESIS- project, a project to develop the tool to improve the precision level of the railway system in joint collaboration of NTNU and SINTEF (a research wing of NTNU).

On this occasion, I would like to express my sincere gratitude to my supervisor **Nils Olsson**, Professor at Department of Production and Quality Engineering, NTNU for his invaluable guidance and constant support to choose this thesis and realizing the thematic goals of this thesis, without his input this thesis would not have come to reality.

My sincere thanks to **Andreas Dypvik Landmark**, Researcher at SINTEF for his guidance to understand the theoretical and practical implications of Precision tool, developed under *Presis* project that was used to evaluate the effects of the renewed railway projects. My vote of thanks goes to my parents and my siblings for their whole-hearted support in all the phases of my life, their love and prays have been driving force in everything that I have achieved in my life.

I am indebted to **Umer and Faheem**, my class fellows, on assisting me to adjust and improve the quality of this report. On this note, I would like to thank all of my friends from different parts of the world who have extended their support in various forms at different stages of this research work.

Trondheim, June 23rd , 2015

ABSTRACT

The objective of this thesis is to evaluate the effect of the railway renewal project. The effects in the railway is generally evaluated after the completion and after the project is able to generate some data that can be expressed numerically to evaluate the proposed objectives as an ex-post evaluation of the project. It has been always interesting to measure the performances of railway system after executing changes, so the performances of the four renewed railway projects; *Double track between Barkåker and Tønsberg, Gevinåsen tunnel between Hommelvik and Hell, Crossing tracks in Jensrud and Vålåsjø* are evaluated. The defined parameters used to evaluate the performances of railway are line capacity, punctuality, travel time and standard deviations between the two stations nearby that includes the renewed railway infrastructure in between. It has been difficult to identify the exact tool out of number of tools that can evaluate the railway project more precisely.

The thesis is mapped with the use of quantitative and qualitative approaches research techniques. The quantitative approach depending on the results derived from *My train tool and Precision tool* followed by statistical measurement, graphical representation and comparisons of the data set derived before and after the renewed railway projects were able to trace the quantitative change in the performance. In addition, the qualitative research technique followed by analytical comparisons between those two tools was able to predict the suitable tool for evaluation more precisely.

Apart from the result, it has been experienced that there is a need for more evaluation parameters with sufficiently updated data to evaluate the railway project more precisely. Nevertheless, some of the solutions mentioned in the further research part of this thesis will aid in solving these problems.

Keywords: Railway, Punctuality, line capacity, travel time, deviation in travel time, evaluation tools

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CHAPTER ONE

1 INTRODUCTION

The primary objectives of this part are to give the reader an overview of the scope of the project, the problem area of origin, goals determined and buildup of the structure in the report.

1.1 Background

Transportation industry has a prominent and crucial role in the development of national economy by setting the central hub for production and distribution of the goods and services. There are various means of transportation where the railway segment shows the dominant effect as being the easier, cheaper and safe means of transportation (Norli and Næringslivets 2007).

History of development of railway in Norway

Norway's first railway was opened on 1 September 1854 and was between Christiania and Eidsvoll. In 1857 Parliament therefore decided that three new railway lines would be built on 50's continued evolution from steam to electricity and diesel on full. In 1961 Nordland path led to Bodø, and the rail network had when it's greatest length with a total of 4415 kms. Since then there have been laid down some side routes and today's railway network at 4179 km.[i] The detailed picture of the development of railways in time line is shown in the sided diagram as;

Figure 1: Time lime in the development of railway (Jernbaneverket Yearly

The present network of the Norwegian Railway is extended in most part of the country from the most south of Kristiansand to the North Bodø. The detailed map of the railway line is shown in the following diagram.

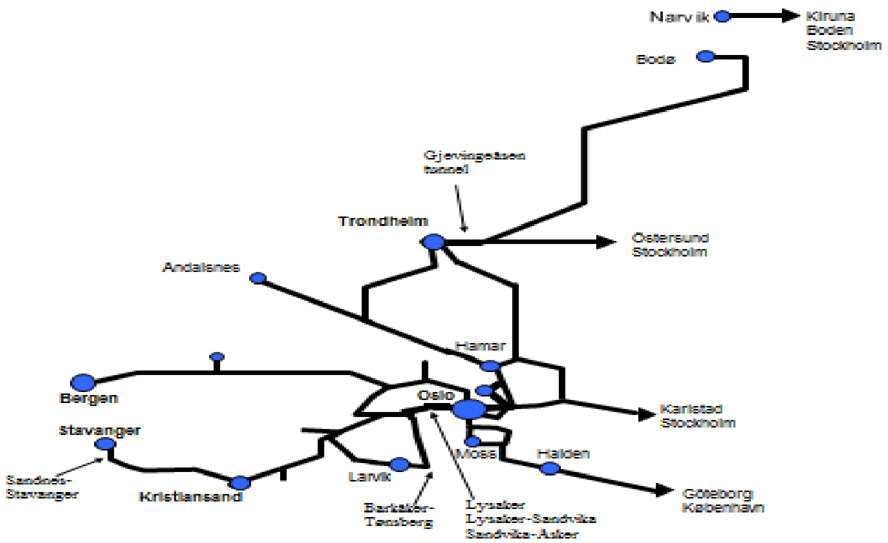


Figure 2: Railway Network in Norway (Sætermo, Olsson et al. 2006)

Scenario on renewal railway project in Norway

Norway have shown a rapid progress in the renewable of the railways system by the modification of the railway track, electrification in the railway line, adopting the various traffic controlling system to boost up the growth in the number of passengers and revenue accordingly. The progress in the renewal railway line shows the significance when the overall punctuality in the eastern line ended up with the achievement of 90, 6 %. The renewal of the railway line is prioritized with the allocation of 168 BNok for the time span of 2014-2023, that shows the huge investment in the renewal project. In contrast, needs the timely evaluation of the project to ensure the achievement of the objective In Norway the NSB (Norwegian State Railways AS) was the core authority responsible in all sorts of railway matters which were broadly divided into the three bodies Norwegian Railway Inspectorate (responsible for supervising all railway operations), Jenbarneverket (maintenance and construction of the tracks) and operating company NSB BA from 1996. (Veiseth, Magnus Hegglund et al. 2011) says that NSB has claimed high standards of train punctuality and make every effort to get passengers to their destination on time as their target is ensured.

1.2 Problem statement

The current pressure of the requirement of more number of railways in Norwegian railway operation focuses more on the matter of construction of railways line. In some extent, it is required to evaluate the effect of the completed railway project to understand the level of achievement, rate of return from the investment to make the infrastructure development more sustainable. In other hand is urgently required for a shift towards more sophisticated and advanced tools for the evaluation of the effects of such completed projects. This requires the development of new basic approaches, methods and tools, modification on existed tool that can support further planning on construction of railways and traffic management.

This research will be based on the comparative analysis of the various renewed railway projects along the different railway line in Norway. The followings are the preliminary problems that were identified which will be further subjected to the through calculation to gain the actual overview of the problems.

The main objective of the study focuses on the evaluation of the effect in renewal project addresses the following research questions.

- What is the change of punctuality, railway capacity, travel time and their standard deviations in travel time in the different projects?
- On what level the evaluation the projects from the perspective of the evaluation tools can be done? Which one is the most suitable tool out of number of tools that can be used to evaluate the effects of renewed railway project?

The first research question will be addressed from the quantitative approach of evaluation. The various sets of data that are generated at prior and post level of the projects are graphically illustrated to find out the status of projects. The evaluation criteria will be analyzed by the use of the tools. Furthermore, the thesis is aided with the actual generated data from Jernbaneverket which includes the stations, train numbers, scheduled travel time and actual travel time that eases the comparisons between the results from the evaluation tool and from data sets. The second research question will be discussed on the basis of the performance of that tool. So, these tools as set as the performance measuring indicator will be evaluated as per their consecutive output in different project. Thus the study gives the most prominent tool that can be used for further evaluation of the projects.

1.3 Limitations of the study

The followings limitations of the project are generalized:

- The scope of the project is limited to the extent of available data generated by *Jernbaneverket (*railway administrative authority in Norway*)*. The generated data were punctuality data including the train number, date of travel, arrival and departure time for individual trains on individual stations.
- The project will be entirely dependent on the data provided by the *Jernbaneverket*, afterward some sort of simulation will be carried out on these data. So, project remains reliable only after the data provided by *Jernbaneverket.*
- Other limitations of work done concern the numbers and data mentioned in the report, are estimates based on aggregate calculations done from the diverse models.
- The evaluation of the projects depends on the utility of the evaluation tool that will be used in this thesis, not all the parameters of tools can be evaluated to limit the scope of this study.
- The calculation is made only with the passengers train passing through the route. So, it might be difficult to identify the overall scenario as freight train and other emergency type of trains are excluded in it.

1.4 Outline of the report

The report is presented in such a way that the first chapter discusses the core issues and thematic areas of the thesis. The second chapter reviews and present the literatures relating on evaluations, parameters of evaluations and the indicators that are measured afterward. The third chapter is related with the explanation of the quantitative and qualitative approaches of study. This chapter also included the methods of data analysis and methods of presenting the results. The fourth chapter deals with the overview of the cased project and associated data. The data obtained from the sources and the tools are analysed further in the cased project. Thus, the analysed data are able to generate the comparative quantitative results of change. The results are further discussed in chapter five with the possible reasons of getting such results and also discuss about the tools that are used in evaluation. The sixth chapter concludes the thesis with answers to research questions and areas of further researches.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Evaluation

Evaluation is defined as "An evaluation is an assessment, as systematic and objective as possible, of an ongoing or completed project, program or policy, its design, implementation and results. The aim is to determine the relevance and fulfillment of objectives, development efficiency, effectiveness, impact and sustainability (Committee 2002)." In general evaluation is used to establish the outcome of the processes, stages and activities with some level of accuracy (Samset 2003). The project on the basis of different levels on their life cycle assessment gives rises to the different level of the questions or queries. (Samset 2003) coined the different level of inquiry during the project execution as:

	LEVELS OF INQUIRY
First order effects	Project performance and production of outputs
Second order effects	Benefits for users
Third order effects	Impact in society
Fourth order effects	Long-term return on investments

Figure 3: Different levels of inquiry during project execution (Samset 2003)

Inquires in the first order of effect are focused on the efficiencies of the project such as the cost and the time constraints. In this the evaluation is based on the contractors' perspective that focuses only on the goals of the project. In the second order effect the inquiries are on the effectiveness on the project. The overall effectiveness addressing the purposes of the project from the perspectives of the users are evaluated. The third order effect is based on the relevance perspective, to what extent the users are benefitted by the project and their judgements regarding the project is evaluated. Lastly the fourth order effect gives rise to the sustainability of the project, it determines to the time constraints on how long the project benefits the stakeholders.

2.1.1 Criteria of Evaluation

OECD sets up the different criteria for the evaluation based on the different parameters. (Samset 2010) in *Early Project Appraisal* explains the various evaluation criteria that accounts the overall life cycle of the project. The criteria are shown as:

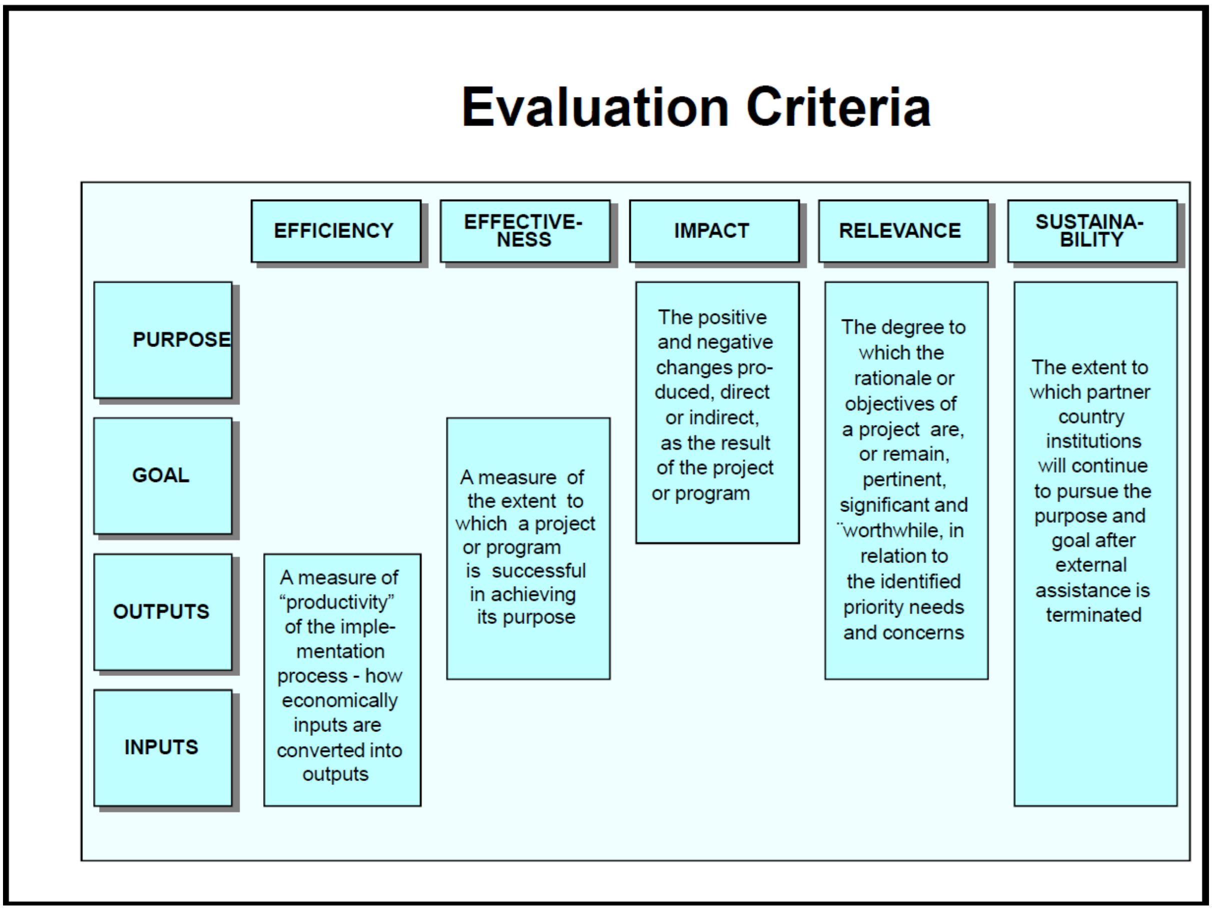


Figure 4: Evaluation Criteria (Samset 2010)

2.1.2 Types of Evaluation in Different Stages of Project

An evaluation should provide information that is credible and useful, enabling the incorporation of lessons learned into the decision making process (Samset and Volden 2013). The evaluation can be categorized into various types as per their uses in their respective project cycles. The different types of the evaluations are can be more explained in diagram as:

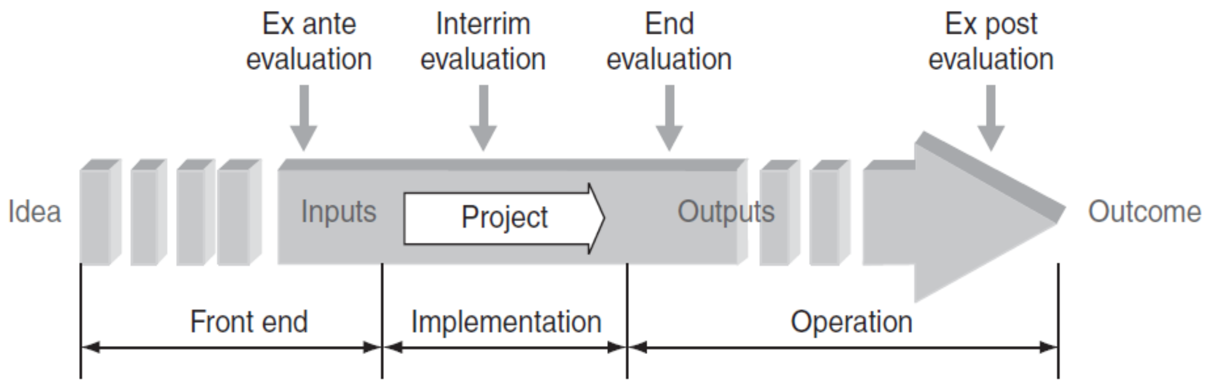


Figure 5: Evaluation at different stages of project (Samset 2010)

- *Ex ante evaluation* is an early evaluation of the project concept. It aims to support the decision of whether or not to finance the project and go ahead with it. It should have a broad view of the project, much as should subsequent evaluations, in order to ensure that it is economically viable, is relevant in relation to user needs, and is likely to be sustainable.
- Evaluations of ongoing projects are called *interim evaluations*, and usually are made midterm in the implementation period or at the end of a distinct phase. They usually help guide management or are in response to requests or pressure from stakeholders or the public. Interim evaluations typically focus on operational activities, but also may take a wider perspective and possibly may consider long-term effects.
- *End-evaluations* aim to establish the situation when the project is terminated and to identify possible needs for follow-up activities. They are made as a formal exercise and focus essentially on the production of project out- puts in terms of quality, timing and cost as well as on the extent to which formally agreed objectives have been or are likely to be achieved.
- *Ex-post evaluations* are made after the project is terminated. Their main purpose is to assess the lasting impact the project may have had or is likely to have. This may require analysis in a broad socio-economic perspective. The motive might be to draw lessons that could be useful for similar projects in the future. In most projects, formal ex post evaluations are not made (Samset 2010).

The thesis is concerned with the evaluation of the effect in the railway project that is mainly categorized in the ex- post evaluation concerning on the impact assessment of the project. Ex-post evaluations are made after the project is terminated. Their main purpose is to assess the lasting impact the project may have had or is likely to have. This may require analysis in a broad socio-economic perspective. The motive might be to draw lessons that could be useful for similar projects in the future. In most projects, formal ex post evaluations are not made. It is the assessment of the project after it has been completed (Olsson, Krane et al. 2010), whereas (Hansen and Pachl 2008) suggests that the railways effect is typically examined using the technological evaluation, business oriented evaluation and overall economic evaluation that can be generalized as the objective of effect evaluation to be punctual and fast transport of passenger and goods at minimal cost for increasing the competitiveness of railways. (Bai, Hou et al. 2011) proposed that the evaluation of project operation effect in the railway is passenger volume of operation, the major technical standards and evaluation of operation effect, technology evaluation, evaluation of technical condition of equipment, operation and management evaluation.

Annual investments in public projects in Norway amount to billions. Examples are roads and rail infrastructure, public buildings, defense acquisitions and large ICT projects. The degree of success and the benefits to society from such investments can only be determined sometime after they have entered into the operational face. However, formal evaluations to this effect are seldom done. Obviously, there is a need to know more about the long-term utility of public investments, and hence for carrying out doing systematic ex-post evaluations. The purpose would be to learn from experience both within the responsible ministries and agencies and government institutions, with the aim to improve public investment projects in the future (Samset and Volden 2013).

An ex-post evaluation should take a broad view of the project which would include both the operational perspective (was it implemented efficiently), the tactical perspective (were the anticipated benefits produced), and the strategic perspective (was it useful to society). Experience is that people’s concern is mostly restricted to the operational aspects of a project and less on the tactical and strategic. The OECD model is widely used for the assessment of evaluation. The model stipulates an assessment of five overall evaluation criteria: that is the project’s efficiency, effectiveness, impact, relevance and sustainability. In addition the teams were asked to perform an economic analysis, which involves an assessment of all economic benefits and costs accruing to the project (Samset and Volden 2013).

2.1.3 Evaluation Criteria for Railway Projects

In general all the projects are evaluated from the same frame of evaluation criteria. (Samset 2003) stated that evaluation is the measure of success, the success of the project need to be measured from the perspective of efficiency, effectiveness, impact, relevance and sustainability. This is the broader criteria for evaluation, while if we are trying to evaluate the railways projects these criteria are fragmented into the divisional dimensions of each aspect. This thesis is concerned with the ex-post evaluation of the railway projects; even in the ex-post evaluation all the evaluation criteria are evaluated. (Olsson, Krane et al. 2010) have divided the criteria of ex-post evaluation into the following dimensions that are applicable in the ex-post evaluation of the railway projects.

Cost Benefit Analysis: This is the major ex- post evaluation as initiated from the governmental bodies in Norway. It is requested by the Norwegian Ministry of communication to carry out Cost Benefit Analysis to the major transportation infrastructure project after 5 years of its operation. The major transportation infrastructure project includes the projects in the railway sector too (Olsson, Krane et al. 2010). This is mainly based on the assumption, however worldwide this type of evaluation is done mostly. Infrastructure investment undergoes mostly the cost and time overrun (Flyvbjerg, Wee et al. 2008). (Mátrai 2013) had purposed that the evaluation periods, discount rates, GDP increase, traffic change, investment cost and schedule, operation and maintenance cost, replacement cost, residual value, time cost saving, rail accident cost saving, economic development and employment creations are the parameters for cost benefit analysis of the investment project.

Business effect Analysis: This approach of the analysis is based on the business effect within the parent organization for the projects (Olsson, Krane et al. 2010). This approach analyzes the impact of the project in the various sets of the questions on the business result in the company. In the case of railway project evaluation, this basically means for the business effects on the traffic operators. It might be easier to evaluate to the effect of those projects that are well defined as the business units already. So, from the perspective of business effect even the railway projects can be evaluated.

Performance Measurement: This type of analysis is based on the evaluation of the few performance measuring indicators. The indicators are pre- defined and is selected in such a way that when these are evaluated, their final results can improve the performance of the system. In the ex-post evaluation of the project relating to the transport infrastructure, the indicators can be traffic volumes, accident, travel time (Oxera 2005).

Apart from these evaluation criteria for railway, the criteria used by *SIKA (Swedish Institute for Transport and Communication Analysis)* can also be used as the part of goal fulfillment of the railway projects. This type of evaluation is based on the evaluation of the extent of fulfillment of overall objective of transport and Communication system. It was initiated in Sweden since 1999. Generally SIKA uses the logical Framework as the basis of evaluation including goal, purpose, output and input as the criteria for evaluation that addresses the different modes of stakeholders.

In all above dimensions of analysis, this thesis is based on the performance measurement approach. The performance indicators picked up, described and used to compare the railway renewal projects are punctuality, the number of trains (volume), travel time, level of crossings and standard deviations in travel time. From the perspective of socio cultural perspective (Samset 2010) of ex- post evaluation these indicators are the major parameters for evaluation in railway project.

2.2 Indicators of ex- post evaluation of railway projects

There are various indicators to measure the performances in ex- post evaluation of railway projects. However, to find the quick look the thesis will be based on the evaluating the following parameters in railway renewal projects.

2.2.1 Punctuality

A train is considered **on time** if it arrives at their destination within a margin of three minutes and 59 seconds and for long distance, this margin of five minutes and 59 seconds in Norway which differs from country to country. The aim of the passenger is that 90% of the trains will reach the final destination on schedule, while the target for the Airport Express Train is 95%. It is evident that In Norway punctuality shows considerable variation and the official target for several railway lines and train is yet to be met, with this context in mind efforts had been employed to provide a holistic explanation regarding factors for influencing punctuality. There are various factors that affect punctuality. (Olsson and Haugland 2004) on accounting some reliable data studied the following factors affecting punctuality.

- Number of passengers: This is the total number of people travelling in the train. The population is depended on the type of study. It might be the total people who buy the tickets before loading into the train or the total number of people who use the services. It is simply the demographic evaluation in certain period of time. This has an inversed relationship with the punctuality, as punctuality reduces as the number of passenger increases.
- Occupancy ratio: This is the ratio between the number of passengers and the number of available seats in the train. It can be called as the percentage of loading within the travel duration.
- Infrastructure capacity utilization: This means the total number of trains passing through the railway track in definite interval of time. Every train operators want to maximize the utilization of the infrastructure, but it solely depends on the time. Especially in the rush hours the utilization is maximum where the punctuality reduces whereas in common period the trains remain more within punctuality limits.
- Cancellations: A cancelled train is said to be the train that does not reach on the final destination, there might be some positive relationship between the punctuality and cancellation. However the cancellation of a train may affect the schedule of another following train.
- Temporary speed reductions: Railways lines have defined maximum speed, which varies along the line. When the line is in non-optimal condition, speed is frequently reduced. Such speeds are often highlighted as major causes of delays.
- Railway construction work: Sometimes there will be the modification, extension of railway lines which affect the punctuality. It might be seen that during the modification period the trains often gets delayed due to lack of enough signaling and information regarding the nature of new railway lines.

In general, it is the railway capacity utilization in the route that influences the punctuality of the trains.

2.2.1.1 Parameters of Punctuality

The punctuality of the railways is widely dependent on the railway timetabling. A master timetable is the backbone of scheduled railway systems and determines directly or indirectly effective railway capacity, traffic performance and quality of transport service, passenger satisfaction, train circulations, and schedules for railway personnel. As such the timetable concerns many actors including (potential) passengers, (passenger and freight) train operators, train personnel, dispatchers, traffic controllers, infrastructure maintenance planners, and connecting public transport providers. European passenger railways are typically based on a periodic railway timetable, where train lines are operated with regular intervals throughout a day and consistent transfers are provided at transfer stations between train lines of different type or directions (Goverde 2005). In this case, the Norwegian railway is also mostly dominant by the periodic timetabling. A main advantage of periodic timetables is that transport chains are fixed throughout the day and travelers only have to remember the departure time of their (first) train in a basic hour, e.g. ‘departure at 05 and 35 minutes of each hour’. Depending on transport demand the periodic timetable may be made more (or less) dense by adding (removing) train services in peak (off-peak) periods, whereas on conventional railway lines equipped with block signals the train driver relies completely on the trackside signals and the timetable, and has no information nor visual clues about the progress of the preceding train due to the large headway distances imposed by long braking distances and fixed block lengths (Goverde 2005). Timetabling is the problem of matching the train line system to the available infrastructure, i.e. finding for each train line a feasible schedule of arrival and departure times at the consecutive served stations taking into account constraints with respect to e.g. the safety and signaling system, transfer connections, and regularity requirements. A scheduled process time typically consists of the following components (Goverde 2005):

- a nominal process time for ideal or average traffic conditions;
- a margin to compensate for less favorable traffic conditions; and
- Scheduled waiting time to fit the process conflict-free in the timetable.

Time measurement:

The punctuality and the extent of delay is measured by the different time measuring units during the operation of the railways. These are described below:

Running Time: It is the time taken by the train to travel from one station to another station. Train running times are calculated as the sum of a nominal running time and a running time margin. The running time margin is generally allocated as some of the percentages of nominal running time. The nominal running time of a train run is calculated from the principles of train dynamics. The change of train speed is determined from the force equilibrium equations of the tractive force and various resistive forces acting on the train during motion (Andrews 1986). The total resistance to motion is the sum of several resistance components: the running resistance (rolling resistance and bearing resistance), air resistance, alignment resistance (curvature resistance and gradient resistance), and acceleration resistance, and is a function of speed. Tractive effort is the sum of tractive forces at the driving wheels — the wheels providing traction — and is also a function of speed (for fixed control settings).

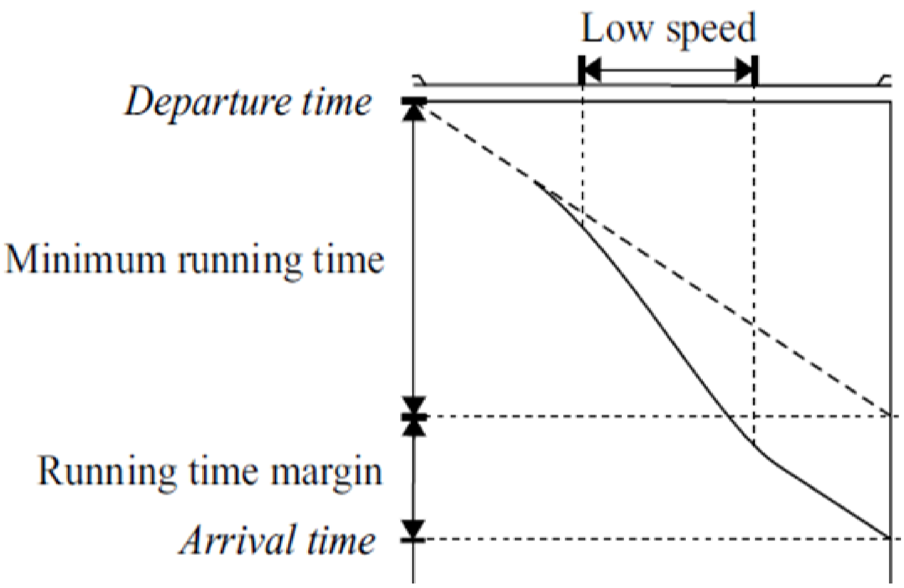


Figure 6: Time distance diagram demonstrating the running and margin time (Andrews 1986)

The nominal running time on a track section is obtained by calculating a feasible speed-distance profile over the open track for given train and track alignment characteristics. The computation of distance as a function of speed requires numerical integration of

R (v/a(v))dv, where acceleration a(v) is a nonlinear function of speed given by the force equilibrium equations over the various regimes and track characteristics. The associated running time as function of distance is subsequently obtained by numerical integration of R (1/v(s))ds over distance (Vuchic 1981). The running time margin is added to the nominal time which is entirely dependent on the nature of train tracks and nature of trains. On depending on the physical characteristics of trains and tracks, it is calculated as 5% to the total travel time in Norway whereas it is 3%-7% in other part of world (Schaafsma and Weits 1996).

Dwell Time: It is the time for boarding the passenger in the train and in some case the transferring time of the train where it is needed. The minimum dwell time is the necessary time for passengers to alight and board the train and sometimes may also include a coupling or uncoupling time. The alighting and boarding time depends on train and infrastructure characteristics (number and width of doors, location of the platform accesses, platform width, level difference between platform and vehicle floor, gap between platform and vehicle) and passenger flows, and fluctuates over the day. A tight dwell time is a source of delay, whilst large dwell time means large travel time and high station capacity utilization. The time for opening the train doors is also included in the minimum dwell time. (Ostermann, Schöbel et al. 2005)

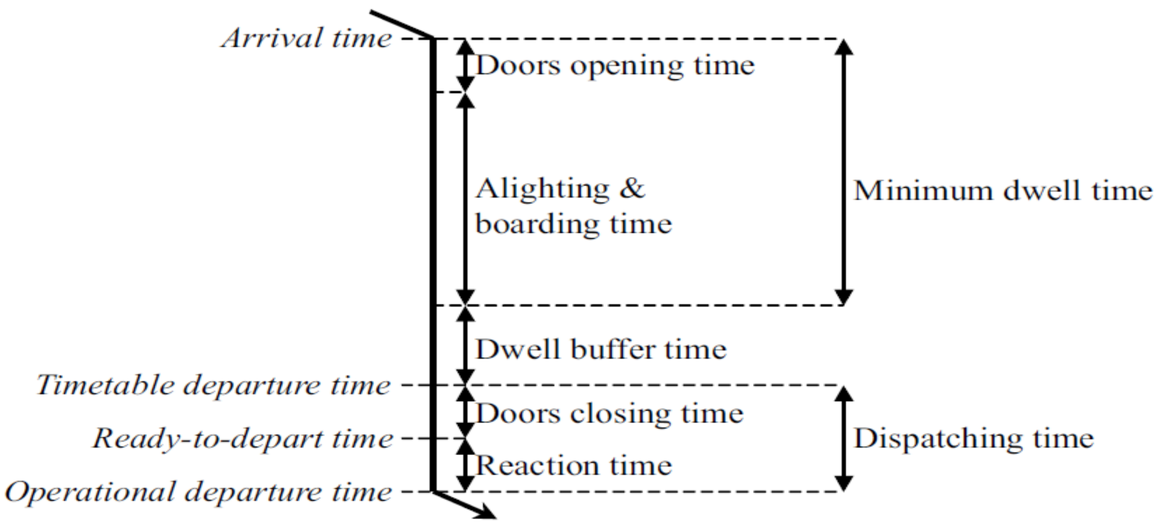


Figure 7: Dwell Time Component (Ostermann, Schöbel et al. 2005)

Minimum Process Time: It is the time required for a larger group of passengers to transfer from feeder train to the connecting train. The minimum transfer time includes alighting time, walking time (including possible orientation), and boarding time. It depends on individual walking speed and acquaintance with the station, the relative position of the arrival and departure platform (cross-platform, two platforms apart, etc.) and the geography on the station (platform lengths, distances between platforms, widths of corridors, door-ways, presence of escalators, etc.), and the pedestrian flows and densities in the station and on the platforms. The underlying processes of the (minimum) transfer time are typically stochastic.

Buffer Time: It is the time between the arrival of the transferring passengers at the connecting train and the departure of these trains or can be defined as the time between the occupancy of the crossings of the train, time in between releasing of crossing by one train to the occupancy of crossing by another train.

Layover Time: Layover time is the time a train spends at a terminal station. The minimum layover time depends on train type and possible shunting activities. For turning multiple units

(EMUs or DMUs) that continue a train service in the opposite direction with the same driver the minimum layover time is given by the closing time of the cabin on one end, the walking time over the length of the train, and a preparation time for departure in the cabin on the other end. The minimum layover time of locomotive hauled coaches (additionally) depends on possible shunting and coupling activities of the locomotive and the possibilities of the station layout.

Synchronization Time: It is the time interval from the end of the minimum dwell time to the end of the transfer time relative to the arrival times of the connected train pair. Synchronization is the coordination of the departure of a train to arrivals of other trains to offer a connection for transferring passengers. Synchronization time is hence the additional time over the minimum dwell time that is necessary for the synchronization of the train departure to transferring passengers.

Scheduled waiting Time: It is time loss in the timetable due to infrastructure restrictions. Because of conflicting train movements running time, dwell time, or transfer time may be forced to be longer than the minimum process time. This additional time is called scheduled waiting time. For instance, a transfer time may be forced to be larger than the minimum transfer time due to minimum headway constraints at arrival and departure. This additional time is called scheduled transfer waiting time. The minimum transfer time must be respected to allow passengers to transfer, whilst additional scheduled transfer waiting time is required because of train traffic constraints.

2.2.1.2 Punctuality Measurement:

The punctuality in the railways in general measured as the percentage of punctual train at the final destination. (Olsson and Haugland 2004) said that punctuality can be further understood by defining it in the terms of unreliability and variability. **Unreliability** is measured when the time is deviated from the schedule. (Rietveld, Bruinsma et al. 2001) illustrates the following ways of measuring the reliability.

- ❖ The probability that a train arrives x minutes late.
- ❖ The probability of an early departure.
- ❖ The mean difference between the expected arrival and the scheduled arrival time.
- ❖ The mean delay of an arrival given that one arrives late.
- ❖ The mean delay of an arrival given that one arrives more than x minutes late.
- ❖ The standard deviation of arrival times.

Variability is the measurement of the uncertainty of trip journey times in transportation. (Noland and Polak 2002) says in railway traffic this includes delays, early arrivals and cancellations. Their use of variability is related to the distribution of arrival times for a train, not focused on the scheduled arrival time. As an example, if a train arrives the same amount of minutes behind schedule every day, the variability is low, while the train from a conventional point of view would be considered as delayed and not punctual, provided that the delay is more than the predefined acceptance level.

Regularity refers to the number of trains that will run as scheduled timetables. Train as far in advance are planned set due to track work will not be included.

2.2.2 Railway Capacity

Railway capacity is the ability of the carrier to supply as required the necessary services within acceptable service Status and costs so as to meet the present and projected demand for such services (Khan 1979). Railway capacity depends not “only” on the rolling stock, the infrastructure and the timetable – sometimes the capacity is reduced due to processes in the operation such as time consuming departure procedures or external factors such as the weather and problems with the rolling stock. Processes can be procedures at departures, staff schedules, many passengers at the stations etc. while the external factors could be e.g. weather conditions, break downs and accidents. Common for the processes and external factors is that it is not possible to predict their influence on the operation but it is tried to minimize this influence by e.g. adding time supplements in the timetable (Landex and Nielsen 2008). The effective capacity of railway infrastructure is therefore defined as the maximal number of trains per unit of time that can be operated given the traffic pattern, operational characteristics or timetable structure. Effective capacity thus depends on the mix of train services with different characteristics (speed, stopping pattern, and frequency), train sequences and orders, and connections at stations.

The following figure shows the overall relationships between the parameters of railway capacity.

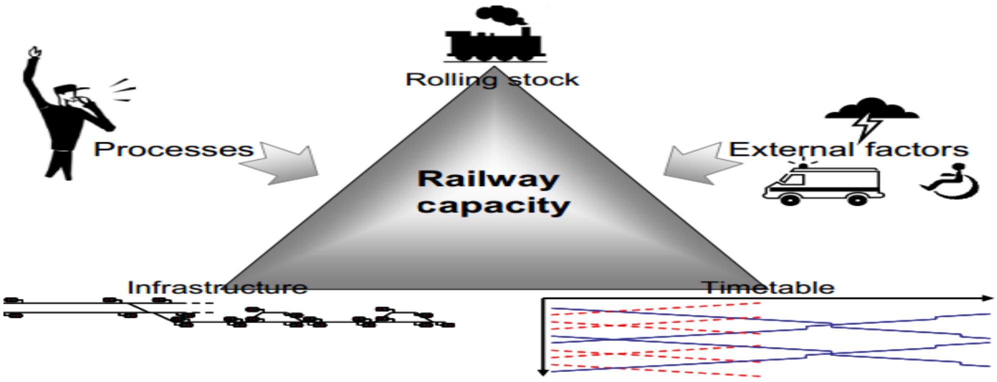


Figure 8: Parameters in Railway Capacity (Landex and Nielsen 2008)

Railway capacity is used to measure the volume of the train using the same capacity in the certain station.

2.2.3 Travel Time:

This is the time taken by the train to travel from one stations to another station. It thoroughly depends on the scheduled time as set by the train operators, the capacity of the railway network, dwell time etc. (Noland and Polak 2002) had derived the equation for the travel time that is widely used by the train operators to generate the schedule time for the train.

$$T(U) = \alpha E(T) + \beta E'(SDE) + \gamma E(SDL) + \theta P_L$$

Here the actual travel time T(U) is calculated from the function of travel time on expected (or mean) travel time E(T), expected schedule delay-early E(SDE), expected schedule delay-late E(SDL), and the probability of late arrival (PL). The values of α, β and γ are calculated from the empirical studies.

2.3 Tool for the Evaluation of the indicators

2.3.1 MY TRAIN punctuality

This is the tool developed by the Norwegian railway infrastructure administrator, Jernbaneverket to measure the punctuality at the different railway stations which is based on data generated by the digital traffic signaling adjusted in different railway stations. This is more sophisticated tool which percentiles the punctuality, delays and train cancelation.

This tool gives the overview and status of punctuality in different stations whereas does not show the pattern of the punctuality over time, so the reasons behind delays over time is difficult to measure with this tool. In addition, this tool is only useful to measure the punctuality between the stations and is not provided to all the railway stations in Norway. This tool cannot be used to measure the volume of train, the travel time and other evaluation parameters that are used measured aftermath in this thesis. The example of the evaluated results using this tool can be diagrammatized as;

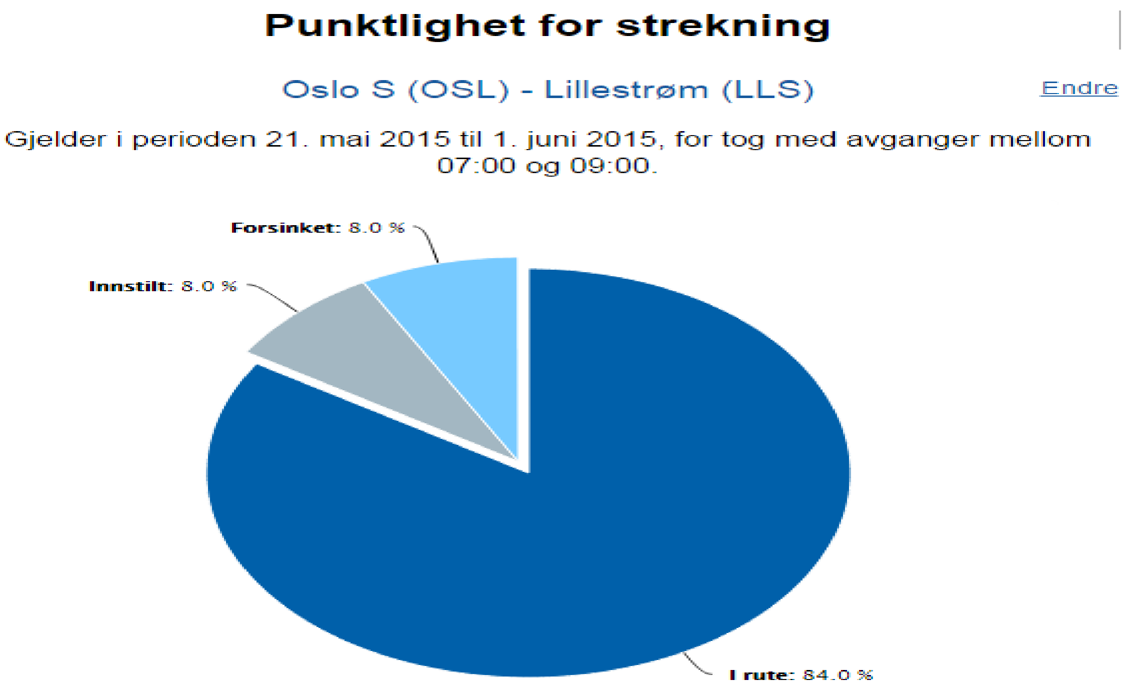


Figure 9: My train: Tool to evaluate the punctuality (taken from web page of Jernbaneverket)[ii]

The above pie-chart is the example of chart showing the percentage of punctuality in route to be 84%, delays to be 8% and train cancellation to be 8% that is obtained between Oslo (S) and Lillestrøm (LLS) over the time period of 21 May 2015 to 1st June 2015. As mentioned above, the defect of this tool is it cannot display the changing nature of punctuality between the stations over time frame.

2.3.2 Precision Tools

This is the useful tool for the measurement of the performances of various trains in the different routes. This tool is the outcome of the *Presis Project* at Sintef, NTNU that tried to quantifies the parameters relating to the evaluation of performance in the railways in Norway.

This tool is sophisticated by the use of the direct data from the Jernbaneverket also comprises of various other sub tools that facilitates the requirement of various parameters in the measurement like punctuality, travel time, number of trains, crossing trains etc. This tool can eliminates the shortcomings on the above mentioned my train to measure the punctuality by showing the changing graphs and nature over time.

2.3.3 Method of measurement and control- Precision tool

The tool comprises of one or both the dimensions of time and distance. This tool can be used from the both the perspective of analysis. The measurement can be done from the time axis frame or from the station axis frame. So, the tools can broadly be divided into:

2.3.3.1 Time axis frame:

Most of the tool is dependent on the time axis frame by plotting the time on x-axis and the parameter of measurement in y-axis. The most common format for analysis over time are different varieties of trend charts, bar graphs, histogram. The measurement like the measure of punctuality over the time, the change of travel time, the variations of the parameters over time can be judged from this category.

Punctuality (%)

Travel time (min/hour)

Variation (min, hour)

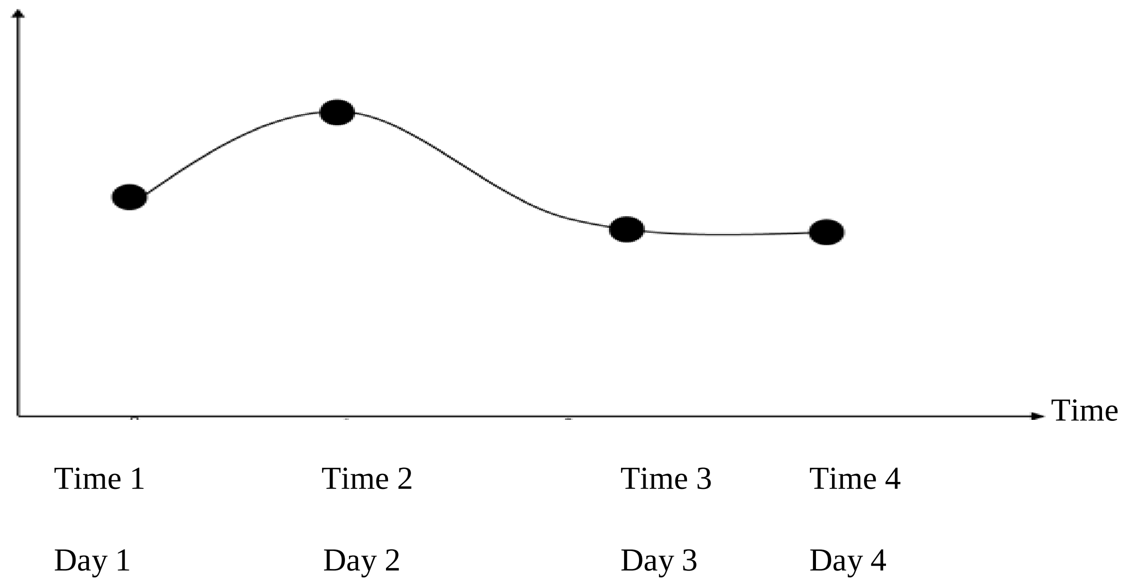


Figure 10: Time axis frame

2.3.3.2 *Station axis frame:*

The parameters like punctuality, variations, travel time, crossing plots etc. can be plotted against the different stations. It is possible to see the nature of trend graphs over the different stations in the certain time frame. The time included in it acts as the virtual axis that is further translated on the station axis at the end.

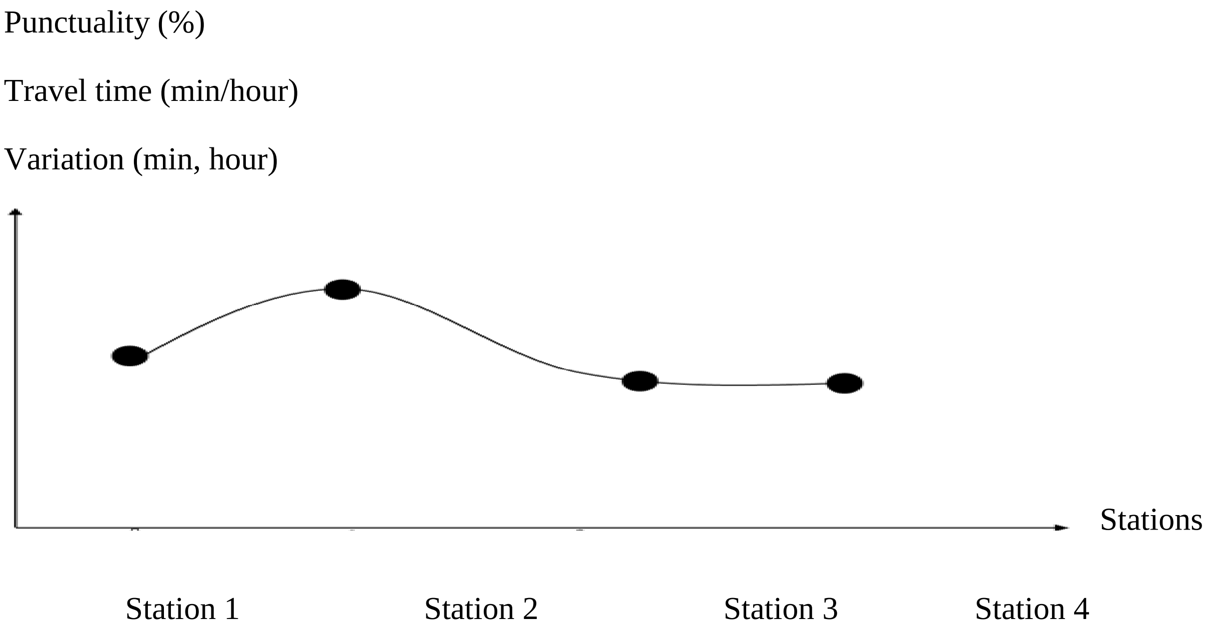


Figure 11: Station axis frame

2.3.3.5 *Combination of time and station axes:*

In this type it is possible to see the change in the parameter in respect to time and the station, where the variables remains as the train number, route number etc. To understand the nature of individual train it can be used. In broader aspect the quantification and evaluation of the delays in different dates and different station this type of tool is used.

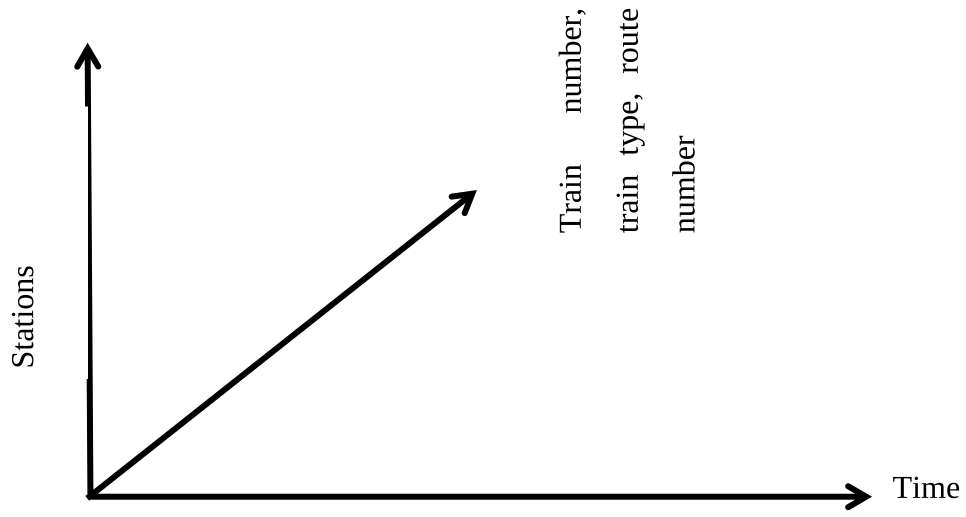


Figure 13: Time and stations axes frame

2.3.4 Sub tools supporting the Precision tool

2.3.4.1 Precision meter

Precision meter is the tool used to measure the status of the change in the punctuality during the certain time frame. It can measure both the arrival punctuality and departure punctuality in the single or multiple numbers of the stations. It can be traced for the single train number or multiple train numbers just depending on the train numbers, the time frame, the stations. It is important that the input data must be viable, to read with this tool. There are the variations in the margin of time frame to select in order to evaluate that is most generally in the format of 0 to 4 minutes. In this thesis the data is evaluated on the basis of the trains delaying with more than 4 minutes, hence the selection of the time margin is 240 seconds i.e. 4 minutes. The line graph generated in this is the combination of the points where each of the points represents the trains.

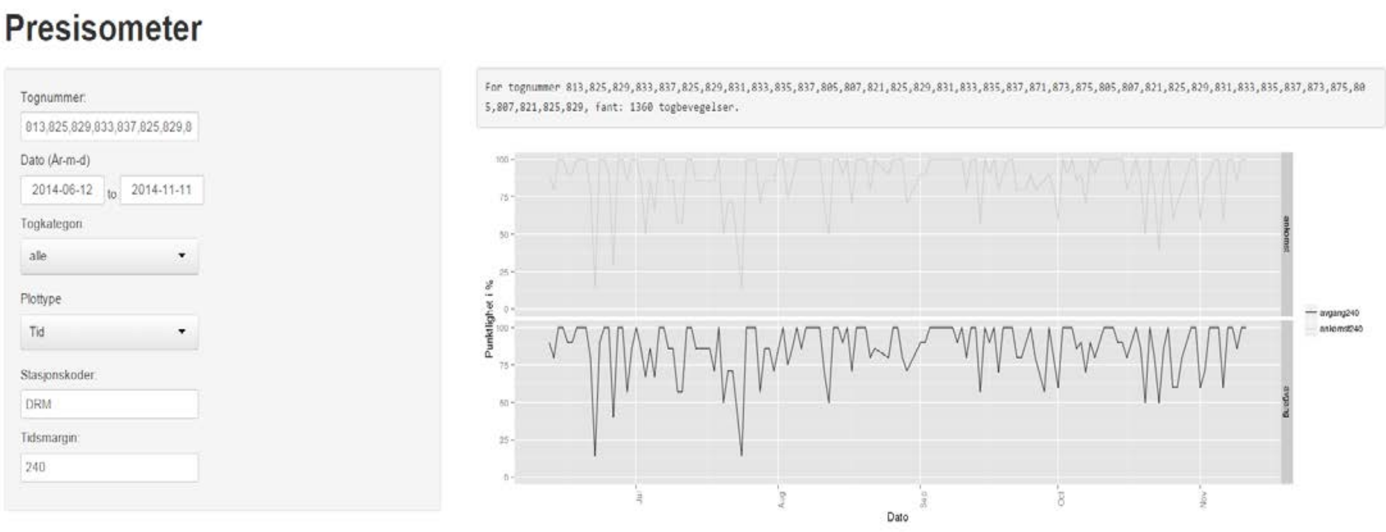


Figure 14: Snapshot of the Precision tool 1: Precision meter

2.3.4.2 Statistical Process control

Statistical process control (SPC) is a term used for using charts and other statistics to analyze a process. These charts facilitate the identification of common cause variation and special cause variation (Odendaal and Claasen 2012). Process control diagram is based on the principle of Total Quality Contol (TQC) and six sigma that limits the travelling time from one station to another in the definite interval of time. (Chiarini 2011) defines TQC as *a network of the management/ control and procedure that is required to produce and deliver a product with a specific quality standard*, as well he states that six sigma take on average from the few months to one year and thus their yields is short- term based. The six sigma is more illustrated with the following formulae.

$$\sigma = \frac{\sqrt{\sum(x-\bar{x})^2}}{n-1},$$

$\bar{x}$ is the mean number of train observed based on their travel time

$$UCL = \bar{X} + 3\sigma$$
$$LCL = \bar{X} - 3\sigma$$

UCL, is the upper control limit of travel time

And LCL is the Lower Control Limit of travel time.

In this case, the higher value of standard deviation means the data is widely spread which is less reliable whereas, the lower value of standard deviation means the data are clustered closely around the mean which is more reliable in the data evaluation.

The dotted points represent the number of train travelling through the observed station. This includes the maximum and minimum limits so the trains within the limits "*innefor margin*" in Norwegian are marked with green dots, whereas the red dotted represents the train that are delayed in the expected duration. The blue line in the center is the mean travel time made by the trains during the particular day. This tool helps to locate the exact number of trains that undergoes delays and the number of trains travelling through the limits.

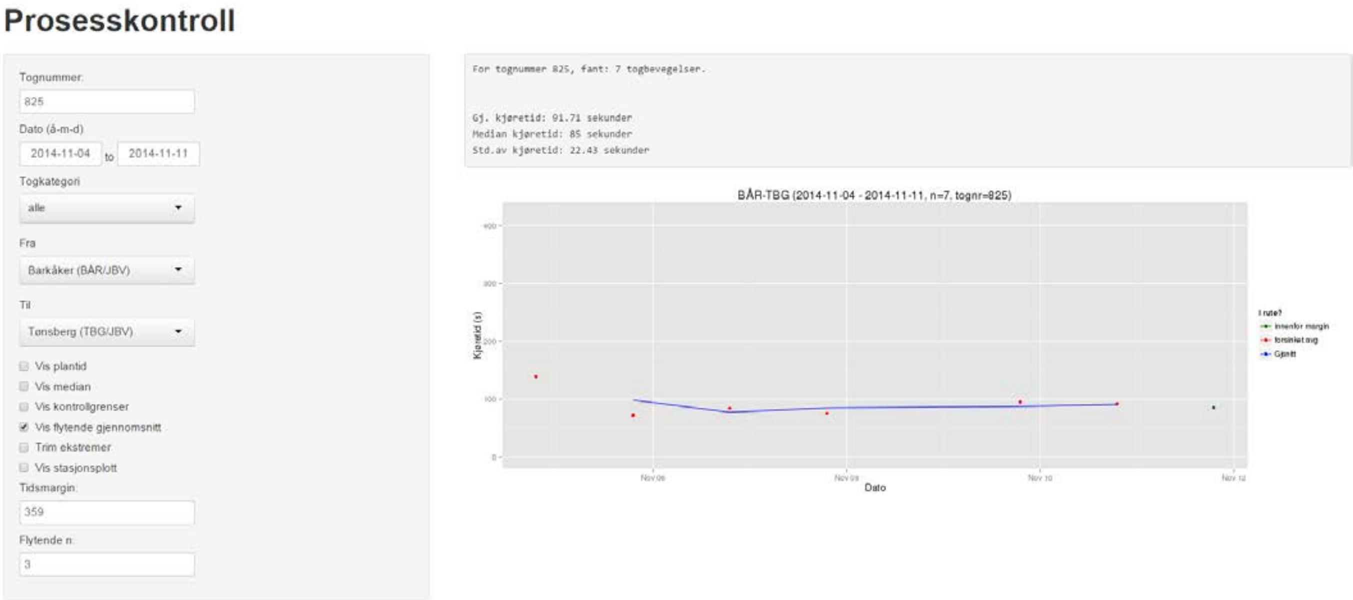


Figure 15: Snapshot of the Precision tool 2: Statistical Process Control Chart

2.3.4.3 Heat map

This tool is used to measure the volume of the multiple numbers of trains in against of the different weeks in a year at the different time of the day along with the measurement of the percentage of the punctuality of the different trains in a single or in the multiple stations. This tool can be used to evaluate both the arrival and departure punctuality in the stations. As shown in the following figures the percentages of the punctuality are marked with the different colors. The most punctual volume of the train is marked by green color which is more than 95%, whereas the least one with less than 70% is marked with the red color.

The main advantage of this tool is to see the nature of train punctuality in the different time of the day. This tool is also based on the punctuality time margin of 3 minutes and 59 seconds.

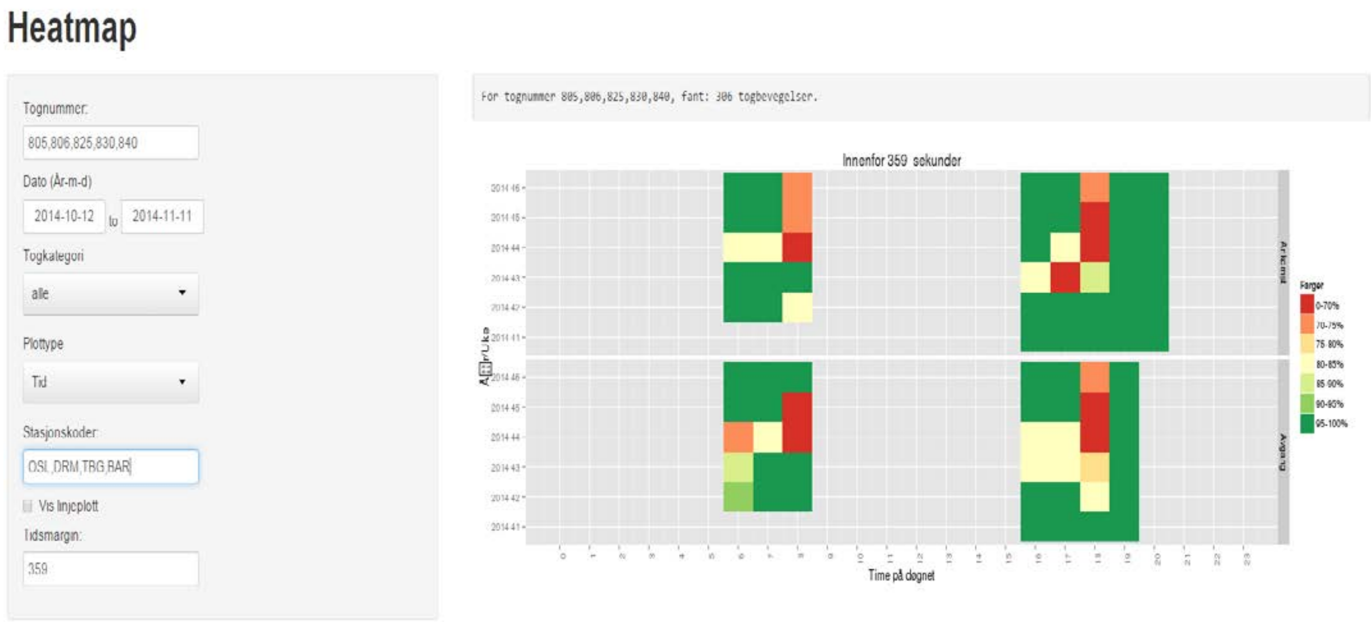


Figure 16: Snapshot of the Precision tool 3: Heat Map

2.3.4.4 Crossing Plots

Crossing plots measure nature of the interaction between the trains in the definite crossing route. Basically, there are two trains which undergoes through the crossing in the same track in a certain time. It is scheduled in such a way that the differences in the time of crossing between the two trains that are maximum enough to use the same railway capacity without interfering the individual train routes. Even though, sometime the train does not travel according to the schedule resulting the delay in either of train. This delay in train might results in the management of the railway capacity at any instance, more over the punctuality is greatly affected in the proceeding station. In this tool the measurement of the time of crossing between two trains in certain time of frame at any station is done. In the following diagram, the dotted spot represents the individual train, where the train marked with red dot means the delay in the crossing by more than 5 minutes and the light green and light yellow represent the delay within the tolerable limits. This tool is widely dependent on the nature of both the trains, so the train marked with the green dots representing the crossing time less than 5 minutes than the scheduled time needs also the consideration as it affects the schedule of the next train. Sometime for easy crossing the trains are subjected to have the crossing prior or after the station which merely depends on the localization of the train. This tool is based on the graphical timetable of trains in certain route that is published by NSB each year. This graph is based on the purposed scheduled time of NSB.

Figure 17: Snapshot of the Precision tool 4: Crossing Plot

2.3.4.5 Route finder

This tool is used to find the travelling route of the train. It is just necessary to enter the train number and the date of the train. This tool shows all the routes that the definite train at definite date will travel through, but the prior knowledge about the train number and the certainty of that train passing on that date when we want to see it on. This can be done only after analyzing the graphical timetable of trains in certain route that is published by NSB each year. This graph is based on the purposed scheduled time of NSB.

Figure 18: Snapshot of the Precision tool 5: Route finder

❖ SUMMARY OF CHAPTER TWO

In chapter two, the literatures relating with the evaluation were coined. As this thesis based on the evaluation of the effect, so the thesis is mostly based on the ex-post evaluation part of the evaluation. Further, the indicators that are used for the ex-post evaluation of the project were studied. Out of number of indicators performance measurement was taken as part of study. The evaluation criteria for the different renewed railway projects set up in this thesis were punctuality, line capacity, travel time and standard deviation in this thesis. Furthermore brief explanations of the tools that are further used in the data analysis chapter were coined in chapter two.

CHAPTER THREE

3 METHODOLOGY

Evaluation reports mostly based on the sophisticated statistical analysis but evaluation is not scientific research and in evaluation of the projects, the quality of the data and the size of the samples may not be such that it warrants the use of the sophisticated methods. The issue is more often to what extent the evaluator should rely on quantitative or qualitative methods. Different parties have different opinions, but most parties, however agree that both types of analysis should be employed simultaneously in varying proportion (Samset 2003).

So, it is prevalent to divide method research strategies in two categories, quantitative, qualitative or a combination of these two.

3.1 Quantitative research strategy:

It is a numerical way of handling the input of data without any influence from the researcher. All information collected is transformed in to numbers for further analyse, whether to map the pattern and find deviations from the normal distribution. Quantitative research is interested in the nature of relationships among variables, and it is a way of testing theory. Quantitative analysis lends itself to systematic manipulation of data, either to describe phenomena in a concise format, to test relationships among variable and generalise findings. (Samset 2003) Reality is objective, the appealing advantage of this type of research tool is it can summarise the findings in an evaluation in clear, precise and reliable way (Bryman 1988).

This involves the generation of the data into the quantitative form which can be subjected to the rigorous quantitative analysis in a formal and rigid fashion (Kothari 2004). In this report it is intended to use the data of time tabling including train number, date of train travel, actual travel time, scheduled travel time between the stations. Moreover the aid from Precision tools that are like punctuality meter, heatmap, process control diagram and route finder are extensively used in the different sets of the project.

This report is mostly based on the quantitative approach of way of handling the data. It is intended to find out the mathematical outcome by evaluating and calculating the data and the tool so, this is the methodology which has core basis on data.

The method of quantitative evaluation is based on the evaluation of the project before and after the execution of the project. It is always questioned that might come over is what time is standard and acceptable to evaluate the project. The project can be evaluated even taking the time of reference for one week or a month but (Flyvbjerg, Wee et al. 2008) argued that the evaluation should be done during the first year of operation, he claims that evaluation after the first year of operation is used because the data for the estimated situation, the changes in the parameters after the project usually is available only after the first year of evaluation. In other hand, the evaluation of the project is widely dependent on the time of references. However, (Olsson, Krane et al. 2010) concluded that measuring averages over a number of years before and after a project appears to be most robust single way of measuring and is quiet relevant as most of the policies and schedules are year based. In this thesis, the time frame for the evaluation that is assumed and evaluated is one year before and one year after the launching of renewal project.

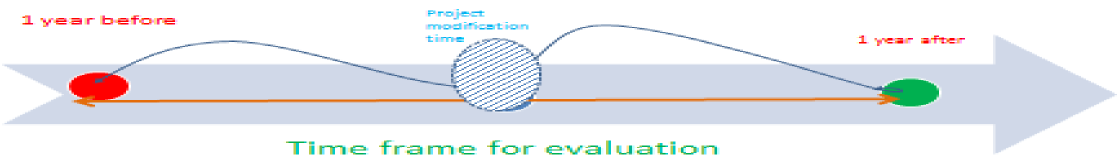


Figure 19: Time frame for ex- post evaluation

3.2 Qualitative research method:

This approach is concerned with the subjective assessment of the attitudes, opinion and behavior. Kothari (Kothari 2004) says this is entirely based on the personal insights of the concerned journals. This method tries to see the world from the eyes of the participants, an in depth analyses. The outcome depends on the researcher's interpretation of data, through textual analyze of information through interviews and ethnography. Newmann (Newman

1998) says theory emerges from data and reality can be perceived as socially constructed methodology. (Samset 2003) argues that this method is based on qualitative data such as detailed description, statements in response to open- ended questions, and is more as the transcript of the opinion of the people, this is more into the context analysis, case study analysis and logical and sequential analysis. It is relatively easier to understand the complex phenomena by the use of this tool.

In this approach various journal relating to the punctuality are studied. Punctuality being a part of ex-post evaluation, the literature review on the ex-post evaluation is also intended. The perspective and status of Norwegian railway along with the theoretical calculating approaches on punctuality is also intended to use.

In this thesis it is tried to compare the nature of the different projects by their successive ex-post evaluation. For the evaluation it is tried to use the evaluation criteria developed described in textbook (Samset 2003) and the evaluation concept used in the four pilot major investment project (Samset and Volden 2013) . In this concept, (Samset and Volden 2013) used the following evaluation criteria to evaluate the project.

Efficiency: This is the measure of the project`s compliance with budget, time and schedule. This is more about the evaluation of the output of the project.

Effectiveness: This criteria evaluates the achievement of project`s goals. This is more into the achievement of strategically objective and to what extent the project is likely to attract people.

Impact: This criteria evaluates the pros and cons of the project. The more on positive effect of the project can mark as the project being successful.

Relevance: This is the socio- cultural aspect evaluation of the project. It evaluates on the local and national, public and governmental support in the project, and determines the interest level of stakeholder in project.

Sustainability: This criteria evaluates the financial viability of the project in relation to funds invested. It means it evaluates the long term self-dependencies on project.

(Samset and Volden 2013) purposed to use these criteria in common art of evaluation through the means of using the radar. He used this concept in the evaluation of the double railway track between Asker and Sandvika. This gave with the result with the following type of diagram:

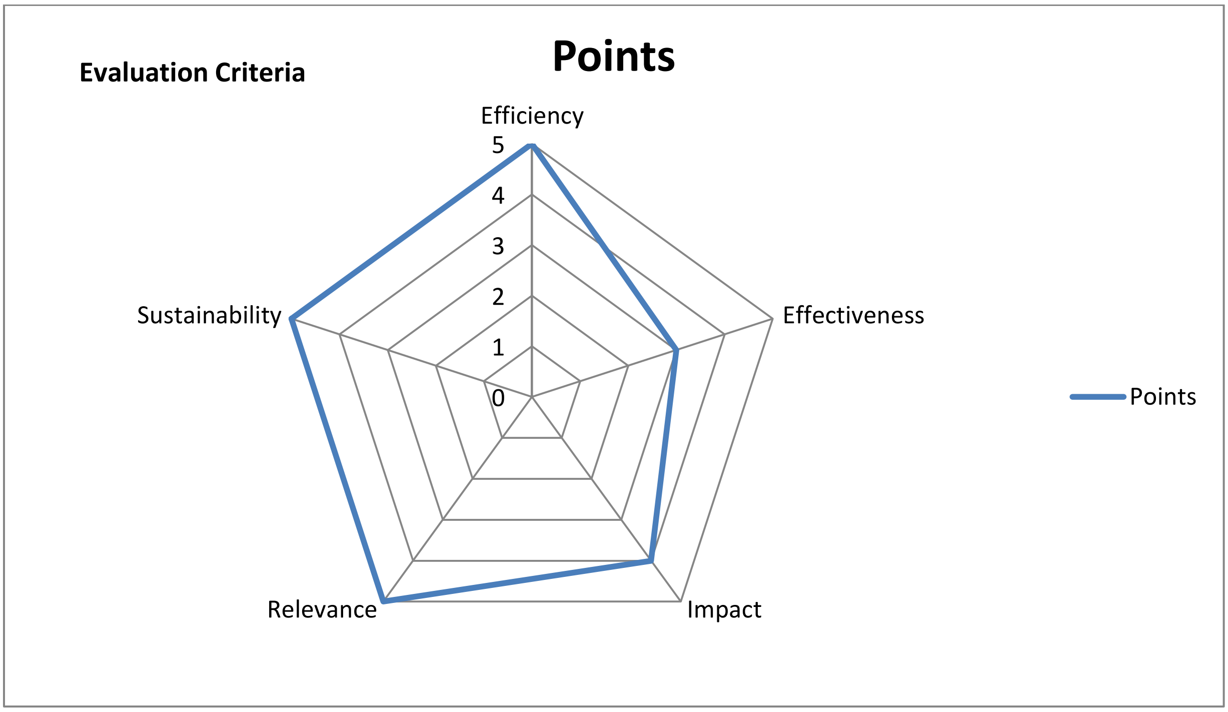


Figure 20: Evaluation of Asker-Sandvika double railway track (Nilsson, Nyström et al. 2012)

This thesis is based on the evaluation of the effects in the railway tracks that are renewed. **The approach mostly used in this thesis is more quanitative, comparing the situation before to the situation after** So, making an analogue with those evaluation criteria with the criteria set up in the thesis, it is intended to develop the similar radar chart to evaluate the effects.

In analogue, in this thesis the evaluation criteria that are set up are the change in punctuality in succeeding and preceding stations from the renewed regions, capacity of railway track, change in travelling time between the stations, and the standard deviations in the route is intended to evaluate against each of the project. That might give the similar figure as used by Samset on evaluation.

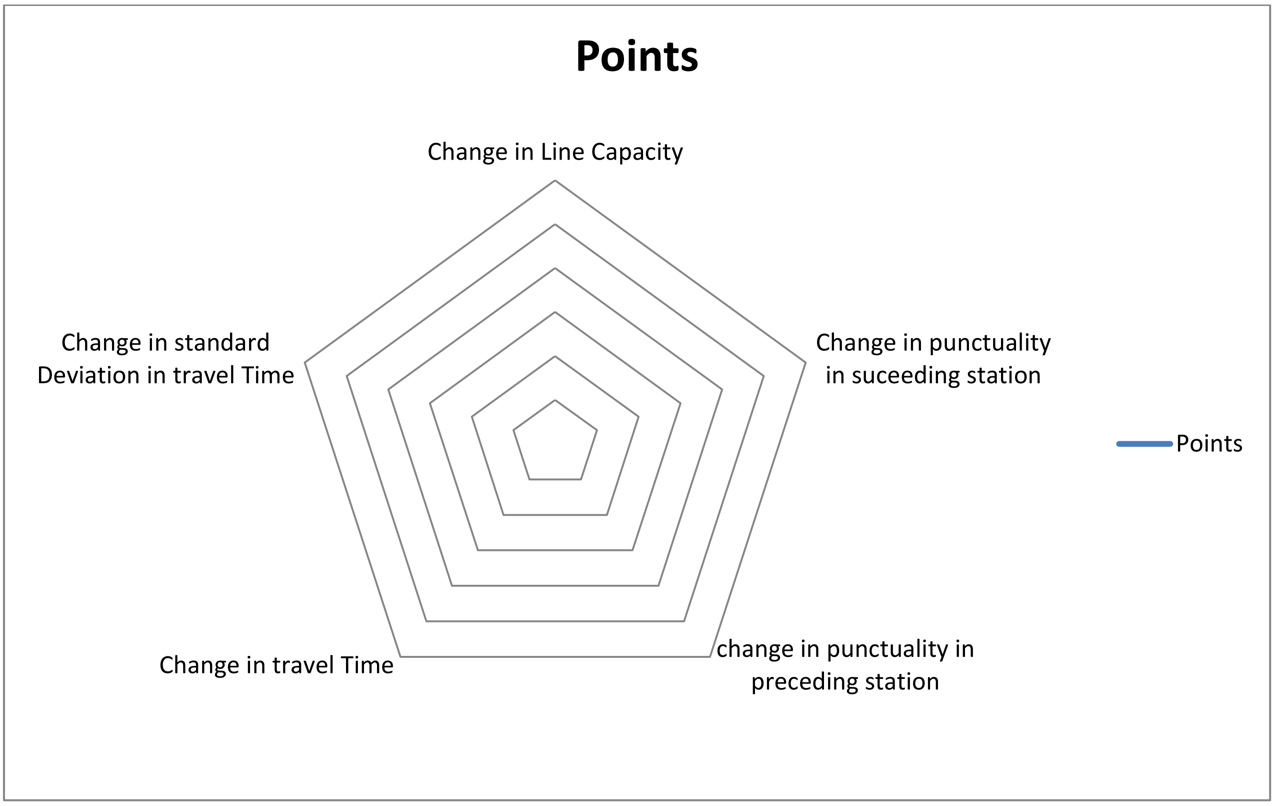


Figure 21: Expected evaluation criteria

Furthermore, the theoretical approaches are finally used in data analysis to generate the require results. The use of google scholars, UNIBYBS of NTNU, available articles and home website of *Jernbaneverket* are extensively used as the research tool.

- **SUMMARY OF CHAPTER THREE**

In this chapter the intended methodologies to carry out this thesis is mentioned. It is intended to use both the qualitative and quantitative approach of research. Quantitative approaches deal with different statistical tool and graphs that are used further in evaluation. So, it is intended to evaluate the projects on the basis of their results from that quantitative analysis. In other hand, the qualitative approaches deal with the personal insights, interpretation of data. So, further the results obtained from the quantitative methods are evaluated from the perspective of fulfillment of goals.

CHAPTER FOUR

4 DATA ANALYSIS

This chapter will present the analysis of the various data in the different projects, it is tried to compare the similar parameters in each of the project to generate some comparative analysis.'

4.1 Data Collection

The data used in this thesis is primarily sourced from the data generated by the Norwegian Railway Infrastructure administrator Jernbaneverket. This generated data is a recorded time measure for each of the trains. The flow of the data that is used in thesis is shown as:

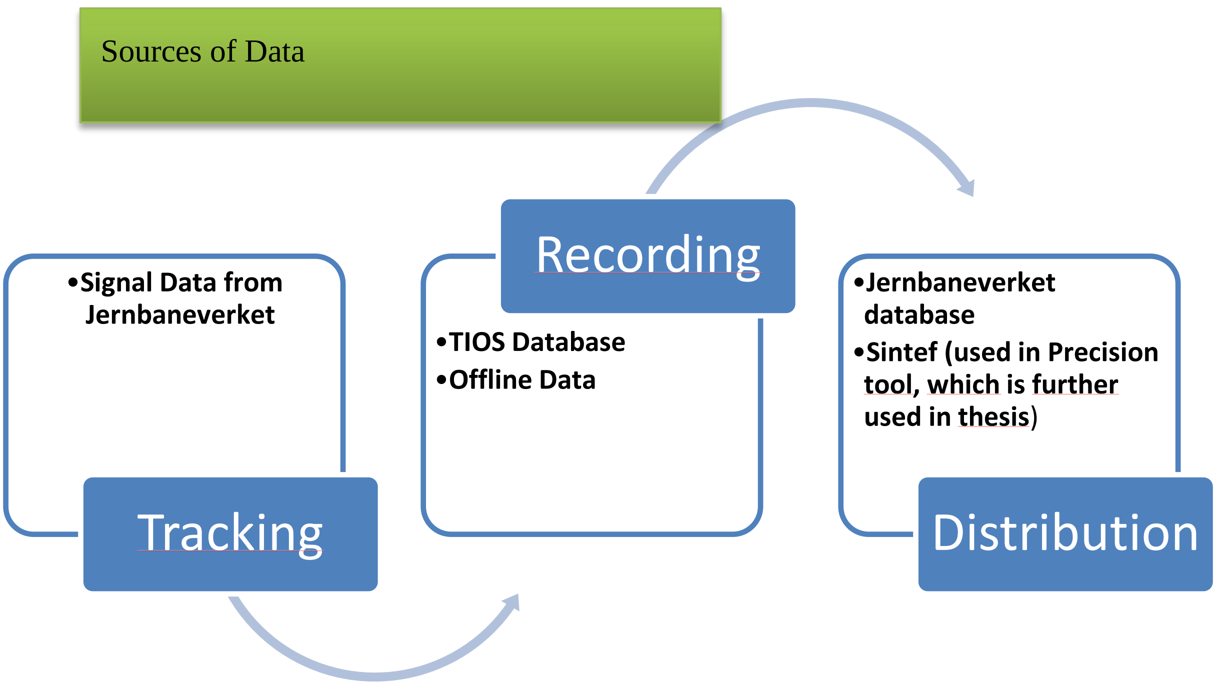


Figure 22: Ways of collecting the data in Jernbaneverket

The data to the different renewal projects are evaluated using the various tools of the Precision project.

4.2 Case Overview

This report will be entirely based on the analysis of the data generated from the various railway renewal projects after their consecutive execution. The data based on the travelling time, number of passengers, delays and in general costumer attitude and response towards the projects will be analyzed. The various railway projects that will be accounted will mostly from the eastern part of Norway called as Vestfold line that has claimed with 90,6 % of punctuality and more costumers satisfaction.

This report is based on the analysis of two big projects (Bårkåker- Tønsberg and Gevingåsen Tunnel) and the two small projects having the new crossings (Vålvåsjø crossing track and Jensrud crossing track).

4.2.1 Double track Barkåker to Tønsberg:

The new double track line between Barkåker and Tønsberg has a total construction length of 7.8 km. The project includes5.8 km of double track line from Skotte, north of Barkåker, to Tønsberg and a ca. 1.75 km tunnel through Frodeåsen, as well as connections to the existing line towards Tønsberg,

Project Information

Sector: Jernbanen (Vestfold line)

Project started: April 2009

Project completed: November,2011

Cost of project: 1490 MNOKs

The tunnel **Jarlsberg Tunnel** (Norwegian: *Jarlsbergtunnelen*) is a 1,750- Meter (5,740 ft) long double track railway tunnel which runs through Frodeåsen in Tønsberg, Norway. Located on the Vestfold Line, the tunnel was built as part of the 7.8-kilometer (4.8 mi) double-track high-speed segment from Barkåker to Tønsberg (Korsnes 2013). The tunnel started at Tomsbakken (national road 19) and emerged at Frodegata in Tønsberg, just outside Tønsberg station. The first sods of earth were cut on 2nd March 2009 and was completed in

November 2013 . The budget for the project was 116 MNOKs. The project has an objective to reduce the travel time to Oslo by 4 minutes..

Figure 23: Map of double track Tønsberg- Barkåker (Vestfold railway line)

4.2.2 Jensrud Crossings (Hakadal and Stryken at Gjøvik railway line)

The new crossing track between Hakadal and Stryken in Gjøvik line is 856 meter long along with 4,2 kilometer new cabling system. The project was started on 2009 and came into operation from June 2013. This project hit the budget of 116 MNOKs.

Project Information

Sector: Jernbanen (Gjøvik line)

Project started: Autumn 2009

Project completed: June,2013

Cost of project: 116 MNOKs

Figure 24: Map of Jensrud Crossings between Stryken and Hakadal Stations (Gjøvik railway Line)

4.2.3 Vålåsjø Crossings (Dombås to Oppdal)

The new crossing track between Dombås and Oppdal is 700 meter long. This project as well comprised with the new crossing track, new signaling system. The project was started on 2010 and ended on June 2013. The total budget of the project was 116 MNOKs.

Project Information
Sector: Jernbanen (Dovreline)
Project started: Autumn 2010
Project completed: June,2013
Cost of project: 116 MNOKs

Figure 25: Map of Vålåsjø Crossings between Oppdal and Dombås (Dovre railway Line)

4.2.4 Gevingåsen Tunnel (Hommelvik and Hell)

Gevingåsen tunnel was built between Hommelvik and Hell on the Nordland Line, through the hill called Gevingåsen. The tunnel is 4.4 kilometers (2.7 mi) long, although the whole project consists of 5.7 kilometers (3.5 mi) of track.The total cost of the project was 677 MNOK, and is categorized as major investment project. The tunnel carries a single track, reducing travel time by five minutes. It has also created the same distance between all passing loops between Trondheim and Stjørdal, allowing the capacity to increase from 5.4 to 8 trains per hour.[iii]

Project Information

Sector: Jernbanen (Nordland railway line)

Project started: 12 August 2010

Project completed: 15 August 2011

Cost of project: 677 MNOKs

Figure 26: Map of Gevingåsen tunnel between Hell and Hommelvik station (Nordland Railway Line)

Summary of the studied projects, including name of the project, budget, size (in km when applicable) and year of opening.

Name of the project	Type of Project	Budget	Length in Kms	Project Duration	
		(In MNOK)		Start	End
Barkåker-Tønsberg	Double Track	1480	7,8	2009	2013
Jensrud Crossings	Crossing Section (Hakadal-Stryken)	116	0,856	2009	June 2013
Vålåsjø Crossing	Crossing Section (Dombås-Oppdal)	116	0,7	2010	June 2013
Gevingåsen Tunnel	New tunnel between Hommelvik and Hell	677	5,7	2009	2011

Table 1: The overview of Projects

4.3 Evaluations of the Projects

The evaluations of the projects are done individually to the overviewed cases. The criteria of the evaluations are the change in the volume of the trains, the change in punctuality, the change in the level of crossing, the change in the travel time and the change in the standard deviations in the travel time before and after the execution of the renewal railway lines. The certain numbers of passenger trains are evaluated and the process of evaluation is aided by the Precision tools of evaluation and in some extent by the *My train application* of *Jernbaneverket.*

Followings are the evaluations of individual cased projects:

4.3.1 Double track Barkåker to Tønsberg

The evaluation of the double track between Barkåker and Tønsberg is carried out by evaluating the following passenger trains numbers: 804, 808, 809, 813, 811, 815, 819, 831, 812, 816, 820, 821, 824, 825, 827, 829, 832, 833 and 837 over one year before and one year after the modification of the route. In this case, as the new double track came into operation from June 2013, so the evaluation is done for one year before (July 2012- June 2013) and one year after (July 2013- June 2014). But to evaluate the change in line capacity, the evaluation is made from 2006 to 2014 to generate the yearly comparisons.

4.3.1.1 Status of change in the volume of the line:

The measurement in the change in the volume of the train travelling through the stations was carried out 2006 to 2014. As the project begins from 2009 and was completed in 2011. The duration before the project gives the mean of the 6500 trains passing through the route in a year whereas during the project period the volume was decreased by 10% to an average of 5800 trains per year. The volume of the train was increased by 20% to average of 6800 trains passing the route per year after the execution of the renewal railway line. So, the changes before the project to the after the project can be marked as overall increase in the volume of the line by 10%.

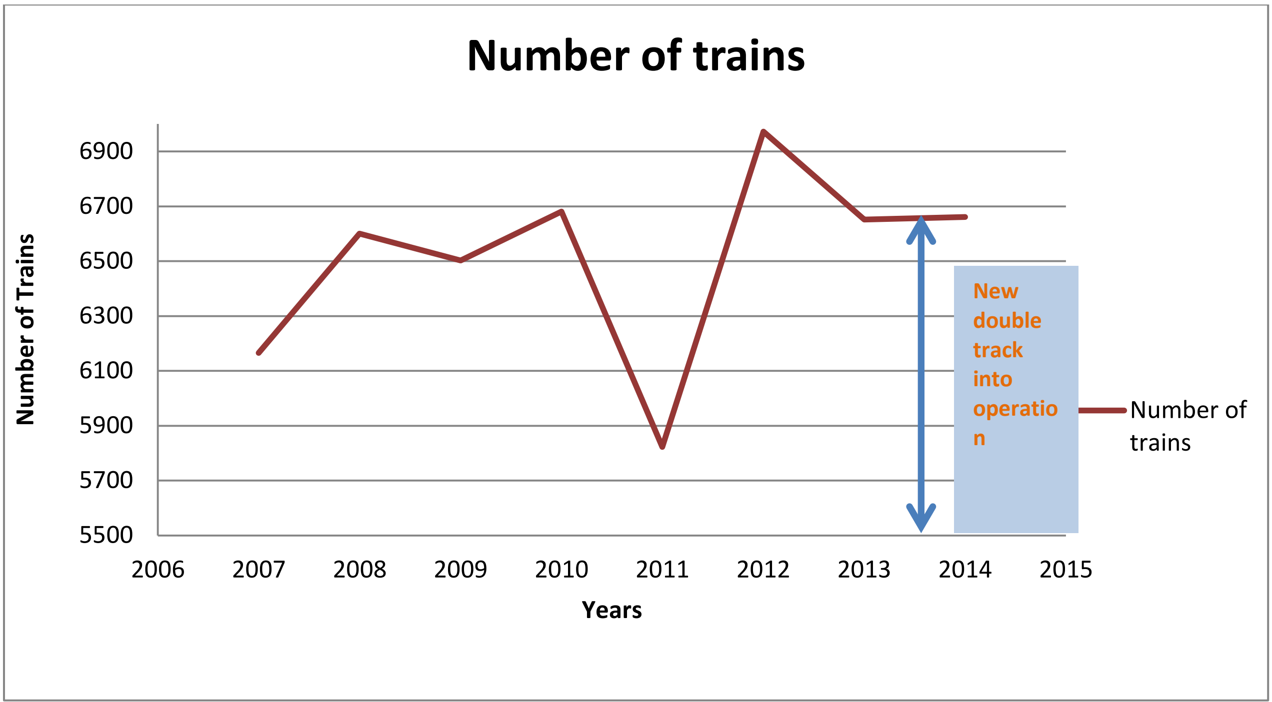


Figure 27: Change in the volume of train in Barkåker and Tønsberg line

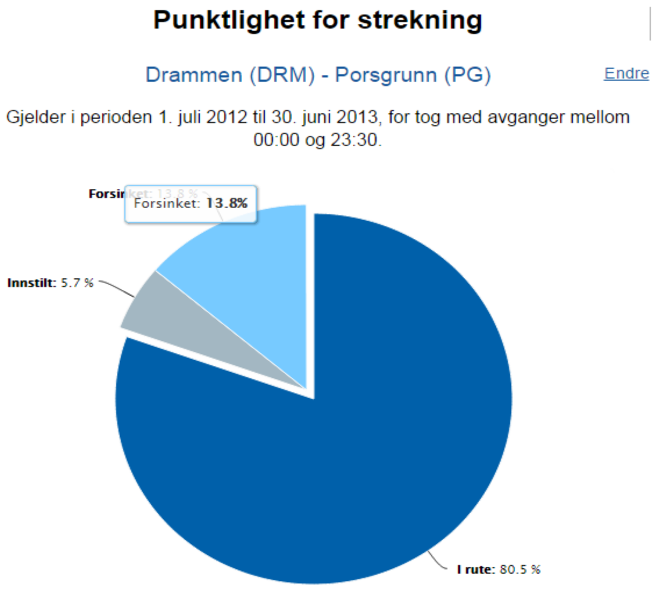
4.3.1.2 Status of Punctuality:

The status of the punctuality can be measure by the use of two tools:

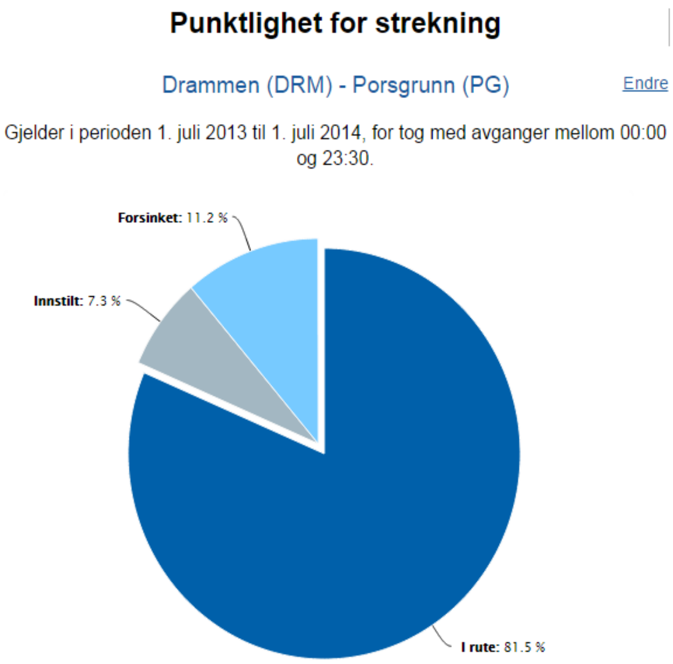
4.3.1.2.1.1 Punctuality measured from My Punctuality tool from Jernbaneverket.

To measure the effect on the punctuality in the Barkåker and Tønsberg double railway track, the big stations nearby the new double track are taken into consideration. To measure the punctuality in arrival in Porssgrunn (PG), the punctuality percentage of the train passing from Drammen (DRM) to Porsgrunn (PG) is measured before and after the operation of new double track. In other hand, the punctuality in Drammen is measured as the train traveling from Porsgrunn to Drammen to calculate the arrival punctuality in Drammen (DRM).

- **Punctuality in arrival in Porsgrunn (PG)**



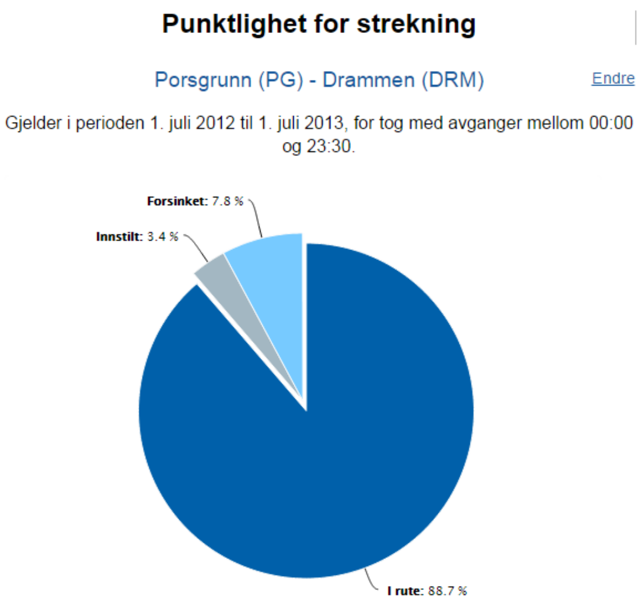
Before the double track



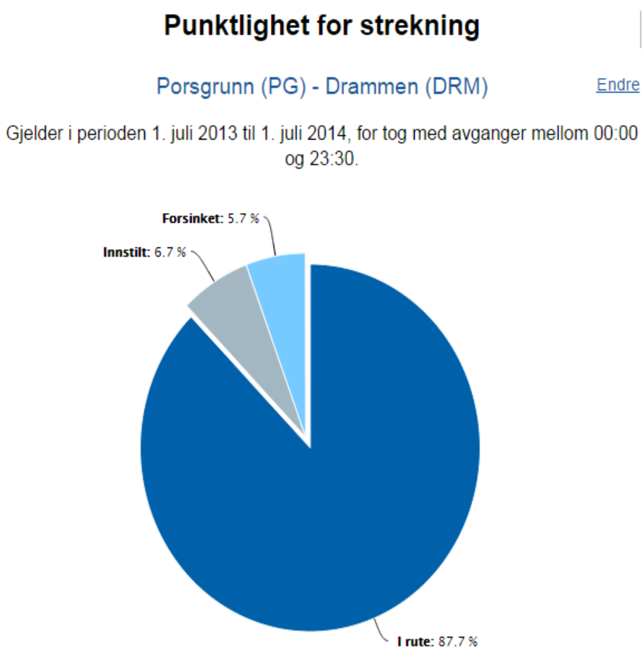
After the double track

From the above diagrams, the punctuality from Drammen to Porsgrunn before the new double track was 80.5% whereas the punctuality after the double track was 81.5%. So, it can be concluded that the punctuality of arrival at Prosgrunn after the new double track is increased by 1%.

- **Punctuality in arrival in Drammen (DRM)**



Before the double track



After the double track

In the above analysis, it can be observed that the punctuality in Drammen was 88.7% before the execution of double track whereas, after the execution of tunnel the punctuality was 87.7%. It can be concluded that the punctuality was decreased by 1%.

4.3.1.2.1.2 Punctuality measured by Precision tool

In the concern of the punctuality, here all the passenger trains running through the Barkåker and Tønsberg route was considered. To show the relative change in the level of the punctuality the two big stations nearby the new renewal line were considered. In this line the punctuality in the arrival to Drammen (DRM) to those train travelling to Oslo from Skien where in between the renewal line is located was considered which were the trains with even numbers, whereas the punctuality of the departure of Eidanger station was considered to those train travelling from Oslo to Skien as locating the new renewal line in between which were the trains with the odd numbers. While we select the train from Skien to Drammen the punctuality in arrival before the new railway line (June 2013), it was observed the average punctuality to be 80% while after the project the punctuality was 84% which shows that the punctuality was raised by 4%. In the same time the departure punctuality in the Eidanger station was 70% before the new railway line which increases to 82% after the new railway line, the net increase in the punctuality was 12% in average. But it can be noticed that the drop in the punctuality in the Vestfold line after May 2014 which is due to the influence of construction work of another double track (2012-2018) between Larvik and Porsgrunn in the same railway line.[iv]

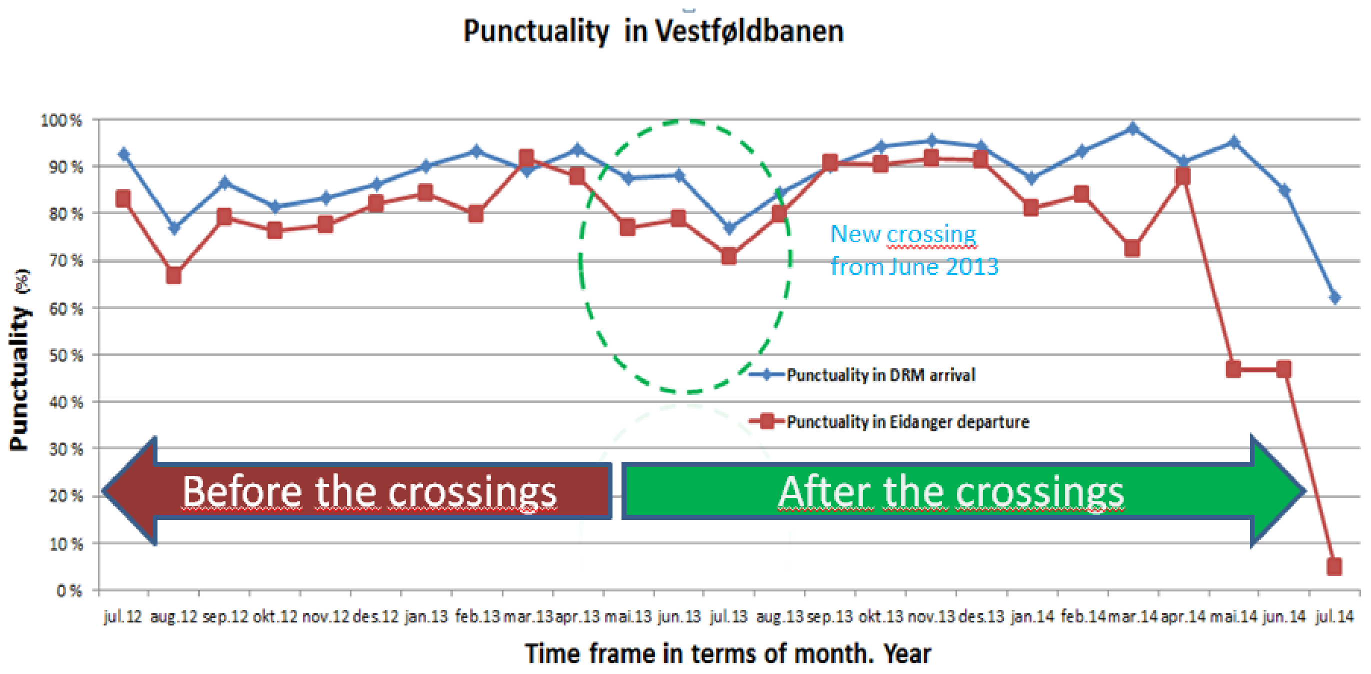


Figure 28: Change in punctuality in Vestfold line

It can be noted that the results from the two different tools is significantly different, it might be due to use of Eidanger station as the observed station in Precision tool whereas, in my train application Porsgrunn is taken as the observed station, as the my train application did not include Eidanger Station and the result is not based on real time system. The evalution of punctuality from Precision tool is taken further as result because the analysis was depended on data.

4.3.1.3 Change in the Travel Time and Standard deviation:

To measure the travel time and standard deviation, the process control diagram from Precision tool was used. In this case to simplify the calculation, the nature of only a single train number 811 was observed, as the travelling time to the multiple train number or the single train number remains almost the same. The situation of the change that are noted as:

- **Before the project**: The nature of the train number 811 before the renewal project, for instance 811 was observed. The travel time between the station Barkåker to Tønsberg was almost 4.5 minutes and the standard deviation was noted to be 107 seconds. The diagram showing the nature of travel time is represented in the format of the points where each of the point represents the individual train and the diagram can be obtained as:

```
For tognummer 811, fant: 198 togbevegelser.


Gj. kjøretid: 266.54 sekunder
Median kjøretid: 301 sekunder
Std.av kjøretid: 107.71 sekunder
```

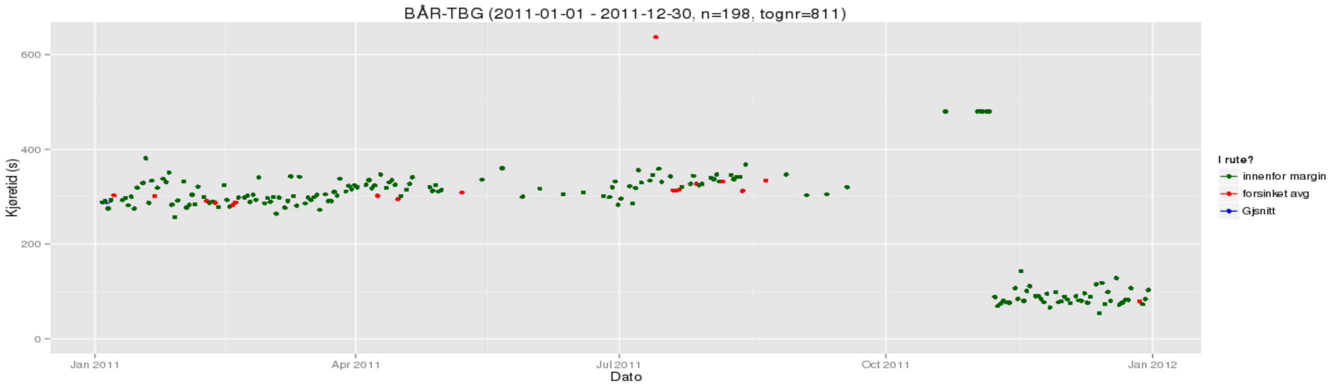


Figure 29: Travel time before project: Barkåker- Tønsberg

❖ **After the project**: The nature of the same number of the train after the execution of the project was observed between mid of 2013 to the mid of 2014. As from the observation, the travel time of the train between the Barkåker and Tønsberg station was 94 seconds whereas the standard deviation was 28 seconds. The following nature of process control graph was observed is the combination of the trains represented in points, the number of points gives the line graph as shown below:

```
For tognummer 811, fant: 359 togbevegelser.


Gj. kjøretid: 93.27 sekunder
Median kjøretid: 85 sekunder
Std.av kjøretid: 27.9 sekunder
```

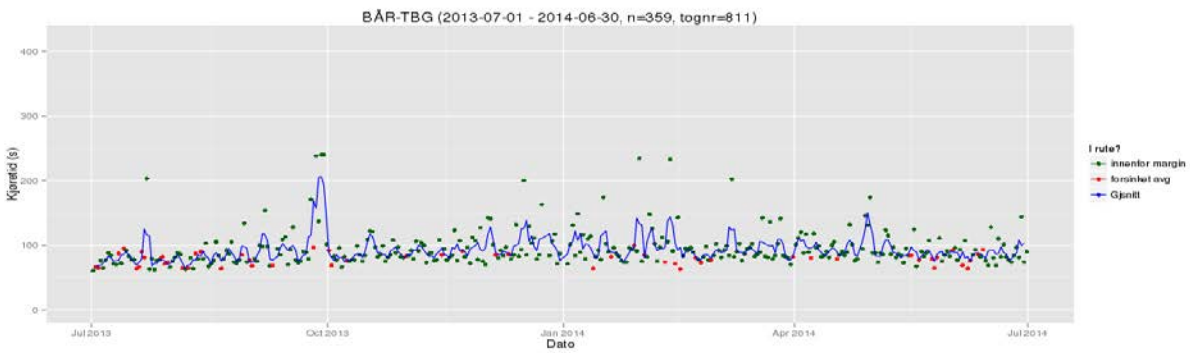


Figure 30: Travel time and standard deviation after the project: Barkåker-Tønsberg

So, it can be clearly noted that the travel time between Barkåker and Tønsberg was reduced by 3 minutes and the standard deviation was reduced by 80 seconds after the execution of double track between the stations.

4.3.2 Jensrud Crossing (Hakadal –Stryken in Gjøvik line)

The evaluation of the double track between Barkåker and Tønsberg is carried out by evaluating the following passenger trains numbers: 200, 206, 234, 280, 202, 204, 230, 272, 274, 208, 210, 284, 286, 216, 220, 222, 232, 256, 238, 240, 242, 246, 258, 254, 262, 264 and 282 as the train passing from Stryken to Hakadal and trains numbers 211, 275, 277, 201, 235, 203, 271, 205, 215, 217, 211, 283, 287, 213, 215, 219, 233, 235, 237, 239, 241, 243, 247, 251, 253, 259 and 279 as the train passing from Hakadal to Stryken over one year before and one year after the modification of the route. In this case, the evaluation is made from July 2012 to July 2014, as the new double track had come into operation from June 2013. But to evaluate the change in line capacity, the evaluation is made from 2008 to 2014 to generate the yearly comparisons.

4.3.2.1 Status of line capacity:

The measurement in the change in the volume of the train travelling through the stations was carried out 2008 to 2014. As the project begins from 2009 and was completed in June 2013. The duration before the project gives the mean of the 18000 trains passing through the route in a year 2008-2010 whereas during the project period the volume was decreased by 3% to an average of 17500 trains in the year 2011. The volume of the train was increased to average of 18000 trains passing the route in the year 2012, as the new crossing opened in June 2013, it can be observed that the mean number of train travelling through the route was decreased in 2013-2014 by 200. So, the changes before the project to the after the project can be marked as overall decrease in the volume of the line by 200 and can be marked as 1%.

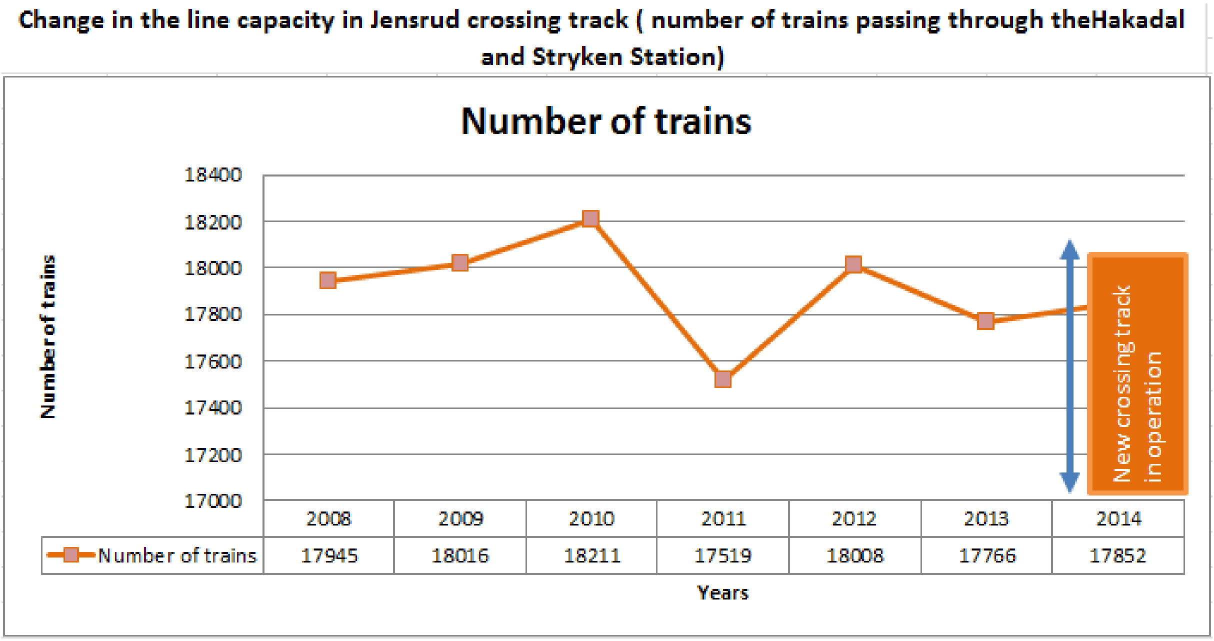


Figure 31: Change in line capacity: Jensrud Crossing

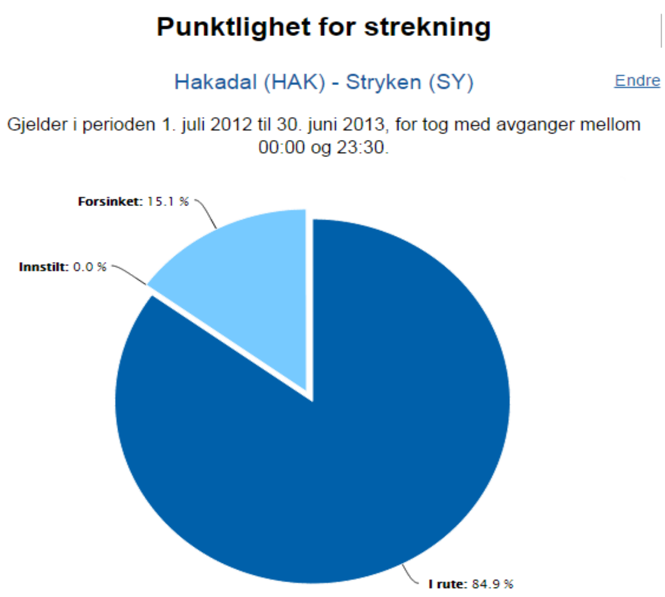
4.3.2.2 Status of Punctuality

The status of the punctuality can be measured from the following two tools:

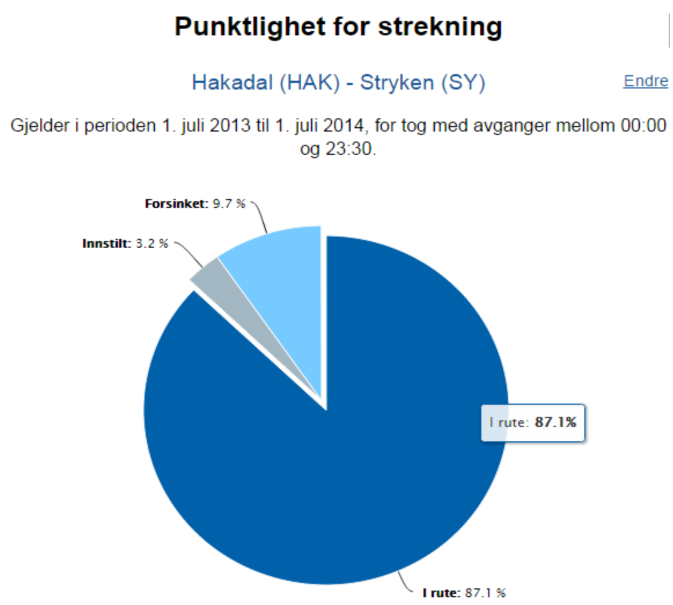
4.3.2.2.1.1 Punctuality measured from My train Punctuality application from Jernbaneverket

To evaluate the punctuality from this tool, the punctuality between Hakadal and Stryken was measured. The train passing from Hakdal to Stryken gives the punctuality at departure in Hakadal, whereas the trains passing from Stryken to Hakadal gives the punctuality of departure at Stryken station. The analysis was carried out between July 2012 to July 2014 as the new crossing between Stryken and Hakadal was introduced from June 2013.

❖ **Punctuality in departure at Hakadal (HAK) station:**



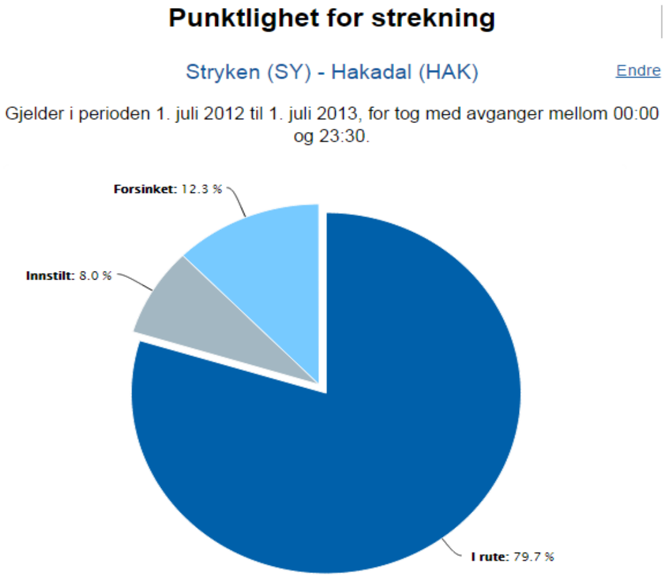
Before the new Jensrud crossing



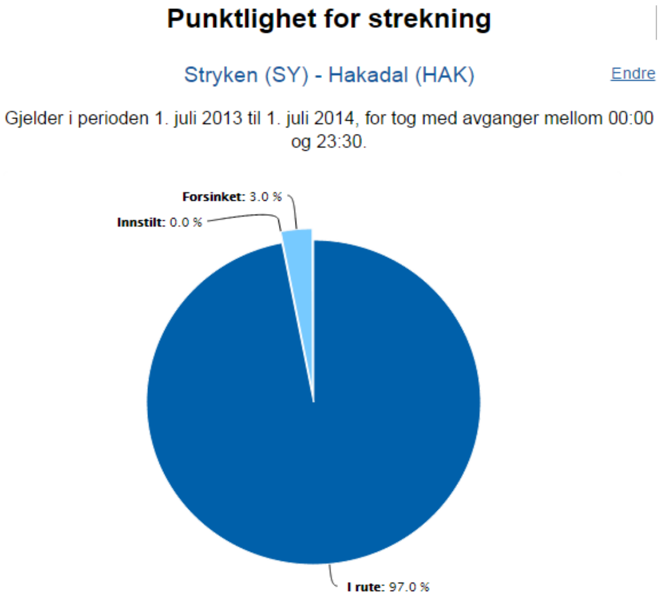
After the new Jensrud crossing

It can be observed that the punctuality before the new Jensrud crossing was 84.9% which was increased to 87.1% after the new crossing. The increase in the departure punctuality at Hakadal station was 2.2%.

- **Punctuality in departure in Stryken (SY) Station**



Before the new Jensrud crossing



After the new Jensrud crossing

In the above analysis, it was observed that the punctuality of arrival at Stryken station before the jensrud crossing was 79.7%, whereas the punctuality after the Jensrud rossing was 97%. The punctuality was increased by 17%.

4.3.2.2.1.2 Punctuality measured from Precision tool:

To measure the punctuality changes in the two stations Hakadal and Stryken was observed. The trains passing from Stryken to Hakadal with the even numbers are observed to get the departure punctuality at the Hakadal station wheras the train number having the odd numbers as travelling from Hakadal to Stryken was observed to get the arrival punctuality at Stryken station. The observation was done one year prior and one year after the execution of new crossings at Jensrud. The graph obtained is the representation of the points, as the number of points getting more gives the line graph.

- ❖ **The departure punctuality at Hakadal Station:**

The trains with the following numbers were observed that passes from Stryken to Hakadal. The following passenger train numbers were observed between 2012 to 2014: 200, 206, 234, 280, 202, 204, 230, 272, 274, 208, 210, 284, 286, 216, 220, 222, 232, 256, 238, 240, 242, 246, 258, 254, 262, 264 and 282. In the observation it was calculated as the average departure punctuality before the Jensrud Crossing was 75%-80% whereas the punctuality after the crossing was obtained to be 95%-100%, which shows that the punctuality is increased by 15%-20% after new Crossing.

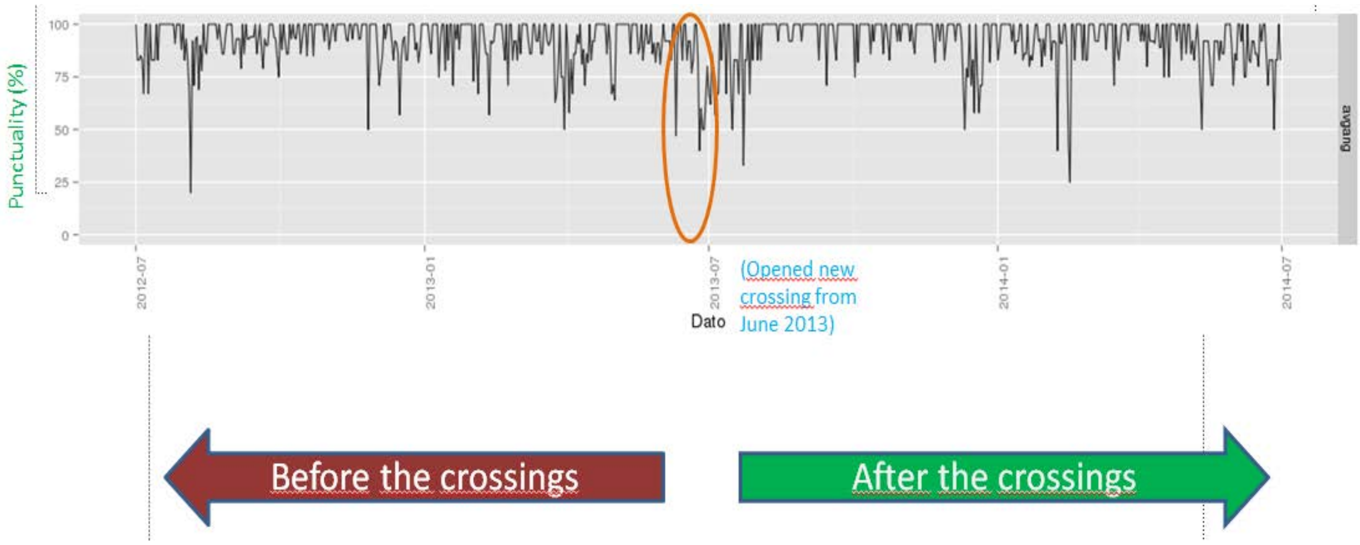


Figure 32: Departure punctuality in Hakadal Station- Jensrud Crossing

- ❖ **The departure punctuality at Stryken Station**

The trains with the following passenger train numbers were observed that passes from Hakadal to Stryken were observed between 2012 to 2014: The following passenger trains number were observed: 211, 275, 277, 201, 235, 203, 271, 205, 215, 217, 211, 283, 287, 213, 215, 219, 233, 235, 237, 239, 241, 243, 247, 251, 253, 259 and 279. In the observation it was calculated as the arrival punctuality at Stryken Station. It was observed that before the Jensrud crossing the arrival punctuality at Stryken was 80%-85%5% whereas the punctuality was increased to 85%-90% after the execution of the tunnel.

Figure 33: departurel Punctuality at Stryken station: jensrud Crossing

From the Precision tool it was pretty difficult to measure the exact change in the punctuality, so the quantitative figure obtained from My train application from Jernbaneverket is taken into further evaluation.

4.3.2.3 Travel Time and Standard Deviation

To measure the travel time and standard deviation, the train with the train number 200 was taken as the observed train. The result remains almost the same in travel time and standard deviation for the multiple train numbers also.

- **Before the Jensrud Crossing**

From the evaluation of the travel time and standard deviation from process control chart before one year of the project, it was observed that the travel time from Hakadal to Stryken station to be 386 seconds (6 minutes and 26 seconds) and the standard deviation to be 49 seconds. The detailed process control chart is as follows:

```
For tognummer 200, fant: 249 togbevegelser.


Gj. kjøretid: 385.57 sekunder
Median kjøretid: 382 sekunder
Std.av kjøretid: 49.08 sekunder
```

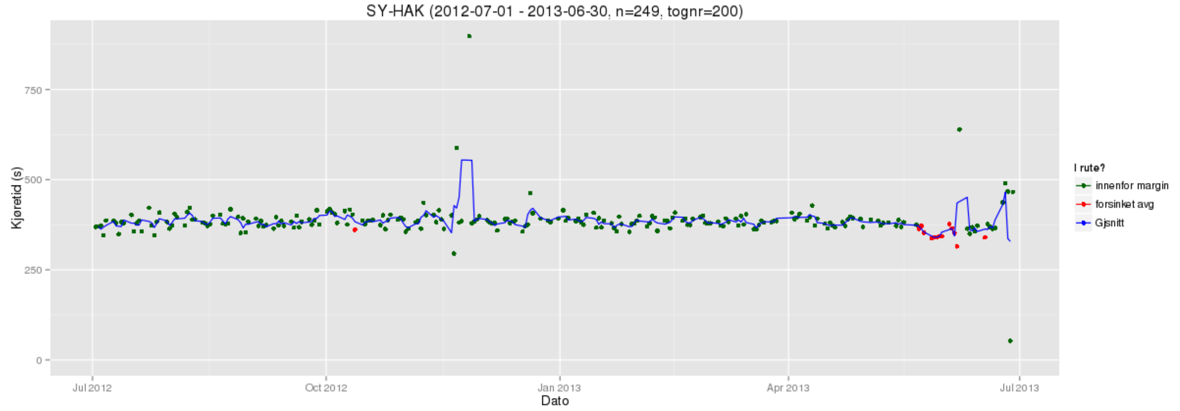


Figure 34: Travel Time and Standard Deviation for Jensrud Crossing

➢ **After the project**:

While the travel time and the standard deviation of the Gjøvik railway line was observed one year after the execution of the new crossing track, it was observed that the travel time and standard deviation from Hakadal station to Stryken station to be 392 seconds (6 minutes and 32 seconds) and the standard deviation to be 35 seconds. The process control diagram for that time period can be observed as:

```
For tognummer 200, fant: 243 togbevegelser.


Gj. kjøretid: 392.71 sekunder
Median kjøretid: 389 sekunder
Std.av kjøretid: 34.59 sekunder
```

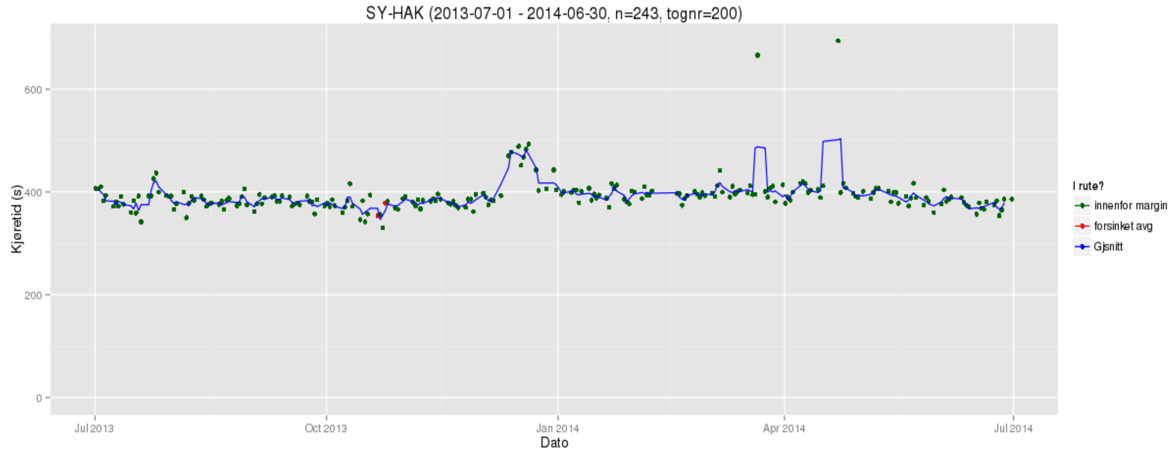


Figure 35: Travel Time and Standard Deviation after the new Jensrud Crossing

In the above diagrams the plotted dots and the lines represents the individual trains and it can be observed that the travel time was increased by 6 seconds and the standard deviation was decreased in between the Hakadal and Stryken Station by after the new crossing while comparing for the same time frame of before and after the execution of the project the standard deviation was decreased by 15 seconds.

4.3.3 Crossing section at Vålåsjø (Between Dombås and Oppdal)

The evaluation of the crossing section between Dombås and Oppdal is carried out by evaluating the following passenger trains numbers: 47, 405, 413, 425, 417, 433, 441, 449, 457, 5707, 1735, 12345, 5709, 5719, 5735, 5737, 5911, 5913, 5921, 5923, 5931 and 5933 as the train passing from Dombås to Oppdal and trains 46, 406, 426, 414, 434, 442, 450, 418, 426, 5708, 5702, 12344, 1704, 5718, 5730, 5734, 5738, 5912, 5932 and 5934 as the train passing from Oppdal to Dombås over one year before and one year after the modification of the route. In this case, the evaluation is made from July 2012 to July 2014, as the new double track had come into operation from June 2013. But to evaluate the change in line capacity, the evaluation is made from 2008 to 2014 to generate the yearly comparisons.

4.3.3.1 Status of line capacity:

The measurement in the change in the volume of the train travelling through the Dombås and Oppdal stations was carried out 2008 to 2014. As the project begins from 2010 and was completed in June 2013. The duration before the project gives the mean of the 1310 trains passing through the route in a year whereas during the project period the volume was decreased by 2% to an average of 1280 trains per year during the crossing track construction period. The volume of the train was increased by 1% to average of 1300trains passing the route per year after the execution of the renewal railway line. So, the changes before the project to the after the project can be marked as overall decrease in the volume of the line by 1%.

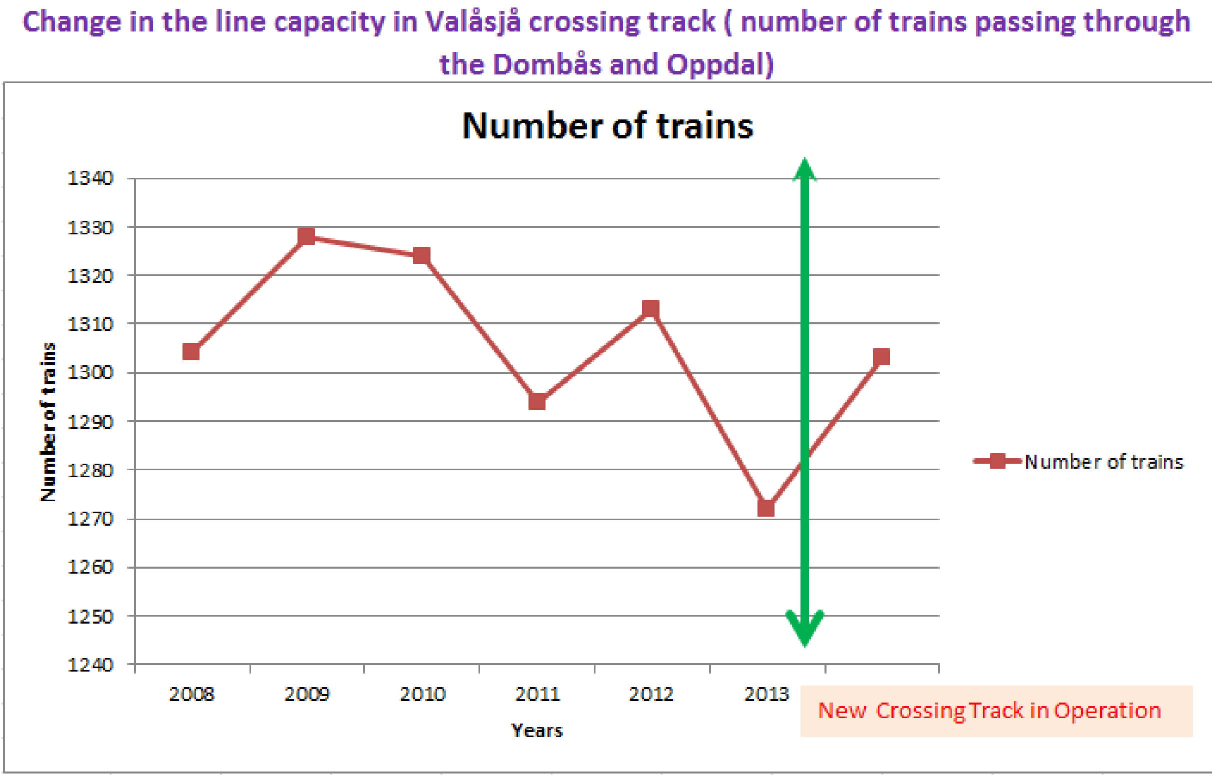


Figure 36: Change in Line capacity in Vålåsjø Crossing

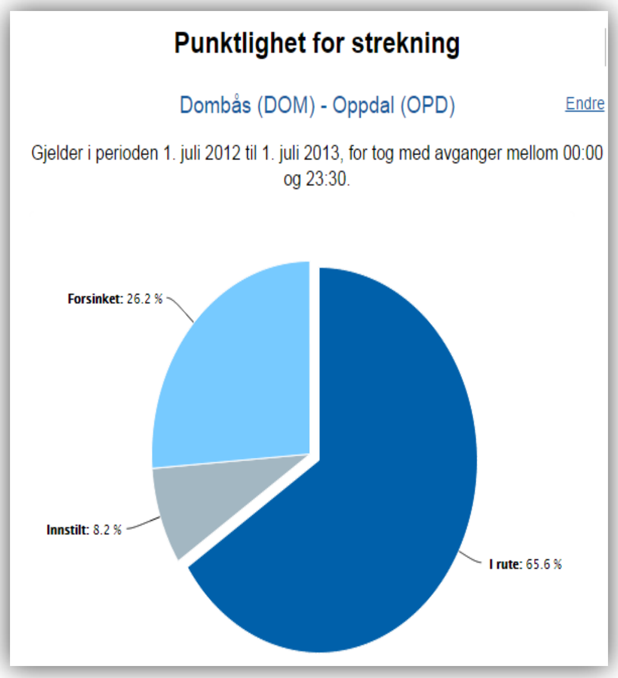
4.3.3.2 Change of punctuality

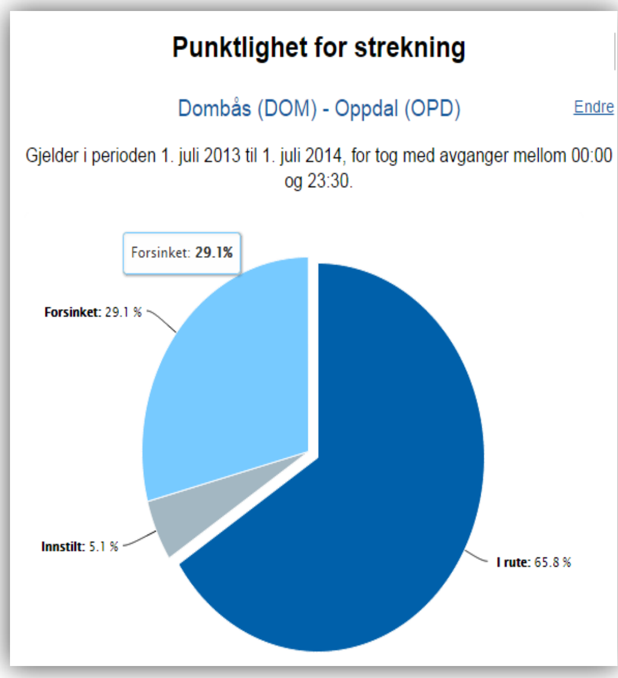
To measure the change in the punctuality, the two tools are used:

4.3.3.2.1.1 Punctuality measured from My train Punctuality application from Jernbaneverket.

To evaluate the punctuality from this tool, the punctuality between Dombås and Oppdal was measured. The train passing from Dombås to Oppdal gives the punctuality at departure in Dombås, whereas the trains passing from Oppdal to Dombås gives the punctuality of departure at Oppdal station. The analysis was carried out between July 2012 to July 2014 as the new crossing between Dombås and Oppdal was introduced from June 2013.

❖ **Departure punctuality at Dombås (DOM) Station:**

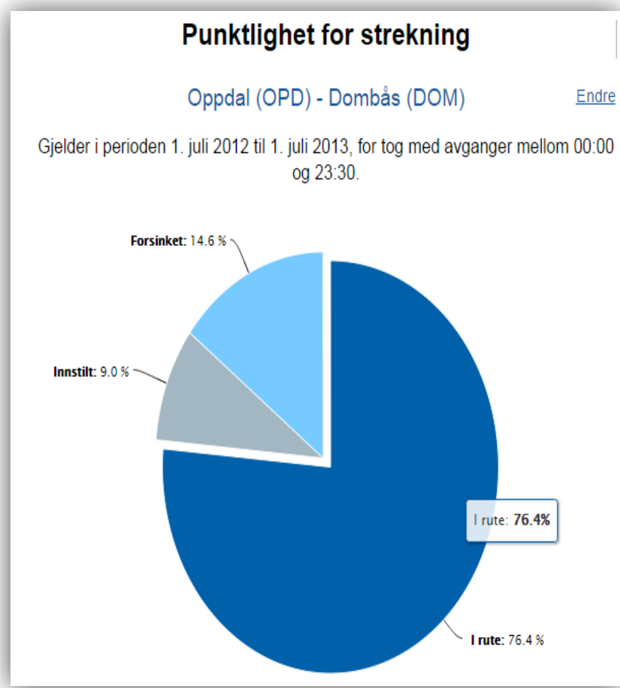


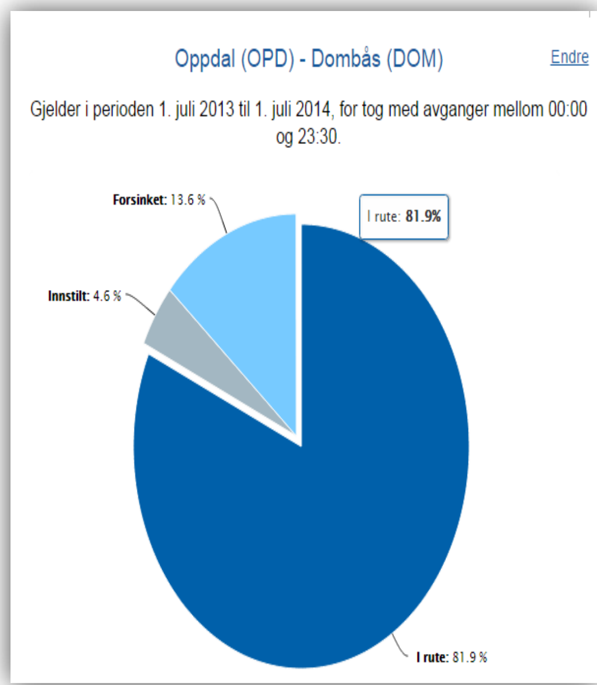


Before the new Valåsjø crossing **After the new Valåsjå crossing**

From the above experiment, it has been noted that, the punctuality at Dombåas Station was almost the same before and after the execution of the new Valåsjø crossings.

❖ **Departure punctuality at Oppdal (OPD) Station**:





Before the new Valåsjø crossing **After the new Valåsjå crossing**

In the above observation, it was observed that the departure punctuality at Oppdal before the crossing was 76.4% and after the crossing the punctuality raised to 81.9%. So the overall increase in the punctuality was 5.4%.

- Evaluation of punctuality from Precision tool

To measure the effect on punctuality due to new valåsjå crossing, the punctuality in Dombås and Oppdal was observed. The trains passing from Dombås to Oppdal with the odd numbers are observed to get the departure punctuality in the Dombås Station, whereas the trains with the even numbers are the trains passing from Oppdal to Dombås are used to measure the departure punctuality at the Oppdal Station. The observation is done one year before and one year after the execution of the project.

- **The departure punctuality at Dombås (DOM) Station**:

The trains with the following trains' numbers were observed from 2012 to 2014: 47, 405, 413, 425, 417, 433, 441, 449, 457, 5707, 1735, 12345, 5709, 5719, 5735, 5737, 5911, 5913, 5921, 5923, 5931 and 5933. In the observation it was calculated as the departure punctuality before the Vålåsjø Crossing was 70%-75%, whereas the punctuality after the new crossing was obtained to be 50%-55%. It means the punctuality of the Dombås station on the departure was reduced by 18% if we take the mean on above changes. The punctuality graph over the time period in Dombås Station was observed as:

Figure 37: Departure Punctuality at Dombås Station- Våaåsjå Crossing

- ❖ **The departure Punctuality at Oppdal (OPD) Station**:

The trains with the following passenger trains numbers were observed that passed from Oppdal to Dombås between 2012 to 2014. The following train numbers were observed: 46, 406, 426, 414, 434, 442, 450, 418, 426, 5708, 5702, 12344, 1704, 5718,5730,5734, 5738, 5912,5932 and 5934. In the observation it was calculated the departure punctuality of the trains in the Oppdal station. It was observed that before the new crossing the punctuality at Dombås was 75%-80%, whereas the punctuality decreased to 70%-75% after the new Vålåsjø Crossings, where the average decrease is assumed to be by 7% The punctuality diagram for the time periods over the station is shown as:

Figure 38: Departure Punctuality in Oppdal Station over 2012-2014

The punctuality results from the Precision tool is taken into the further evaluation as the results being relatively more precise.

4.3.3.3 Travel Time and Standard Deviation

To measure the travel time and the standard deviation, the train number 406 was taken as the observed train. The observation time was one year before and one year after the execution of the new crossing track between Oppdal and Dombås Station. The consideration was made for the individual trains, the increasing number of trains when plotted gave the line format. It was assumed that all the trains passing through the route have similar nature of travel time and Standard Deviation.

- **Before the new Vålåsjø Crossing**

From the evaluation of the travel time and standard deviation from the process control chart before one year of the execution of the project, it was observed that the travel time from Oppdal to Dombås was 1 hour 6 minutes and 43 seconds and the standard deviation was 9 minutes and 24 seconds. The detailed process chart is shown as:

```
For tognummer 406, fant: 411 togbevegelser.

Gj. kjøretid: 4003.09 sekunder
Median kjøretid: 3890 sekunder
Std.av kjøretid: 564.59 sekunder
```

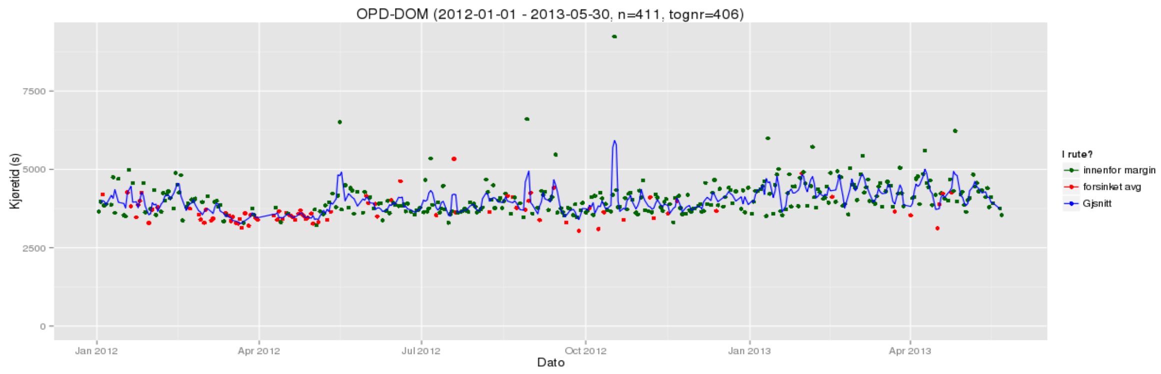


Figure 39: Travel Time and Standard Deviation before new Vålåsjø Crossing between 2012-2013

- ❖ **After new Vålåsjø crossing**

When the observation of the travel time between oppdal and Dombås after one year of the execution of new crossing, it was observed that the travel time was 1 hour 9 minutes and 25 seconds, whereas the standard deviation was calculated as 8 minutes and 11 seconds. The detailed process chart is shown as:

```
For tognummer 406, fant: 447 togbevegelser.


Gj. kjøretid: 4165.63 sekunder
Median kjøretid: 4079 sekunder
Std.av kjøretid: 491.83 sekunder
```

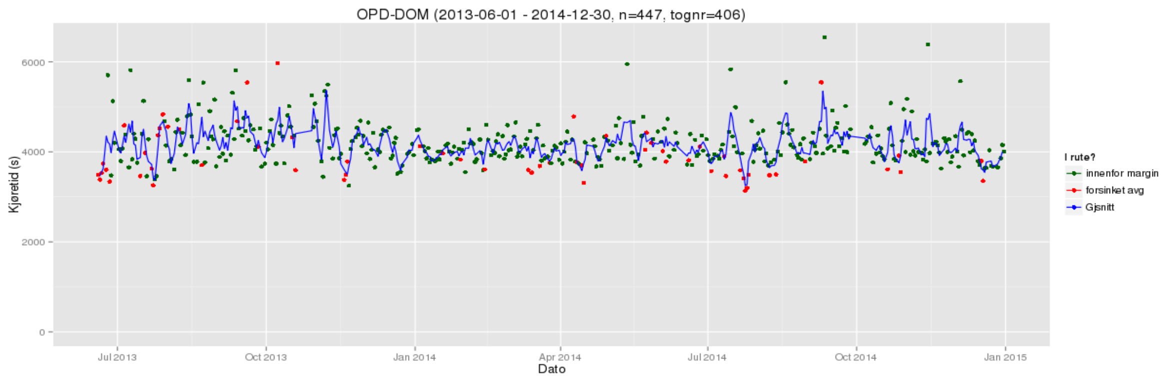


Figure 40: Travel Time and Atandaed Deviation after new Vålåsjø crossing between 2013-2014

So, it can be observed that the travel time from Oppdal to Dombås after the new vålåsjø crossing has been increased by 2 minutes and 48 seconds whereas the standard deviation is decreased by 1 minute 13 seconds.

4.3.4 Gevingåsen Tunnel between Hommelvik and Hell

The evaluation of the effect of new tunnel between Hommelvik station and Hell station was carried out by evaluating the following passenger trains numbers: 381, 382, 383, 384, 425, 426, 433, 434, 441, 442, 449, 450, 457, 471, 472, 475, 476, 477, 1702, 1761, 1760 and 1762 before one year and after the modification of the route. In this case, the evaluation is made from January 2011to August 2012 as the new Gevingåsen tunnel came into operation from mid of August 2011.

4.3.4.1 Status of Line Capacity

The measurement in the change in the volume of the train travelling through the stations was carried out 2011 to 2013. As the project begins from 2009 and was completed in August 2011. Due to unviability of the data, the calculation is limited to before 8 months of the execution of the Gevingåsen tunnel and after one year of the operation of tunnel. While talking the average of monthly 1050 trains travel through the route before the new tunnel. The number of the trains is increased to 1160 per month after the execution of new tunnel. It shows that the capacity of the railway track due to new tunnel is increased by 10%. The change in the capacity of railway track is diagrammatized as:

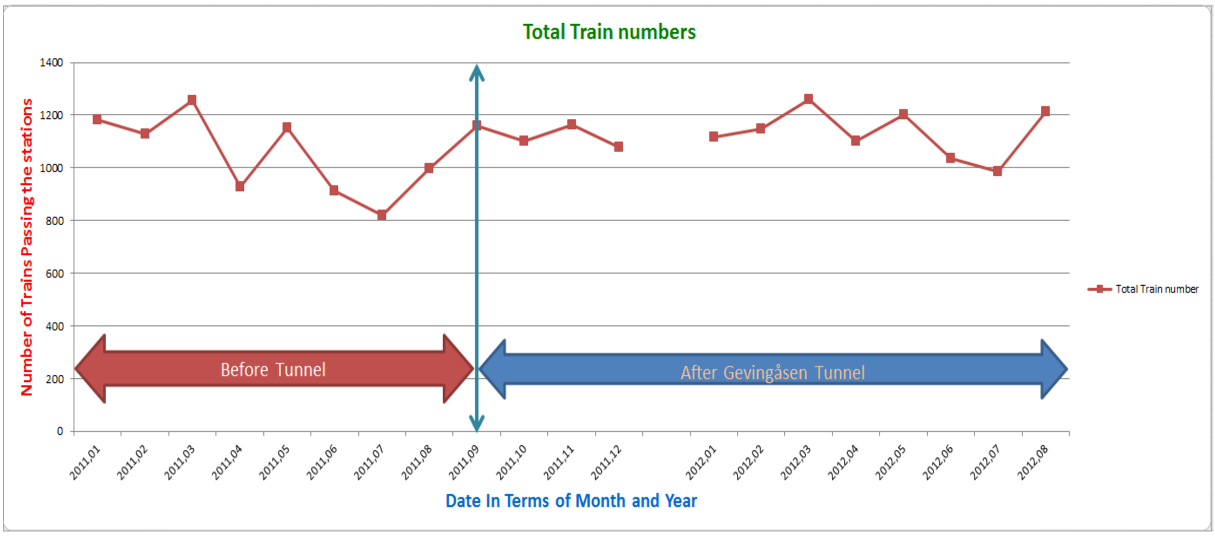


Figure 41: Change in the Railway Capacity due to new Gevingåsen tunnel over 2011-2012

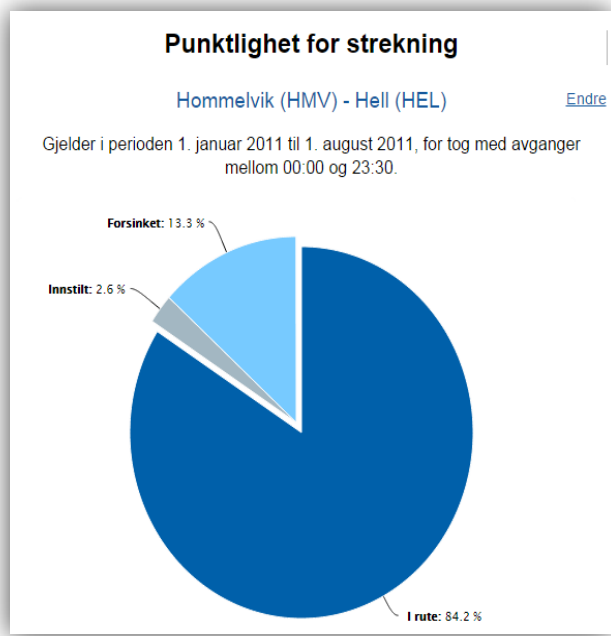
4.3.4.2 Status of Punctuality

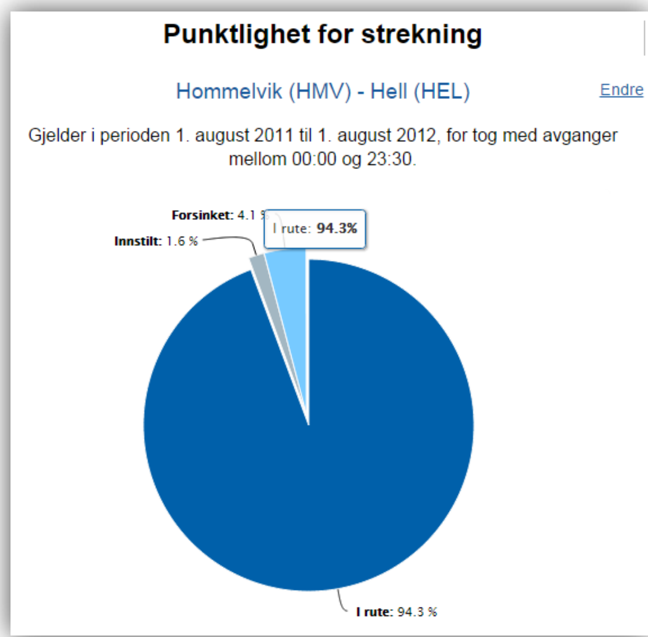
The punctuality effect between Hommelvik and Hell station was evaluated by two approaches:

4.3.4.2.1.1 Punctuality measured from My train Punctuality application from Jernbaneverket

To evaluate the punctuality from this tool, the punctuality between Hommelvik and Hell was measured. The train passing from Hommelvik to Hell gives the punctuality at departure in Hommelvik whereas the trains passing from Hell to Hommelvik gives the punctuality of departure at Hell station. The analysis was carried out between January 2011 to September 2012 as the new tunnel crossing between Hommelvik and Hell was introduced from August 2011.

- **Departure punctuality at Hommelvik (HMV) Station**

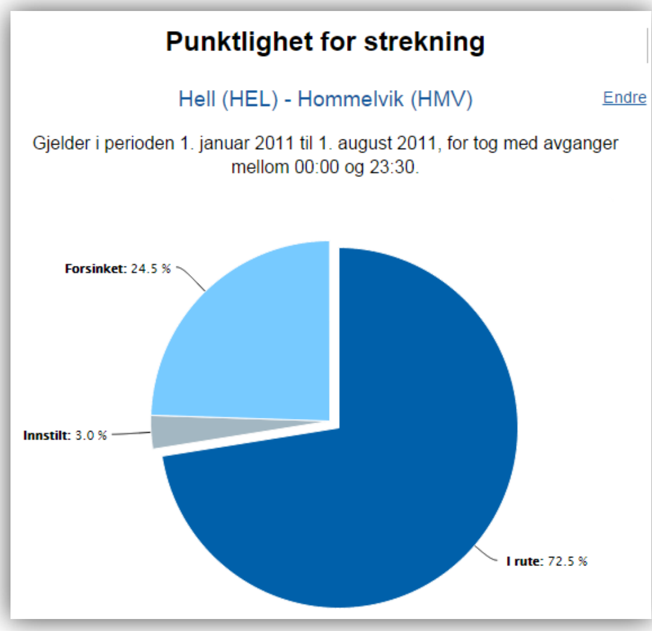


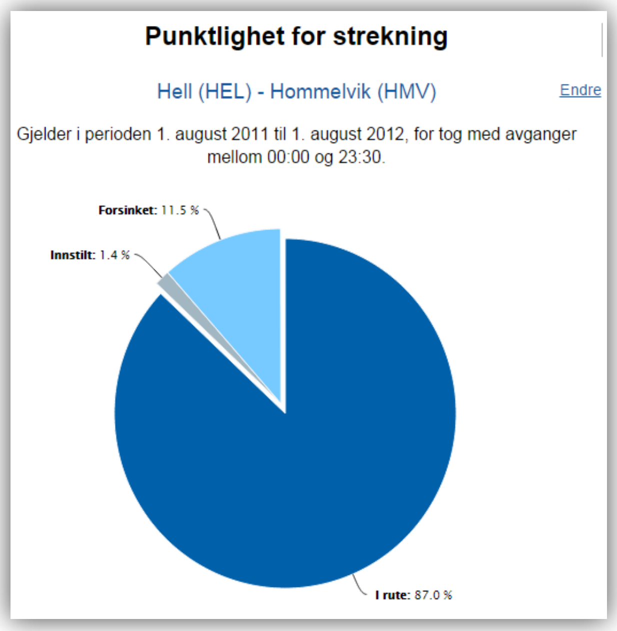


Before the new Gevingåsen tunnel **After the Gevingåsen tunnel**

From the above evaluation, it can be observed that the departure punctuality at Hommelvik before the tunnel was 84.2% which was increased to 94.3% after the tunnel over 2011-2012.

- **Departure punctuality at Hell (HEL) station**





Before the new Gevingåsen tunnel **After the Gevingåsen tunnel**

From the above evaluation, it can be observed that the departure punctuality at hell station was 72% before the tunnel which rises to 87% after the tunnel. So, th increase in punctuality was by 15%.

4.3.4.2.1.2 Evaluation of the punctuality from Precision tool.

To measure the change in punctuality, the two stations preceding and succeeding the Gevingåsen tunnel was taken into observation. The stations are Hommelvik and Hell. In both cases the departure punctuality in both the station is taken into consideration. The observation is made one year before and one year after the execution of new Gevingåsen tunnel.

- **The departure punctuality at Hell (HEL)**

The trains with the even numbers that passes from the Hell to Hommelvik were observed and the punctuality of the departure at Hell Station was calculated. In the observation, it was calculated as the average departure punctuality before Gevingåsen tunnel was 70%-75% whereas, the punctuality after the execution of the tunnel was obtained to be 85%-90%. It shows that the punctuality of departure in the Hell station was increased by 15%. The level of punctuality between the stations over the time period 2011-2012 is shown as:

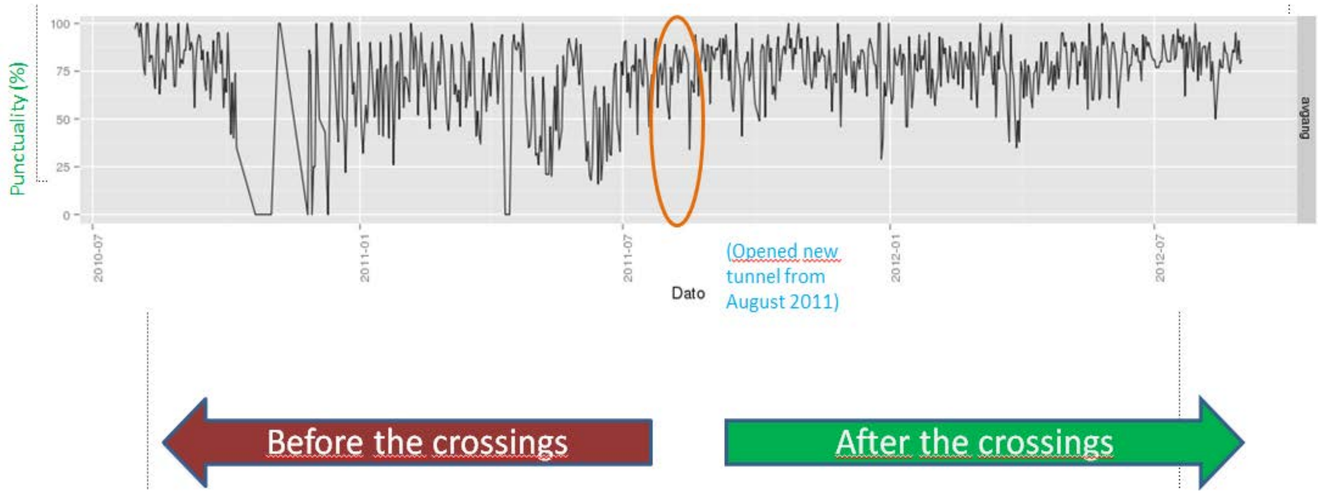


Figure 42: Departure Punctuality in Hell Station - Gevingåsen Tunnel

❖ **Departure Punctuality at Hommelvik (HMV) Station**:

The trains with the odd numbers that passes from Hommelvik to Hell are observed and the departure punctuality at the Hommelvik Station was calculated. In the observation, it was calculated the departure punctuality before the Gevingåsen tunnel was 80%-85%, whereas, the punctuality after the execution of the tunnel was obtained to be 90%-95%. This shows that the punctuality was increased by 10% in the Hommelvik Station. The change in the level of punctuality over the period of 2011-2012 in Hommelvik station is diagrammatized as:

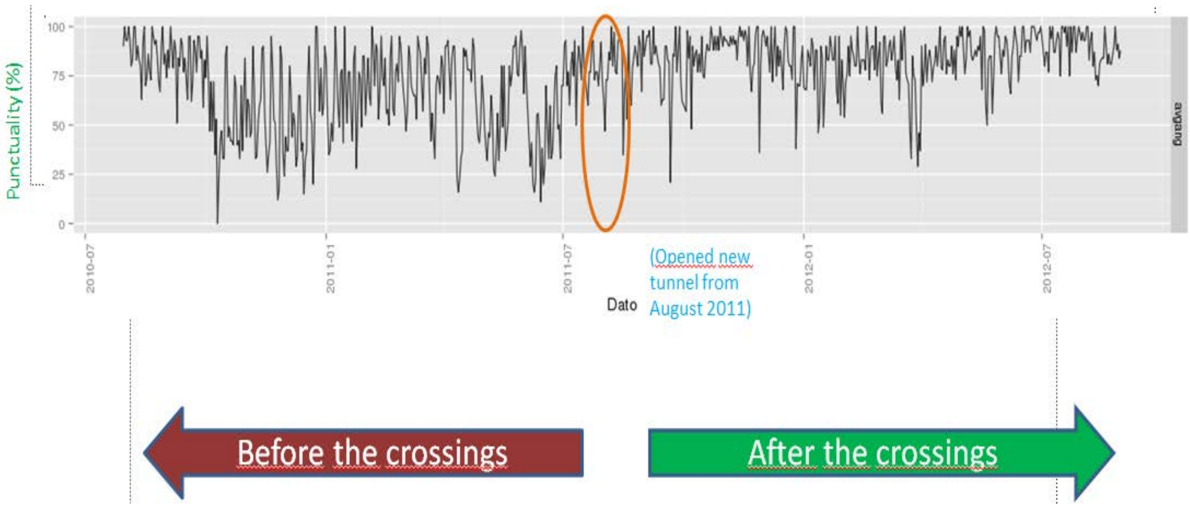


Figure 43: Change in punctuality in Hommelvik Station over 2011-2012

Here from both the evaluations same result of departure punctuality at Hommelvik to be 10% and of Hell to be 15% were obtained, that are further subjected to evaluation.

4.3.4.3 Travel Time and Standard deviation

To measure the travel time and standard deviations between the Hell and Hommelvik Station the train number 472 was observed. The observation was made over the period of 8 months before and after the execution of the project. It was assumed that the multiple train numbers also shows the almost same time frame.

➢ **Before the Gevingåsen tunnel**

From the evaluation of the process control chart, the travel time calculated between the Hommelvik and Hell station before the Gevingåsen tunnel was 6 minutes and 25 seconds, whereas the standard deviation was calculated as 47 seconds. The process control diagram over the time period 2011-2011 between the stations before the new tunnel can be diagrammatized as:

```
For tognummer 472, fant: 200 togbevegelser.


Gj. kjøretid: 372.12 sekunder
Median kjøretid: 370 sekunder
Std.av kjøretid: 47.86 sekunder
```

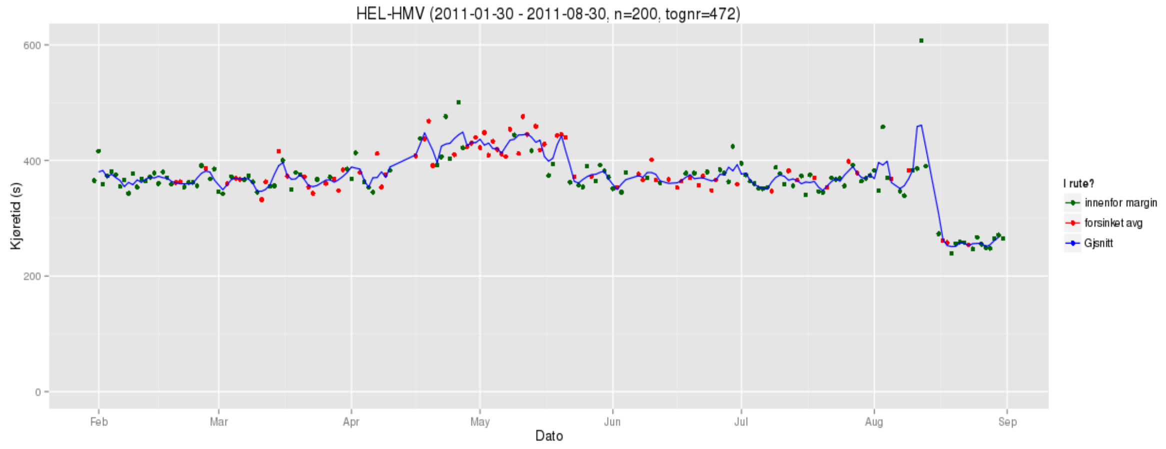


Figure 44: Travel Time and Standard deviation between Hommelvik and hell between 2011-2012

➢ After the Gevingåsen tunnel

The travel time between Hommelvik and Hell when observed after one year of the execution of Gevingåsen tunnel found to be 3 minutes 33 seconds whereas the standard deviation was reduced to 28 seconds. The nature of process control diagram that was observed on time frame of 2011-2012 was diagrammatized as:

```
For tognummer 472, fant: 352 togbevegelser.


Gj. kjøretid: 213.44 sekunder
Median kjøretid: 207 sekunder
Std.av kjøretid: 28.17 sekunder
```

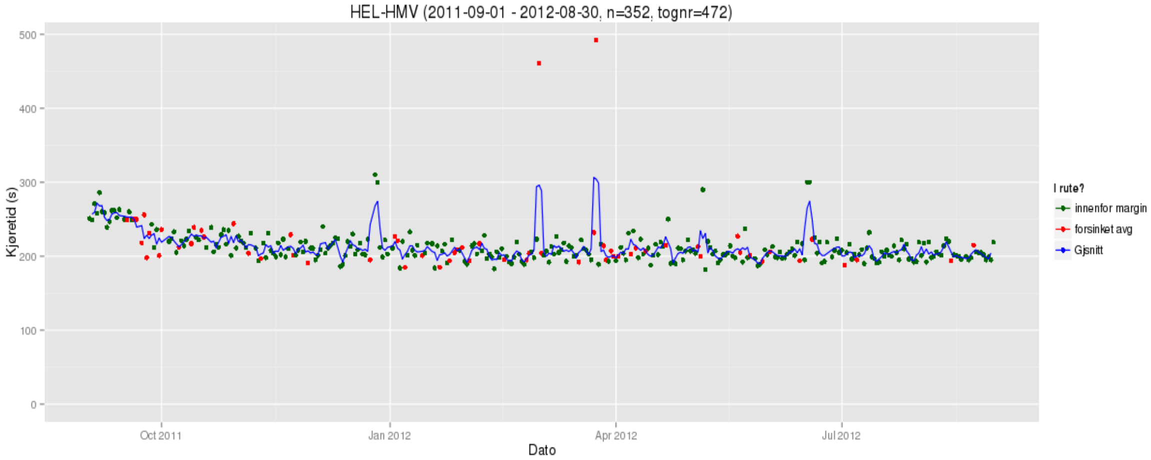


Figure 45: Travel Time and Standard deviation between Hommelvik and Hell over 2011-2012

It can be observed that the travel time between Hommelvik and Hell was reduced by 2 minutes and 53 seconds and the standard deviation was reduced by 19 seconds after the execution of new Gevingåsen tunnel. In the above diagrams of travel change and standard deviations, the graph is the output of the individual train represented as the dotted points, when the increasing number of dots gave the line format also.

Summary of the results from the observations of four railway projects:

The results of the change in the evaluation indicator can be summarised as:

Renewal Projects	Evaluation Criteria (Change in)	Results		Net change result
		Before the modification	After the modification	
Double Track Barkåker-Tønsberg	Line capacity	6500	6800	Increase by 5%
	Punctuality at Station Drammen (Arrival)	80 %	84 %	Increase by 4%
	Punctualityat Eidanger (Departure)	70 %	82 %	Increase by 12%
	Travel Time	4,5 minutes	1,5 minutes	Decreased by 3 minutes
	Standard Deviations	107 seconds	27 seconds	Decreased by 80 seconds
Jensrud crossing (Hakadal-Stryken)	Line capacity	18000	17800	Decreased by 1%
	Punctuality at Hakadal (Departure)	95 %	92 %	Decreased by 3%
	Punctuality at Stryken (Departure)	97 %	95 %	Decreased by 2%
	Travel Time	804 seconds	812 seconds	Increased by 8 seconds
	Standard Deviations	68 seconds	53 seconds	Decreased by 15 seconds

Valåsjø crossing (Dombås-Oppdal)	Line capacity	1310	1300	Decreased by 1%
	Punctuality at Oppdal (Departure)	72%	54%	Decreased by 18%
	Punctuality at Dombås (Departure)	80%	73%	Decreased by 7%
	Travel Time	1 hour 6 minutes and 43 seconds	1 hour 9 minutes and 25 seconds	Increased by 2 minutes and 42 seconds
	Standard Deviations	9 minutes 24 seconds	8 minutes 11 seconds	Decreased by 1 minute 13 seconds
Gevingåsen tunnel (Hommelvik-Hell)	Line capacity	1050/month	1160/month	Increased by 10%
	Punctuality at hell (Departure)	72,5%	87%	Increased by 14,5%
	Punctuality at Hommelvik (Departure)	84%	94%	Increased by 10%
	Travel Time	6 minutes 25 seconds	3 minutes 33 seconds	Decreased by 2 minutes 52 seconds
	Standard Deviations	47 seconds	28 seconds	Decreased by 19 seconds

Table 2: Summary of the reults of evaluation

4.4 Analysis of the results

The quantitative results from the evaluation of the various indicators of evaluation measurement are subjected to the analysis of the success through the radar plotting of each of the evaluated indicators. The approach is mostly used in this thesis is more quantitative, comparing the situation before to the situation after So, making an analogue with those evaluation criteria with the criteria set up in the methodological part of thesis as described by (Samset 2003), the radar is developed to evaluate the nature of the projects.

In analogue, in this thesis the evaluation criteria that are set up are the change in punctuality in succeeding and preceding stations from the renewed regions, capacity of railway track, change in travelling time between the stations, and the standard deviations in the route are evaluated against each of the project.

Assumptions in the radar Analysis

- ❖ All the rational increase and decrease in the results comparing to the before and after the situation are expressed in terms of the change percentage.
- ❖ The increase in line capacity and punctuality after the execution of project is marked as the positive effect of the project, whereas the decrease in the values are marked as the negative impact
- ❖ The decrease in the travel time and standard deviations of the travel time between the two stations after the execution of new renewed projects are marked as the positive impact, in contrary the increase in these quantities are marked as the negative impact on the project
- ❖ The success of each of the project is evaluated on the basis of nature of the graph obtained from the radar analysis.

4.4.1 Analysis of results in Double Track Barkåker- Tønsberg

From the results obtained from the quantitative analysis of the evaluation indicators such as the change in punctuality, the change in the line capacity, the change in the travel time and the change in the standard deviation between Bårkåker and Tønsberg before one year and after one year of double track execution (new double track from November 2011), the success of the project from the perspective of those indicators can be evaluated through the analysis of the following radar chart.

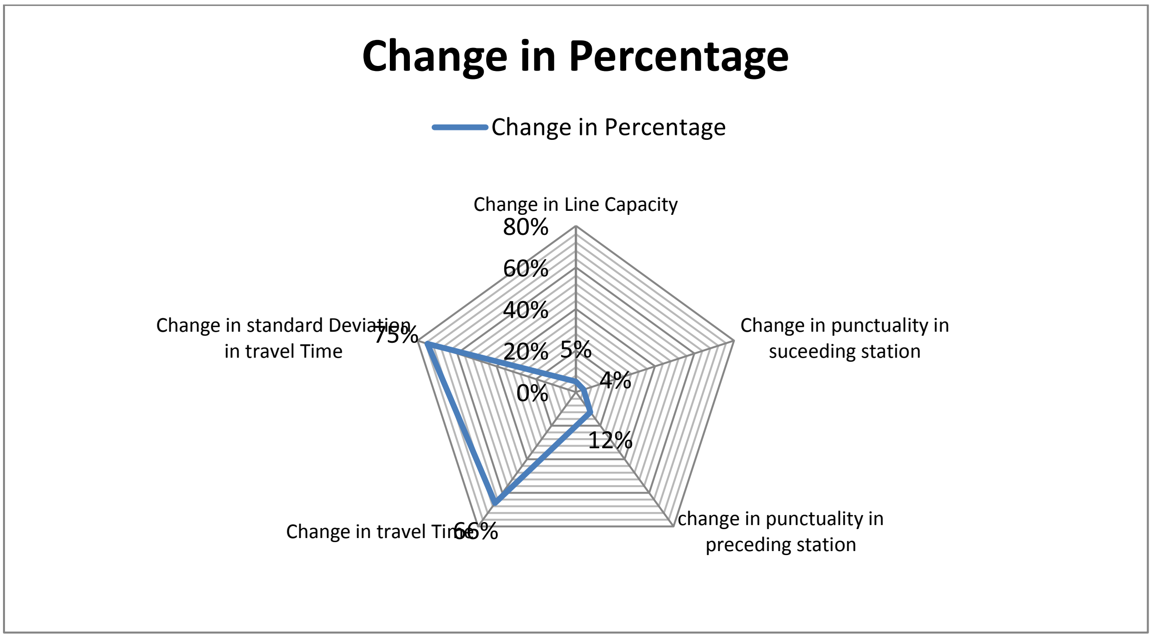


Figure 46: Radar Analysis of Changes in Double Track Bårkåker and Tønsberg

From Figure 46, it can be analyzed that in the new double track between Barkåker- Tønsberg in Vestfold railway line all the results of the evaluation indicators have positive impacts, as comparing to the situation before the project, the line capacity and punctualities between the stations have been raised significantly, in addition the travel time and the standard deviations in travel time have been decreased. So, the renewed railway lime has shown positive attitude towards the evaluation criteria.

4.4.2 Analysis of the results in new Jensrud Crossing:

The results obtained from the analysis of the evaluation criteria between hakadal and Stryken station before one year and after one year of the execution of the new Jensrud Crossing (new crossing from June 2013) between those stations can be plotted in the radar diagram as:

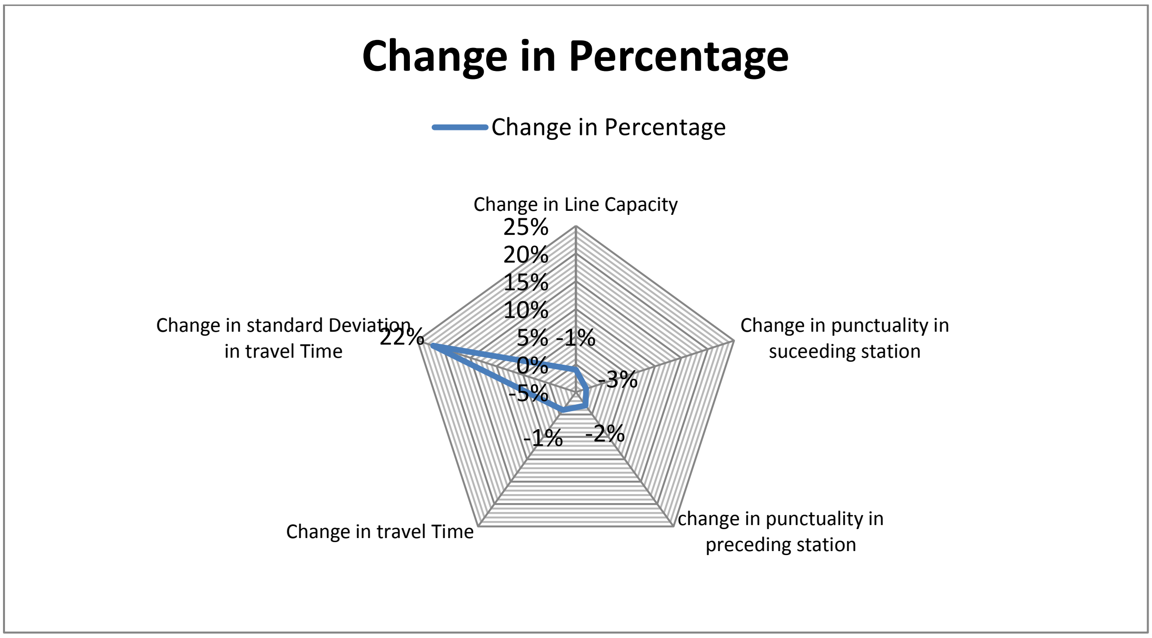


Figure 47: Radar Analysis of Changes due to new Jensrud Crossing between hakadal-Stryken

From the above Figure 47, it can be analysed that in the new Jensrud crossing between Hakadal and Stryken in Gjøvik Railway line, the indicators like the line capacity, the punctualities in the stations after the Jensrud crossing have been decreased than before the Jensrud crossing. This shows the negative attitude of the project toward these indicators. In addition, the travel time between the station have also been increased, that reflects the negative attitude of project, whereas the standard deviation in the travel time have been reduced that means the most of the trains travel in the marginal limit, so positive standard deviation reflect positive nature in the project.

4.4.3 Analysis of the results in new Vålåsjø Crossing:

The results obtained from the analysis of the evaluation criteria between Oppdal and Dombås station before one year and after one year of the execution of the new Vålåsjø Crossing (new crossing from June 2013) between those stations can be plotted in the radar diagram as:

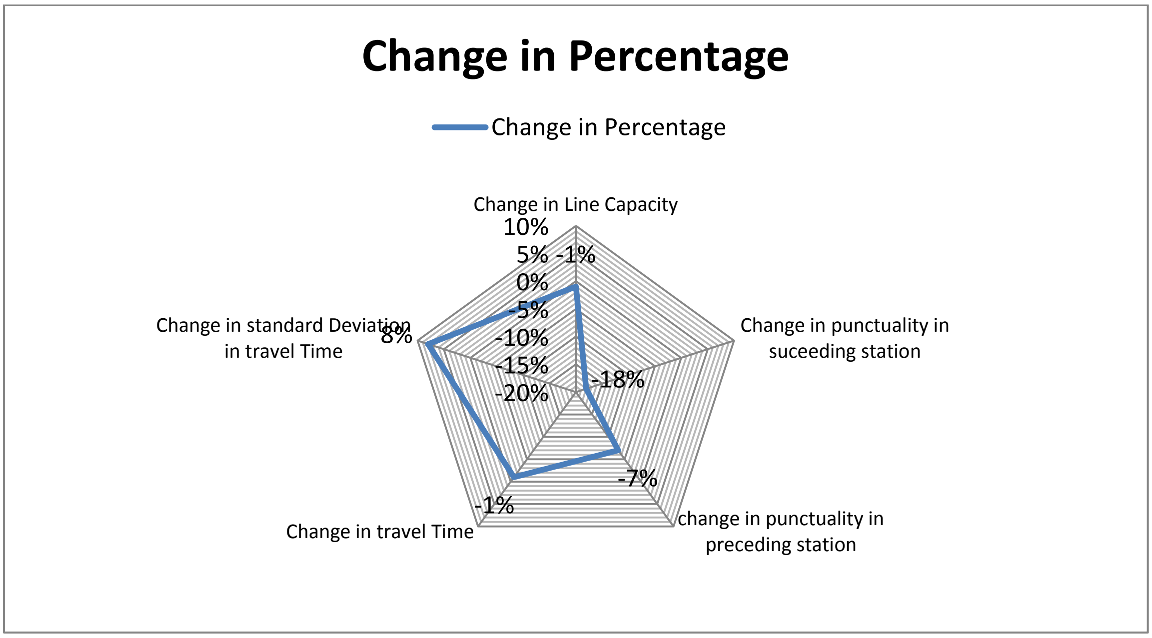


Figure 48: Radar Analysis of Changes due to new Vålåsjø Crossing between Oppdal and Dombås

It can be observed from the above Figure 48 that the line capacity, punctualities in the stations was decreased after the opening of Vålåsjø Crossing. This result shows that the attitude of the project toward those indicators were negative. In addition there is the increase in the travel time between the stations resulting the negative attitude towards the project from the perspective of that indicator. But the decrease in the standard deviation in the travel time had an positive impact of getting the most of the trains within the limits of travelling time.

4.4.4 Analysis of the results in Gevingåsen Tunnel:

From the results obtained from the quantitative analysis of the evaluation indicators such as the change in punctuality, the change in the line capacity, the change in the travel time and the change in the standard deviation between Hommelvik and Hell which includes Gevingåsen tunnel in between before one year and after one year of new tunnel opening (new tunnel from august 2011), the success of the project from the perspective of those indicators can be evaluated through the analysis of the following radar chart.

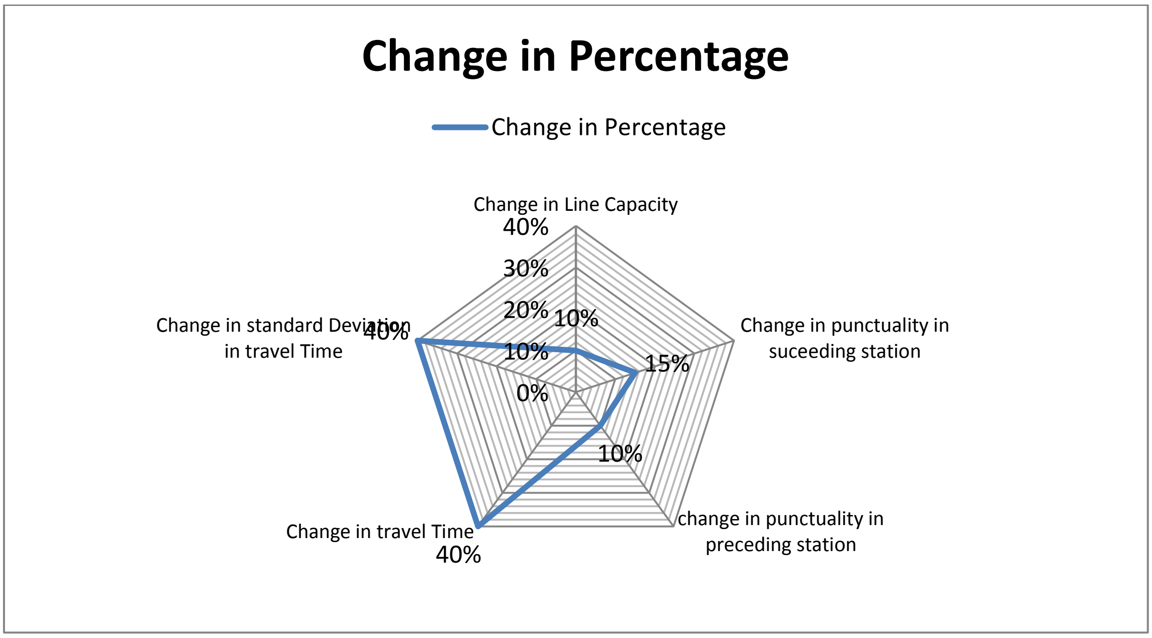


Figure 49: Radar Analysis of Changes due to new Gevingåsen tunnel between Hommelvik and Hell

It can be observed from the above Figure 49 that the values of the indicators like the line capacity, punctualities in the stations are increased after the opening of Gevingåsen tunnel. The increase in the values of that indicator indicates the positive attitude of the indicators towards the project. In the mean-time, it was observed that there are the significant decrease in the travel time and the standard deviation between the stations. This also expresses the positive attitude of those indicators in this project.

❖ SUMMARY OF CHAPTER FOUR

In chapter four, four different renewed railway projects are evaluated. The evaluation was based on the evaluation criteria that were set up in the literature review. The impacts on punctuality, line capacity, travel time and standard before and after the renewal were analyzed. The quantitative changes in the value of those evaluation criteria were further projected into the radar graph to understand the nature of change in the individual project. So, from this chapter by the use of the evaluation tool: *My train application* from *Jernbaneverket* and *Precision* tool from PRESIS project, it was able to quantify the changes in the evaluated criteria.

CHAPTER FIVE

5 DISCUSSION

5.1 Suitability of tools:

In this report there were basically the two tools used to evaluate the effect of the renewed railway project. The measurement and evaluation of the changing values of punctuality, the line capacity (volumes of trains), travel time and standard deviation were done through inputting the sets of data in those tools. The experiences, pros and cons of the tools during using can be discussed as:

5.1.1 My train tool from Jernbaneverket

This tool was used to measure the punctuality of the different stations in different time frame. The result was shown as in the form of percentages in the pie chart illustrating the punctuality in line, delays and cancellation of trains. This tool was found to be simple, user friendly and easier tool and can provide the general outlook of the nature of punctualities in the railway lines. The tool was sophisticated with the predefined sets of digitally stored data. So, this tool is more the result oriented. In addition, the positive side of the tool was the punctuality of the trains can be obtained in different time zones of the day too, can be useful to find out the punctuality in the busy hours and silent hours. In other hand the demerits of this tool was the tool could not hold all the railway stations in Norway, still some of the stations were missed and the tool could not detect those stations. This is not a real time system, but an opportunity to apply for punctuality back in time. Not all railway stations have automatic detection of punctuality data. This applies to stations and stops without technical installations that could detect trains passages. Because of its result oriented nature it cannot be expected to get the process and data used for the calculation from this tool, so it might be hard to identify the how and when the improvement and diminishment of the punctuality that limits the chances of further research from this tool. In addition, the tool can only be used to evaluate the punctuality and others parameters of effect evaluation of train cannot be assessed from this tool.

In conclusion, this tool can be used for a instance and is not suitable for long term evaluation or research on the measurement of punctuality in the railway lines.

5.1.2 Precision tool

This was the tool conceived and developed from the PRESIS project of SINTEF, NTNU. The major purpose of this tool was to measure the precision level in the Norwegian Railway system through the measurement and evaluation of the punctuality, line capacity and variation in driving time along with developing the relationships between these parameters. This tool also depends on the digitally recorded data from the train passages. In this thesis this tool was massively used to evaluate the effect parameters of evaluations like punctuality, line capacity. Travel time and standard deviations.

The experiences on using the Precision tool can be summarised as:

❖ **Better set of tool to evaluate the effect parameters:**

Precision tool is composed of multiple numbers of sub tools that aid on evaluating the different parameters relating to the railway line. This tool is capable to increase the predictability in the railway system. The different types of sub tools assist to identify the problems of delays, accidents and train cancellations. The tool is based on the data generated after the execution of railway project. So, for ex- post evaluation of projects the results generated from the tool can be used to measure the performance of new railway projects. Due to the many sets of evaluating tools, Precision tool as a whole is a complete set of tool to evaluate the evaluating parameters such as punctuality, line capacity, levels of crossings, travel time and their deviations and to develop the relationships between these parameters.

❖ **Difficulties in using and understanding the tool:**

This tool was a bit more complex to understand and use it in the evaluation processes. The prior knowledge to use this tool is important to understand the tool. It was experienced that the results however was based on the detailed process and graphs, changing scenario over time, plotted individual nature of each trains, but still the outcomes or results are displayed in the form of graphs that are difficult to extract the quantitative measures of the required values. The further analysis on the graph depends upon the expertise of user to estimate the average values from those graphs. In some extent this complexity on understanding the graphs can be reduced on evaluating the characteristics of few number of trains over short term of period but the evaluation process as stated in literatures is better for longer time frame and multiple number of trains that can aid to compare the results over the longer time to decide the further objectives from the stakeholders. In addition while plotting the multiple number of trains in same graph gives the result in the format of line that are joined, so the actual values is difficult to estimate.

- **Requires the testing and adjustment of Precision tool:**

The tool when it is about to come in the operations need to be tested and adjusted to evaluate the required measures, that can be done through the manual evaluation of small sets of data as the results obtained from the data can be compared with the results obtained from new set of tool to test and adjust the tool (Andersen and Fagerhaug 2002). So, in this thesis it was tried to compare the results of evaluation from the Precision tool with the results obtained from the manual calculation of the data that was available for Double track between Barkåker and Tønsberg. It was obtained near about the same results, but still the testing of the new tool need more comparisons with other sets of data to ensure the efficiency of the tool.

- **Utilities of the sub tools**

In this thesis, all the sub tools of Precision tool are not completely used. The most used sub tools were Precision meter, Heat map and Statistical Process Control. Those tools were used to measure the punctuality over stations, volume of the trains (line capacity) and travel time along with the standard deviations simultaneously, whereas the other tools like crossing plots, route finders were not used more. So, in this type of the evaluation of the project in these sets of evaluating parameters, it can be discussed as the tools like Precision meter, Heat Map and Statistical Process Control had higher usages than the rest two sub tools. It might be possible that Route Finder and Crossing Plot tool can be used for the evaluation of the nature of the trains in their crossings, the change in the crossing accuracies etc. This thesis had not dealt with the evaluations of those parameters, so had supposed the lower utility of those sub tools. However the utilities of those tools can be made by further evaluating those parameters.

It can be concluded that the Precision tool is an effective tool to evaluate the punctuality, line capacity (volume), travel time and standard deviation along the railway routes over the long or short period of time that can generate the output in the forms of graph which can be used to evaluate the nature of train but the need of required testing, need of prior knowledge limits the utilities of this tool. However this tool is new and gaining the maturities along with concise development, so it can be expected that those limits might be eliminated.

The characteristics of two different tools that were used to evaluate the projects can be compared as:

Tools	Advantages	Disadvantages
My train tool from Jernbaneverket	• Quantitative approach of evaluations, can figure out the exact figure of evaluation. • Ease in handling and understanding the tool. • Sophistically tested tool. • Results are not complex even the time of evaluation is longer.	• Specific tool: just used for evaluating punctuality, cannot be used for more aspects of evaluation. • The result cannot be forecasted for future. • Unable to recognize all the railway station in Norway. • Depends on the data digitally generated from stations based on passing of train.
Precision Tool	• Number of sub tools, more aspects of evaluation including punctuality. • Possibilities in forecasting the results that can be used for future researches. • Viable to most of the railway stations in Norway. • Manually and digitally registered data are used.	• Qualitative and quantitative approaches of tool, the results are mostly based on estimation. • Difficult to handle and to understand the tool. • New tool that requires more testing to validate. • The estimation of results are complex if the evaluation is done within longer time period.

Table 3: Comparisons of the suitability of evaluation tools for railway projects.

5.2 Results from Evaluation

5.2.1 Overall Results of the Evaluations in four different project

The summary of the results of changes in punctuality, line capacity, travel time and standard deviations by the use of evaluation tools: My train tool and Precision tool in four different railway renewal projects, the following radar chart can be obtained:

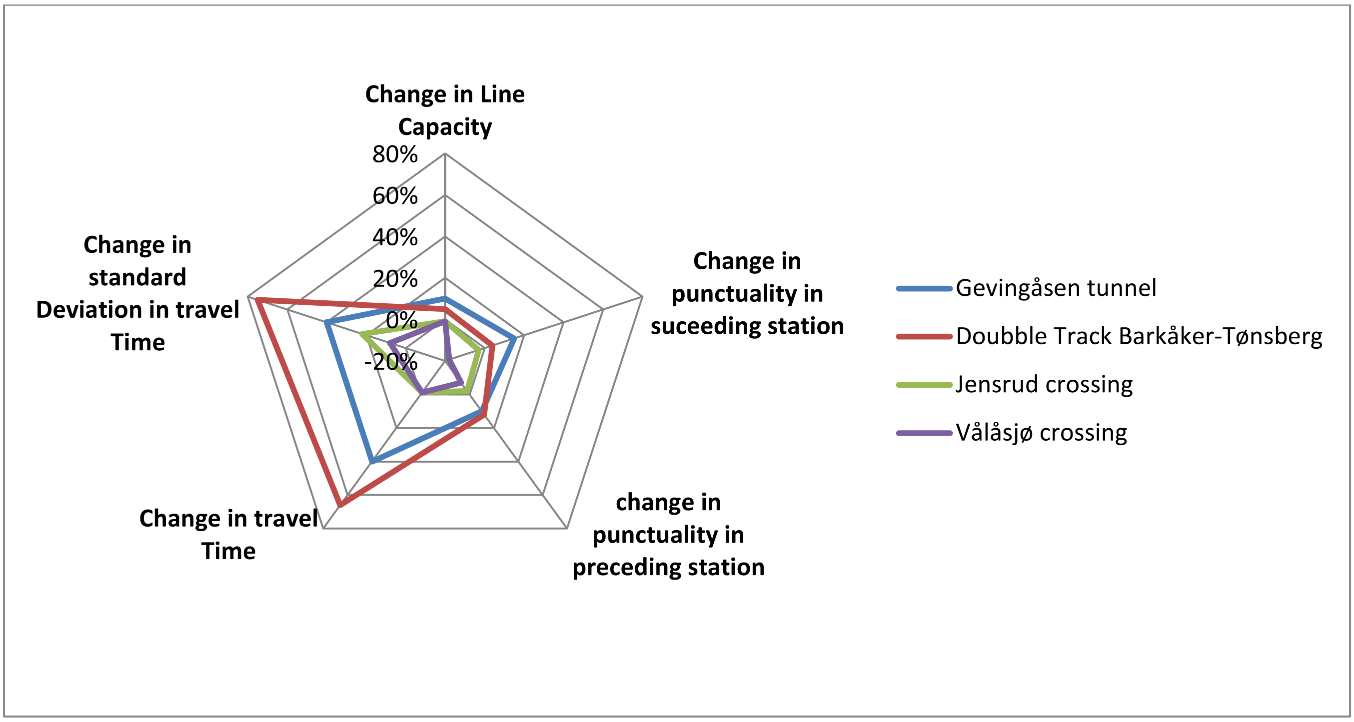


Figure 50: Radar chart: Summary of the results

Above Figure 50 shows the overall results from the evaluation. Different pattern of the lobes of the radar can be observed for the different projects. It can be discussed that the project covering the more area in the radar with longer lobes can be marked as the most successful project. According to the evaluation criteria set up in this thesis, the project having the most significant percentage of the positive changes is marked as the successful project. According to the above Figure 50 it was observed that the project the new double track between Barkåker and Tønsberg in Vestfold railway line was the most successful project among four projects which had the largest area of lobes in the positive changes followed by Gevingåsen

Tunnel between Hommelvik and Hell in Northern railway line, Jensrud Crossing between Hakadal and Stryken in Gjøvik railway line and Valåsjø crossing beterrn Oppdal and Dombås in Dovre railway line with least area of lobes in change in evaluation criteria.

The probable reasons behind the noticeable differences in the change percentage area of lobe in the above Figure 50 in different projects can be discussed as:

- **Big Projects Vs Small Projects**

The project of new double track between Barkåker and Tønsberg had an investment of 1480 MNOKs with the total construction period of 4 years (2009-2013) had more positive drastical changes in evaluated criteria (line capacity, punctuality, travel time and standard deviations). Secondly another big project Gevingåsen tunnel which had investment of 677 MNOKs with construction periods of 2 years (2009-2011) showed the significant positive changes in the evaluated criteria whereas the small project Jensrud crossing with construction year 4 years (2009-2013) and Vålåsjå Crossing constructed within 3 years (2010-2013) having both the investment of 116 MNOKs showed the relatively lower changes in the evaluated criteria, even the effect getting negative in some criteria. In general, it can be concluded that the big projects had more dominant changes rather than the small projects. It can be due to the objective set up in the big projects to improve punctuality, travel time , line capacity of passenger and freight trains and changes in the railway schedule after construction that showed more changes rather than the small project that have the minimum objective of just facilitation for the railway transport without changing in the railway traffic schedule. The expectation of those small projects might not were to increase the changes in our evaluated criteria. From broader analysis, it was obtained that the smaller project like Jensrud crossing and Vålåsjø crossing were meant for easing the transportation of freight trains rather than passenger trains.[v] As this thesis is limited in the evaluation of passenger trains, so the relative impact of changes in passenger trains were not observed in those small projects.

- **Time of reference in the evaluating the projects:**

The time of reference taken for the evaluation of those projects was one year before and one year after the project. The differences in the changes in projects can be due to the time reference. The big projects like Double track and tunnel: after completion shows more impact in the change in evaluated criteria due to relative change in the railway schedule, whereas the smaller projects of crossings did not change the schedule of train. In other hand the smaller projects had the equivalently the same construction period of big project that influenced on showing the more effects. It can be discussed as the effects are not more likely to be more during the construction period and after just sometime of completion of project. The effects of transport infrastructure projects will often not be achieved until a critical mass of projects have been completed (Olsson and Bull-Berg 2015). So, more time of reference for evaluation is required to evaluate the projects completely.

5.2.2 Nature of effects of individually evaluated parameters

The effects that are evaluated in the different projects can be further studied by fragmenting into the single effect parameter. The results of the evaluation when compared against individual parameters: punctuality, line capacity, travel time and standard deviation the following nature of variations can be observed.

- **Nature of punctuality changes:**

The change in the punctuality has a direct relationship with the change in the schedule of train passing through the routes. Most of the railway projects after completion bring the change in the train schedule. This evaluation as being based on before and after effects of railway renewal, the significant changes in the punctuality was noted in four projects. The comparisions of the changes in the punctuality is shown in the following diagram.

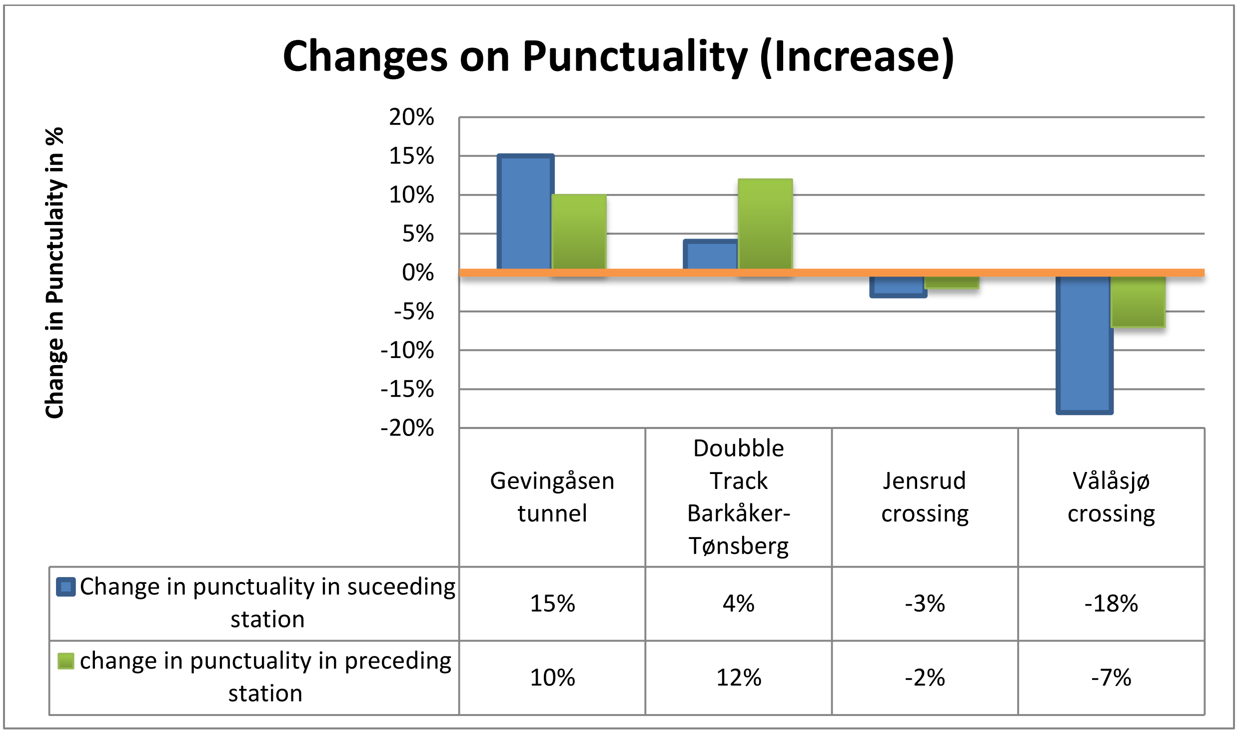


Figure 51: Changes on Punctuality in four different projects

In the Figure 51 the different results of the change in percentage in different project is shown. The different values of punctuality in two stations that includes the renewed project in between can be observed. After Gevingåsen tunnel the punctuality in Hell was increased by 15% and the punctuality at Hommelvik was increased by 10% in Northern railway line. After Double Track Barkåker- Tønsberg in Vestfold railway line the punctuality of the trains reaching to Drammen from Skien was increased by 4% and the punctuality of the trains reaching to Eidanger after the new double track was increased by 12%. In the case of small projects, the punctuality at Stryken was reduced by 3% and the punctuality was also reduced to the Hakadal station by 2% after new Jensrud crossing in Gjøvik railway line. Similarly, the punctuality in Oppdal was decreased by 18% and the punctuality in Dombåas was also decreased by 7% after the new Vålåsjø crossings in Dovre railway line. In the above analysis, it can be observed that the big projects Double track and tunnel projects have more significant changes in the punctuality rather than the small projects of crossings. Even the punctuality was decreased in the small projects.

➢ **Nature of line capacity: volume of trains**

The changes in the line capacity; volume of the trains in the railway networks before and after the new renewed project were evaluated, it was observed the relative change in the volume of the trains in the railway line in four different projects. The changes in terms of percentage in four railway project can be illustrated in diagram as:

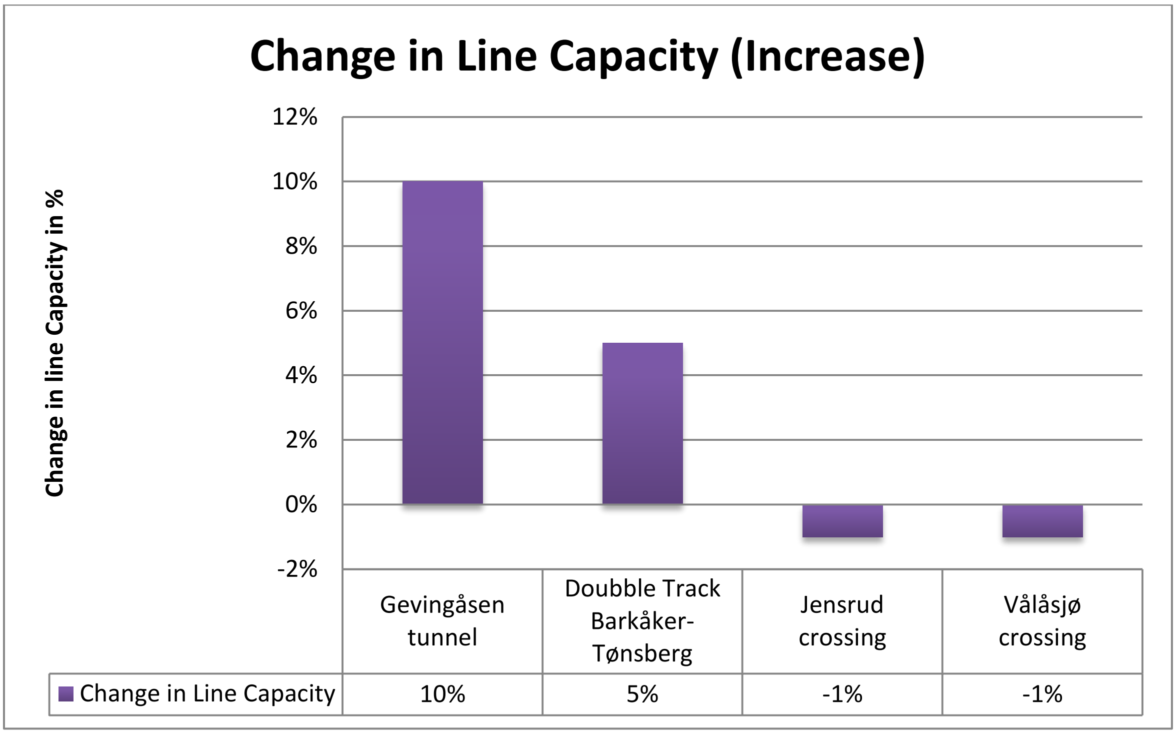


Figure 52: Changes on line capacity in four different projects

In the Figure 52, it can be observed that the line capacity in the Northern railway line after the Gevingåsen tunnel was increased by 10%. The change in the line capacity after the Double track between Barkåker and Tønsberg was increased by 5% in Vestfold railway line. Similarly, the line capacity in both of the small projects after Jensrud crossing and Vålåsjø crossing were decreased by 1%. In this case also the changes in line capacity in the big projects are more than the small projects. It can be concluded that the change in the line capacity in the big projects were not as targeted, as both the projects were expected to increase the line capacity by 30%[vi].

- **Nature of Change in Travel Time**

The changes in the travel time in the four different railway projects were evaluated. It had been observed the significant changes in the travel time between the stations that included the renewed projects in between. The changes in the travel time as represented graphically can be compared as:

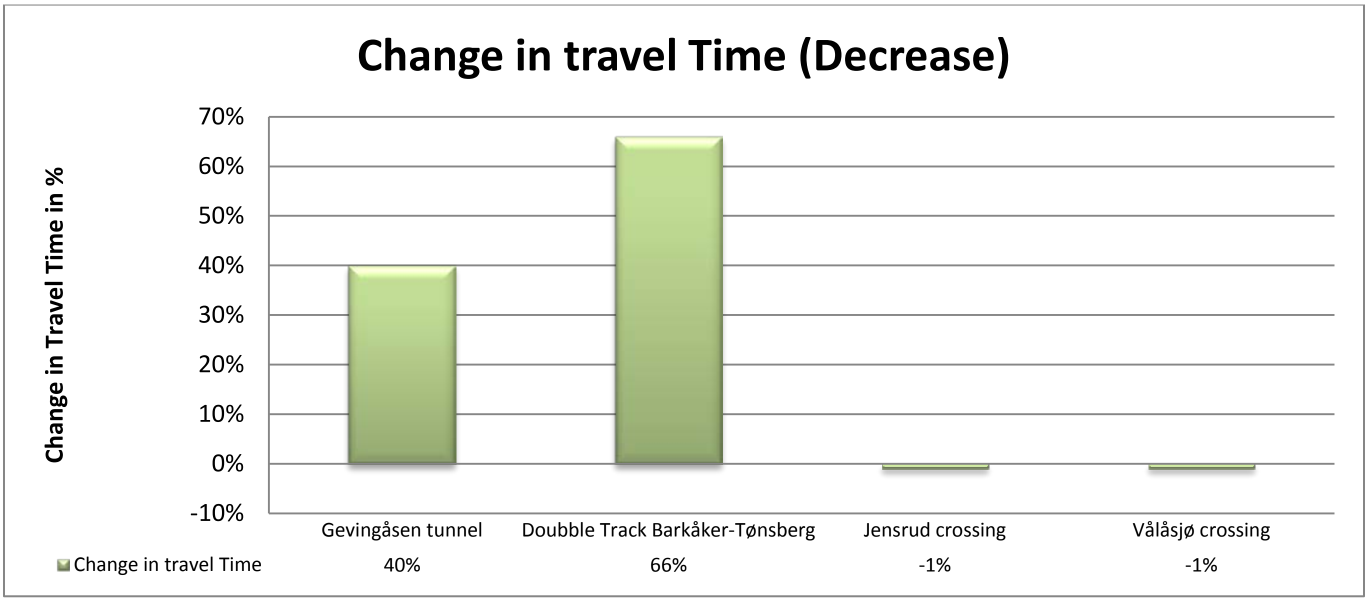


Figure 53: Changes on Travel Time in four different projects

In the Figure 53, it can be observed that the change in the travel time between Hommelvik and Hell stations in Norther railway line after Gevingåsen tunnel was decreased by 40%. Likewise the travel time between barkåker and Tønsberg in Vestfold railway line was decreased by 66% after the new double track. In the smaller projects the travel time was increased by 1% between Stryken and Hakadal in Gjøvik railway line and in Dovre railway line the travel time between Oppdal and Dombås was increased by 1%. It can be noted that there was huge improvement in the travel time in the big projects whereas the smaller project did not show any relative changes in travel time.

- **Nature of Change in Standard Deviation**

The standard deviations calculated was based upon the mean travel time, standard deviation measures the randomness of data being deviated from the mean value. The decrease in the standard deviation favors more number of trains travelling around the mean average travel time. The different natures of the standard deviations in the travel time between the stations in four different projects are compared as:

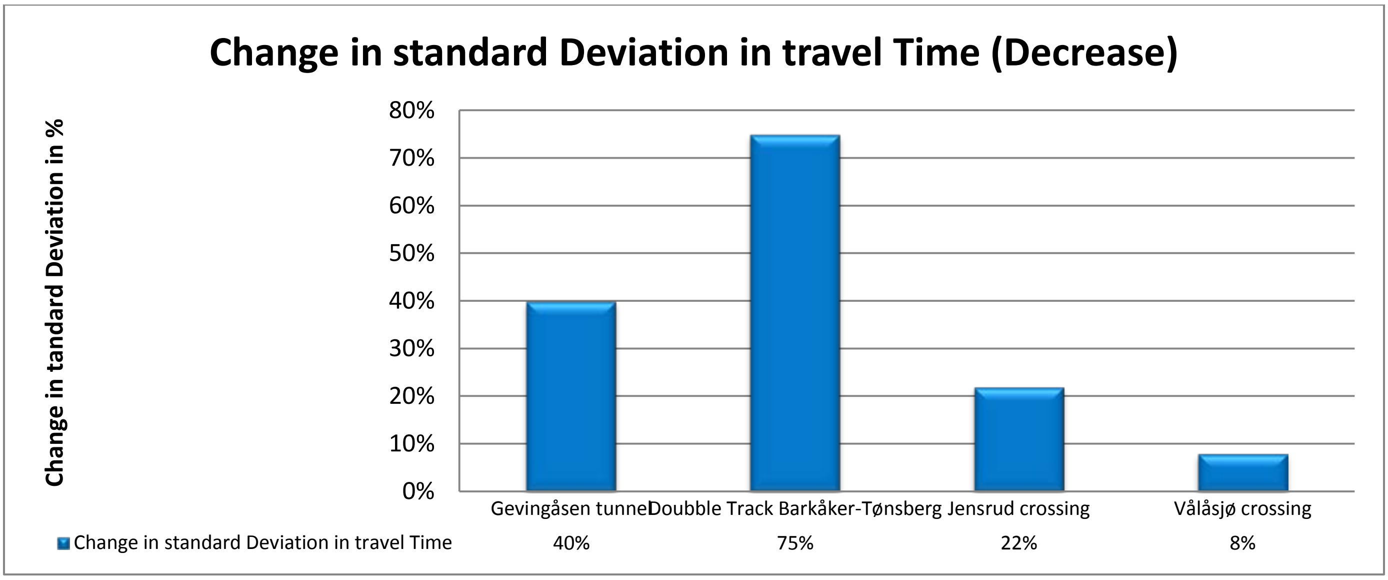


Figure 54: Changes in Standard Deviations in four different projects

In the Figure 54, the different percentages of the change in the standard deviation in four projects can be observed. All the values being positive means there were decrease in the standard deviation in all the four projects. The standard deviation in the travel time between Hommelvik and Hell was decreased by 40% after completion of Gevingåsen tunnel. Similarly, there was 75% decrease in the standard deviation in the travel time between Barkåker and Tønsberg after the completion of Double track. The decrease in standard deviation by 22% after jensrud tunnel in the travel time between Hakadal and Stryken was observed. The standard deviation in travel time between Oppdal and Dombås due to Vålåsjø crossing was reduced by 8%. The big projects showed the remarkable deduction in the standard deviation, whereas, the smaller project also showed the comparative deduction in the standard deviation. The nature of the result obtained from the positive change in standard deviation leads to the following discussions:

Due to the positive results in the standard deviations in the entire four railway project, it can be discussed that the projects might show more positive results in the punctuality afterward, as this evaluation was based on one year and one year before the operation of new renewed projects. So, the relative impacts were not noticed after one year, but still the deduction in the standard deviations if continued in future too, it will be able to bring travel time of all the trains into the average travel time reducing deviations that eventually will improve the punctuality of trains.

❖ SUMMARY OF CHAPTER FIVE

In chapter five the results from the data were discussed. The discussion was made from the two perspectives of evaluation. In first case, the suitability of the tool used on the evaluations of the project was discussed. The through positive and negative aspects of the used tool generalized the idea of better tool to use in the process of evaluation in the ex-post railway projects. Similarly, the results of the individual evaluation criteria for the different projects were plotted, so the discussion made was on the success of the each project. From this discussion, a conclusion on the goal fulfillment of each project can be observed. In addition the change in the value of individual evaluated criteria: line capacity, punctuality, travel time and standard deviation over four different projects were discussed.

CHAPTER SIX

6 CONCLUSION

This thesis was based on the evaluation of the four different railway projects through the measurement of the changes in the evaluated parameters by the use of the different tools for evaluation. The results of the changes obtained from the calculations from the evaluation tools like *My train tool from Jernbaneverket and Precision tool from SINTEF* was obtained. In addition the utility of the evaluation tool in relation to their precise measurement was identified.

In the conclusion, it was experienced that there were some changes in the values of the parameters before and after the execution of the renewed railway projects in respect to the results obtained from the tools used. However, for better reflections of the changes, it requires more sets of evaluation parameters apart from the line capacity, punctuality, travel time and standard deviation to evaluate the effect results in depth and precise. In the concern of the suitability of the tool, it has been observed that the available tools were able to generate some results in the changes. However for the better and precise result the need of timely updated database and need of more improvement in the existed tool are experienced.

Furthermore, the conclusion is structured in such a way that it presents more conclusions made on the course of addressing the answer of the research questions and linked with the areas of further researches.

6.1 Answer to research question 1

- ❖ Research Question 1: What is the change of punctuality, railway line capacity, crossing points, travel time and their standard deviations in travel time in the different projects?

Answer: The four renewed railway projects were evaluated using the evaluation tool: My train tool from Jernbeneverket and Precision tool from SINTEF, NTNU within one year before and one year after the execution of renewed projects. The significant changes were observed in punctuality, railway line capacity, travel time and standard deviations in the bigger projects like Double track Barkåker- Tønsberg and Gevingåsen Tunnel. In other hand, in the case of the smaller projects of Jensrud and Vålåsjø Crossings, it was observed relatively lower values of changes over evaluated criteria.

- In Double Track Barkåker-Tønsberg (Vestfold Railway Line): The change of punctuality in Drammen for the trains passing from Tønsberg was increased by 4% and the punctuality at Eidanger passing from Barkåker to Skien was increased by 12% after the execution of new project. Similarlt, the line capacity was increased in Vestføld railway line by 5%. The travel time between Barkåker and Tønsberg was decreased by 66% and the standard deviation in travel time was decreased by 77%.

- In Gevingåsen Tunnel between Hell and Hommelvik (Northern Railway Line): After the execution of Gevingåsen tunnel, the punctuality in the Hell station for the trains passing from Trondheim to Fauske (Bødo) was increased by 15% and the punctuality for the trains from Fauske to Tronsdheim in Hommelvik station was increased by 10%. Similarly, the railway line capacity in the northern railway line was increased by 10%, the travel time between Hommelvik and Hell stations was reduced by 40% and the standard deviation in the travel time was reduced by 40% as well.

- In Jensrud crossing between Hakadal and Stryken (Gjøvik Railway Line): After the execution of the Jensrud Crossing, the punctuality at Stryken Station for the train travelling from Oslo to Gjøvik was decreased by 3% and punctuality at Hakadal station for the train travelling from Gjøvik to Oslo was reduced by 2%. Similarly, the line capacity in Gjøvik line was reduced by 1% with the increment of travel time between Hakadal and Stryken by 1%. The standard deviation for the trains travelling between those two stations was decreased by 22%.

- In Vålåsjø crossing between Oppdal and Dombås (Dovre Railway Line): The punctuality of the trains at Oppdal station passing from Dombås to Trondheim was decreased by 18% and the punctuality of the trains at Domås for the trains passing from Trondheim to Dombås was decreased by 7% after the execution of the Vålåsjø crossing. Similarly, the line capacity of the Dovre Railway Line was reduced by 1% along with the increment of the travel time between Oppdal and Dombåas by 1%. The standard deviation of travel time between those stations was reduced by 8%.

6.2 Answer to research question 2

- Research Question 2: On what level the evaluation the projects from the perspective of the evaluation tools can be done? Which one is the most suitable tool out of number of tools that can be used to evaluate the effects of renewed railway project?

Answer: There were different criteria of evaluation of the railway projects which mostly depends on the basis of evaluation. The projects can be evaluated from economic, social, environmental, cultural and other perspectives. The evaluation process here done was ex-post evaluation to understand and analyse the changes brought about from the modifications of new projects. This thesis was based on mostly the social aspect of evaluation that includes punctuality, line capacity, travel time and standard deviation of travel time as the criteria for evaluation. The tools that were used in the evaluation of those criteria were the *My train tool* from Jernbaneverket and *Precision tool from SINTEF, NTNU*. Both of the tools were based on the digital database stored by Jernbaneverket that included the characteristics of the trains in the railway passages. The tools used in this thesis were able to evaluate those parameters, so the evaluations of those criteria can be done in other different railway project using these tools further; at least the tools were able to generate the quantitative results of the changes. Thus, the results were able to be used to analyse the various nature of the graphs that can be further used to determine the success of the railway projects. So, the tools are efficient to evaluate the social benefit and perspective of the projects quantitatively and qualitatively.

On the basis of the two tools used to evaluate the railway projects, My train tool from Jernbaneverket was sophisticated tool and was just capable to quantify the punctuality between the stations, along with deficiencies to recognize some train stations too. In response, Precision tool from SINTF, NTNU was able to quantify the results of punctuality, travel time, line capacity in addition, but the results from this tool was expressed in the form of graphs, so the use of knowledge of assumption for exact values from the graph might limits the effectiveness of the tool. To determine the suitable tool out of these tool, it can be suggested that for the instance to get the values of punctuality within short time My tool application from Jernbaneverket can be used until the tool recognize the railway stations, whereas, for the evaluation of the project further, to develop more natures and forecasts of trains in different railway networks Precision tool can be used. In addition a larger flexibility in the modification of the Precision tool can break through the chances of further researches. So, it can be concluded that Precision tool will be most suitable tool to evaluate the railway projects but the tool requires more development and testing.

6.3 Areas of Future research

From the analysis of the four railway renewal projects, we can observe the relative improvement in the values of the indicators for the more costly projects than the less invested projects. However, we can see the change in the values of punctuality, line capacity and travel time depends on the train scheduling from railway authority, apart this the evaluation indicators might have been less for the overall conclusion and feedback for the nature of renewed railway projects.

Following are the areas of the further research that can be done to optimize and evaluate the effects due to renewed projects.

- ❖ Evaluations using more evaluation criteria

The evaluation result of those four projects can be made more reliable using more evaluation criteria like measuring the crossing accuracy between the trains in the railway line and measuring the nature of the correlation between the variable such as punctuality vs train stations, relation between delay and stations, nature of trains reaching the succeeding stations etc. In this thesis, from the evaluation of the four railway renewed projects, it was interesting to find the improvement in the standard deviation of the travel time. In all the four projects there were reductions in the standard deviations in the travel time between the routes. So, the future research can be made on evaluating the correlation nature of the train punctuality with the stations. The values obtained from the correlation helps to find the exact station from where the train suffer delays that affects the punctuality in long run.

- ➢ Correlation between the punctuality and train stations:

The further research can be to quantify the correlation coefficient values in the stations relative to punctuality and setting the methodology to develop the threshold values in relation that can make the change in the proportion of delays of train between the stations. (Olsson and Haugland 2004) had tried to correlate the factors affecting punctuality with the stations, even it was critical to quantify the threshold values for those correlations. Precisions tool as developed by SINTEF, NTNU that was used for the evaluation of the projects in this thesis can further be used to measure the correlation between the punctuality and train stations.

For instance, it was tried to see the nature of the correlation with punctuality in the train passing from Oslo to Skien including the new double track between Barkåker and Tønsberg.

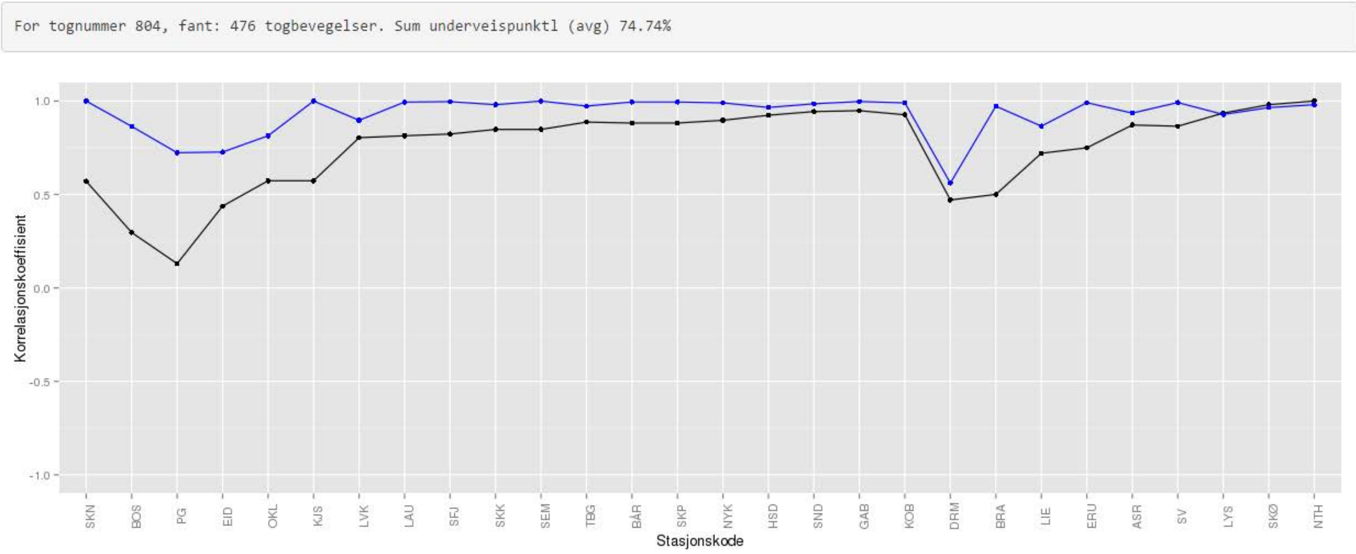


Figure 55: Correlation between punctuality and train stations in train number 804 between Skien to Oslo

In the Figure 55, the train number 804 passing from Skien to Oslo shows the different values of correlation coefficient in comparison with the station and punctuality. The positive correlation values means either increase or decrease in the values between the variables parallel whereas the negative values means the increase in one value results in decrease on the other value. In respond the correlation exist the relation between delays and the stations. In comparison with the change in the standard deviation the reduction in the delays can be counter argument by the evaluation of those correlation graphs.

However, as mentioned before the quantification of the threshold values of correlation subjecting the punctuality and station as the variable, it might be the areas of the further evaluation to measure the effect of new projects.

❖ Flexibility in time tabling to improve the values of evaluated criteria

It has been observed that the values of the punctuality, travel time and line capacity is mostly dependent on the scheduled time of the railways between the routes. Adriano in (D'Ariano, Pacciarelli et al. 2008) purposes that a standard practice to improve punctuality of railway services is the addition of time reserves in the timetable to recover perturbations occurring in operations. However, time reserves reduce line capacity, and the amount of time reserves that can be inserted railways area. The solution can be use of flexible timetable that can be an effective policy to improve punctuality without decreasing the capacity usage of the lines. The principle of a flexible timetable is to plan less in the timetable and to solve more inter-train conflicts during operations. In his research in Dutch Railway line, he came up with the idea of extensive computational algorithm for generating the real time scheduling that shows the improvement in punctuality. This timetable was practiced in the congested railway areas but he argued in the possibility of using this approach for the normal railway lines. But the need of advanced system for timetabling and real time criticality might sophisticate this process. So the further research can be on developing the effective time planning of railway in the Norway and evaluate the changes in those criteria used in this thesis.

In another way, punctuality can be more flexible by accounting the slacks and precision strategies in the travel run. (Forsgren, Aronsson et al. 2013) defines slack as the extra time given to a train relative the minimum time it needs including any planned stops, to cover the distance of the whole trip. Olsson in (Olsson and Haugland 2004) argues that slack might be due to the increased station time, reserve on board personnel and rolling stock reserves in the case of primary delays whereas few trains in comparison to rolling stock, low utilization of infrastructure, lack of rules and communication between the trains may give rise on slack in the case of secondary delays.

To avoid the slack, slack strategy is to be developed, for instance the reduction in the delays when the train gets closer to the final destination, increase in the scheduled time in the timetable can reduce the delay. But the challenges can be on positioning the slack in terms of localizing personnel and rolling stock, infrastructure and distribution of slack in the timetabling, expensive in operation, whereas the simple execution and relative impact on short duration are its counter challenge features.

Precision strategy is the enablers for the railway components. The railway components include infrastructure, train operation, rolling stock maintenance and other auxiliary components that are needed for the operation of the train. This strategy can be maintenance of infrastructure & rolling stock, calibrated timetable, management in passengers boarding, prioritization of the trains etc. for the purpose of avoiding primary delays. In other hands, atomization of trains, reduction in speed delays, monitoring the causes and type of trains causing frequent delays can be the ways of reducing secondary delays. This technique is based on the Just in time technique (JiT) which purposes on minimizing the waiting time and other types of delays. *JiT in industrialization means to avoid the overstocking of raw materials and products*, which means to reduce buffer time and dwell time in railways. This is more focused on developing the punctuality culture among the network so has low operational and delay cost. But the wide commitment from the each stakeholder to generate organizational behavior results this process to be more time consuming. In this strategy the flexibility can be practiced in execution phase too as it has large degree of freedom due to enough time whereas flexibility might not be accounted much in planning phase due to longer execution and operation phase.

So, the further research can be done in developing the new strategy for the enabling the precision strategy to cope with the changes in the railway components by the reductions in the primary and secondary delays and to evaluate the changed values after the renewed railway projects.

- **SUMMARY OF CHAPTER SIX**

In chapter six, the research questions of this thesis based on the evaluation of the effects in the four different railway projects were answered through the conclusion in the quantitative changes in the evaluated criteria and extent of expertise of tools that can be used to evaluate the railway projects. Furthermore, in this chapter, results from the discussion addressed the possibilities of further researches that can be done to obtain more precise results on evaluation and coined the areas of improvement for better output from such renewed railway projects.

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