From Manual to Robotic

- Assessing the Potential Benefits of Automation in Railway Inspections and Maintenance

LUNDS UNIVERSITET
Lunds Tekniska Högskola

LTH School of Engineering at Campus Helsingborg
Railway Engineering

Bachelor thesis:
Benjamin Furberg

LTH School of Engineering
Lund University
Box 882
SE-251 08 Helsingborg
Sweden

LTH Ingenjörshögskolan vid Campus Helsingborg
Lunds universitet
Box 882
251 08 Helsingborg

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Abstract

The railway industry plays a crucial role in the global freight transport and passenger mobility market, providing an efficient and low-emitting mode of transportation. However, to compete with other modes of transportation, the railway must improve its reliability. Frequent inspection and maintenance work are essential for ensuring the reliability, safety, and efficiency of railway operations. This thesis especially focuses on the atomization of railway inspections to improve the efficiency on inspections and lighter maintenance activities, giving more time for the maintenance personnel to do the heavier maintenance tasks. The approach used were interviews, field studies and database analysis. The interviews and field study were held in Norway with Norwegian track technicians, while the database analysis was done with Swedish data. This because I was not able to receive the Norwegian data and had to resort to the Swedish. Results of the conducted data collection methods were that there are a lot of potential cost and efficiency benefits by robotizing and automating certain tasks and processes, as well as the safety and health of the technicians. Another important aspect was the perceived positivity from the track technicians regarding an implementation.

The thesis examines the current maintenance market Norway and discusses the challenges and opportunities for improvement. Further delimitations in the thesis are a greater focus on maintenance and inspection tasks in proximity to railway turnouts. By analyzing studies, industry data and interviews with maintenance personnel this thesis will set out to identify how robotization and automation could optimize railway inspections and lighter maintenance work to ensure a more reliable and sustainable system.

Keywords: Railway, Inspections, Maintenance, Robotics, Automation, Turnouts,

Sammanfattning

Järnvägsindustrin spelar en avgörande roll på den globala marknaden för godstransporter och passagerarmobilitet, och ger ett effektivt och lågemitterande transportmedel. För att konkurrera med andra transportmedel måste järnvägen dock förbättra sin tillförlitlighet. Frekventa inspektions- och underhållsarbeten är avgörande för att säkerställa säkerheten och effektiviteten i järnvägsverksamheten. Denna avhandling fokuserar särskilt på automatiseringen av järnvägsinspektioner för att förbättra effektiviteten på inspektioner och lättare underhållsaktiviteter. Detta ger i sin tur mer tid för underhållspersonal att utföra tyngre underhållsuppgifter vilket skall leda till ett mer pålitligt järnvägssystem på lång sikt. Avhandlingen undersöker den nuvarande underhållsmarknaden i Norge och diskuterar utmaningar och möjligheter till förbättring. Vidare avgränsningar i avhandlingen är en större fokus på underhålls- och inspektionsuppgifter i och i närheten av järnvägskorsningar. Genom att analysera studier, branschdata och intervjuer med underhållspersonal kommer denna avhandling att söka identifiera hur robotisering och automation kan optimera järnvägsinspektioner och lättare underhållsarbete för att säkerställa ett mer pålitligt och hållbart system.

Nyckelord: Järnväg, besiktning, underhåll, robotisering, automation, växlar

Foreword

Railway transportation has been a vital mode of transportation for over two centuries, providing an efficient and cost-effective means of moving people and goods across long distances. With the increasing demand for reliable and safe transportation, railway inspections and maintenance have become an essential aspect of railway engineering.

This bachelor's thesis focuses on the critical importance of railway inspections and maintenance. The goal of this research is to analyze the current practices in railway inspections and maintenance and evaluate their effectiveness. The research aims to identify the significant issues and challenges that railway maintenance personnel face in their day-to-day operations and provide recommendations to improve the efficiency and effectiveness of railway inspections and maintenance.

The research presented in this thesis has been conducted with a systematic approach, utilizing data analysis from available databases, and qualitative research methodologies. The study's findings will be valuable for railway maintenance professionals, policymakers, and stakeholders who are interested in improving the safety and reliability of railway transportation systems.

I hope that this thesis will serve as a valuable resource for those interested in the field of railway inspections and maintenance. I would like to express my gratitude to my advisors and colleagues who have supported and encouraged me throughout this research project.

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1 Introduction

1.1 Background and motivation for the research topic

The demand for maintenance work in the railway industry is growing in pace with the increase of traffic and thus wear on the infrastructure and rolling stock (IEA, 2019); (Papaelias, et al., 2016). At present, inspections on the railway infrastructure are done by measurement trains or track technicians who walk long distances along the track and ocularly look for irregularities and defects. The inspections are done periodically in predefined intervals for the different types of components and facilities (Trafikveket, 2019). Interviewee, Heine Abrahamsen, stated that the result is heavily dependent on the subjective opinion of the inspector, relying on the inspector’s aptitude for simultaneous focus on multiple tasks, experience, and knowledge (Interview found in Appendix A). Other factors that will decide how well the work will be put out is the tools and methods used and how familiar the inspector is with the regulations. These jobs are also highly repetitive, requires workers to travel long distances and is often carried out in dirty environments. The activities also require the technicians to enter hazardous areas with the risk for serious injury and even death while working in the proximity to high voltage facilities and possibly adjacent tracks with traffic.

Other industries have been working to cut down on these challenges by root cause analysis and condition-based maintenance made possible by robot inspections, for a long time, implying there is no lack of knowledge at the field. Examples of this is maintenance and inspections on nuclear power plants as well as structure monitoring by robot inspections on road bridges (Liu, 2006); (Lim, 2011).

However, there are certain tasks carried out by robots and autonomous systems (RAS) in the railway industry. In a study on the implementation of RAS it is stated that out of 65 authentic studies done on development of RAS in railway maintenance the distribution is mainly toward the rolling stock (56%) and rail track maintenance (28%), the rest of the research are evenly distributed between bridges, tunnels, power transmission making out the remaining 16% (Vithanage, 2019). A specific example of this is RAS used for cleaning the rolling stock on the East Japanese railway company (Yaguchi, 1995)

1.2 Aim of study

As the researcher conducting this study, it is important to highlight that a neutral and unbiased position was maintained in relation to the manufacturers of robotics and automation technologies. The aim was to approach the topic with objectivity and independence, focusing on gathering and analyzing relevant data and information from various sources. No affiliations or conflicts of interest with any specific manufacturers were present during the research process, ensuring the impartiality of the findings and conclusions. The intention was to provide an objective assessment of the potential benefits, challenges, and implications of implementing robotics and automation in railway maintenance, considering the broader industry context and the interests of all stakeholders involved.

Problem statement:
The current method for inspecting and maintaining railway turnouts is a labor-intensive, repetitive, and potentially hazardous task that requires skilled personnel to walk long distances along the track and look for irregularities and defects. The need for automation or robotization arises from the high cost, time, and safety risks associated with manual inspections and maintenance. Therefore, there is a need to investigate the feasibility of automating or robotizing turnout inspections and maintenance.

The findings of this research will hopefully provide valuable insights into the potential benefits and limitations of robotizing railway inspections and maintenance. This information will be useful for railway companies and policymakers who seek to improve the efficiency and safety of railway maintenance operations.

The purpose of this thesis is to investigate the effects of introducing robots to perform railway inspections and lighter maintenance activities in railway turnouts. This research attempts to achieve these by answering the following research questions:

1. What are the current processes for inspecting and maintaining railway turnouts, and what are the associated safety risks?

2. What are the technical challenges and opportunities for automation or robotization of turnout inspections and maintenance?

3. What is the potential cost and time benefits of automation or robotization of turnout inspections and maintenance, and how can these be quantified?

The concept of the "robot" discussed in this study should be understood as a hypothetical entity rather than an existing technological artifact. It is important to note that the robot described herein is considered a realistic possibility based on current advancements in robotics and automation. While the robot in question has not been developed or implemented at the time of this research, its feasibility and potential benefits are supported by existing studies and the expertise of robot manufacturers. The purpose of considering this hypothetical robot is to explore the potential advantages and implications of integrating robotics and automation into railway maintenance processes.

1.3 Scope of study

The inspections consist of geometrical measurements and general inspections of the turnout and its surroundings. Specifically, I examine the potential benefits of this technology regarding cost, efficiency, and safety for maintenance personnel.

To achieve these goals, I analyze relevant literature and gather information through database analysis, interviews with railway professionals and experts, and a field study.

It is important to note that the field studies and interviews conducted for this thesis were carried out in Norway, reflecting the local context and experiences of railway personnel in this region. However, the database analysis utilized data from Trafikverket in Sweden. The choice of using Swedish data was primarily driven by its accessibility and the similarity of the railway networks between Norway and Sweden. Despite the geographical difference, the insights gained from the database analysis are still relevant and applicable to the Norwegian railway context. It is worth acknowledging that further research and data collection specific to Norway would provide additional insights and a more comprehensive understanding of the topic.

2 Literature review

The following chapter will present the main findings from relevant literature reviewing the research questions.

2.1 Current maintenance practices

Maintenance in the railway industry is traditionally separated between the preventive and corrective maintenance activities. The preventive maintenance on railways can further be subdivided into smaller routine works and projects which consists of inspections and smaller repairs and lubrication. These works are smaller and are not as time consuming as the corrective maintenance tasks (Budai, 2004). Corrective maintenance tasks, however, involve identifying, isolating, and resolving faults to replace or restore a failed piece of equipment to an operational condition within the established tolerances or limits for in-service operations. This approach does not involve any actions aimed at preventing faults, as the only way to detect them is by waiting for the equipment to fail (railwaysignalling, 2017).

The railway industry encompasses diverse fields of expertise, encompassing the superstructure (comprising track, ballast, and fastenings), power supply, signaling system, telecommunications, and substructure (comprising groundwork, drainage, and under ballast). Maintenance personnel and specialists with specialized knowledge in their respective fields are responsible for maintaining and inspecting the specific components and facilities associated with each field (TRVINFRA-00271). For example, rail and geometry inspections are performed by two maintenance workers who are specialized in superstructure. The railway is divided into hundreds of segments to make these inspections easier to schedule. According to Peng, who studied periodic rail inspection tours, these segments should be inspected periodically at a certain frequency (which often varies between once a month and once a year) to ensure operational safety (Peng, 2011).

As stated by Lidén, (Lidén, 2015) the railway industry in Europe has undergone progressive deregulation since the 1980s, which has led to the emergence of commercial competition between maintenance contractors. This shift has heightened concerns related to contractual forms, public procurement, and planning. Given the increased volume of traffic and the interdependency between maintenance and traffic, efficient planning has become critical, prompting further research in this area, as further noted by Tomas Lidén (Lidén, 2015).

In situations where work requires secure access to infrastructure, a work possession permit must be obtained. These permits can either affect or conflict with train paths, leading to their classification as major or minor work possessions. Major possessions significantly impact traffic capacity and pose challenges to effective planning due to their framing of work planning and cost conditions, which must be considered in freight corridor and timetable revision planning. In contrast, minor possessions are typically planned closer to the time the activity is carried out (Lidén, 2015).

2.2 Turnouts, switches/crossings

Railway turnouts consist of switches and crossings and are a crucial part of the infrastructure that provides flexibility to railway traffic operations. Switches and crossings are considered the most vulnerable points in the system due to their importance in providing train routes, as well as providing decisive flexibility in case of failures (Hassankiadeh, 2011). This due to the turnouts many moveable parts. Many maintenance databases suggest that turnouts are responsible for most of the reported track failures, which in turn leads to high costs (Kassa, 2006). Turnouts are subject to special wear, especially at the crossing point and heavy-duty components. Additionally, fastening, sleepers, and ballast are more susceptible than on a free track, as longitudinal pressure, and tensile forces from two tracks are transferred to one track. Due to more moving and special parts that are more susceptible to wear, maintenance and operating operations that are unproblematic on a free track can easily damage the components of a turnout, Turnouts are also a track component that leads to a sudden change in stiffness along the track, which affects the rate of decay (Jernbaneverket, 2016). Figure 1 shows an overview of a single switch with its different components.

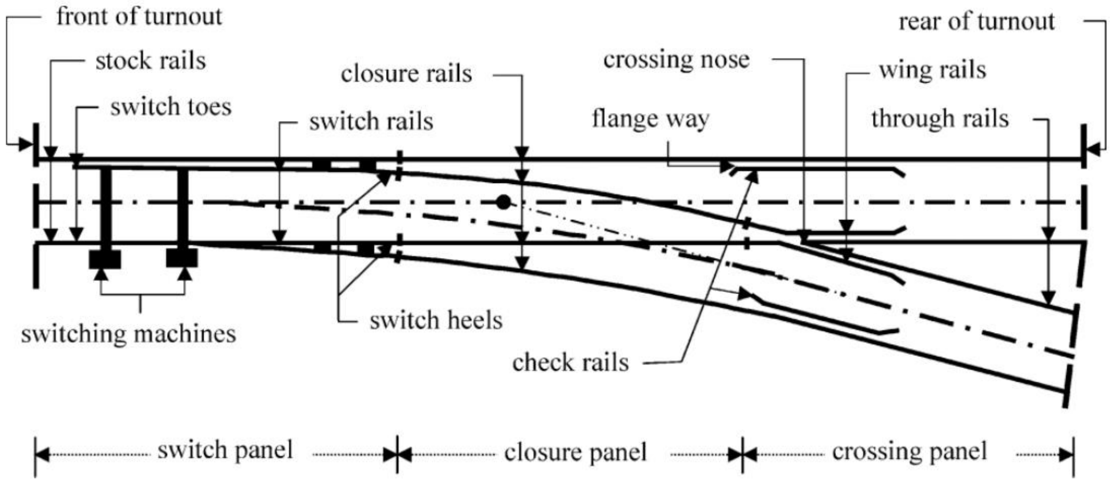


Figure 1, Components of a turnout (Kassa, 2006)

According to Honauer and Ödeen (2022), the most economically extensive measures involve the replacement of bridges, tracks, and turnouts, as well as the refurbishment and replacement of overhead power lines. These measures could be avoided in many cases by more frequent inspections of the infrastructure (Ulrika Honauer and Sven Ödeen, 2022). In Norway, inspections of railway turnouts are thoroughly described in the technical regulations for the maintenance and inspections of different types of turnouts (BaneNor, 2023). The inspections involve geometrical measurements of specific points in the turnout, as well as a visual inspection of irregularities and abnormalities found in and around the turnout.

(Appendice B) describes which specific points of the turnout that are measured and which parts of the rail head that are measured. The measurements made are compared to the tolerances specified in the regulations. This specific turnout is the most used and is called “single rail switch”. And is in relation to other more complex railway turnouts easier to inspect. For reference see (Appendice C). Both were inspected in the field studies.

2.3 Dependence on Inspector Experience and the Role of Working Memory Capacity in Turnout Inspections

The result of the inspections, however, is heavily dependent on the experience of the inspector. The certified inspectors at Trafikverket for instance, often comes from different backgrounds and fields of expertise. Axelsson and Thomasson (2013) conducted interviews with inspectors and found that divergent opinions regarding the state of the inspected facility is a common phenomenon. Nevertheless, due to the inspector’s certification, the differing diagnoses are considered equally valid. Furthermore, the literature on simultaneous attention suggests that this depends on the individual's working memory capacity. Working memory is assumed to be the cognitive system responsible for the temporary storage and manipulation of information necessary for complex cognitive tasks such as comprehension, reasoning, and learning (Baddeley, 2010).

Studies have shown that individuals with high working memory capacity are better able to maintain multiple attentional foci and rapidly switch their attention between different tasks, while individuals with lower working memory capacity struggle to perform such tasks. Again, referring to the appendix showing the multiple points which are to be inspected during an inspection (bilaga). This suggests that the ability of simultaneous attention is closely related to working memory capacity, proposing that these tasks are fitting for people with this trait.

For example, Valeri M. Beck (2012) conducted a study on the ability of simultaneous attention and visual search, finding that experienced individuals rely on working memory representations to rapidly switch their attention. The experiments conducted in the study was limited to visual search of two templates sequentially and simultaneously. However, Valeri states that the typical storage capacity of visual working memory is limited to three or four items at a time. Thus, an inspector could maintain focus on three to four activities simultaneously, but it presupposes that the inspector has experience and has been trained in working memory throughout their professional life

Overall, the literature suggests that the ability of simultaneous attention is dependent on working memory capacity and can be improved with training. Therefore, improving working memory capacity through training could potentially enhance an individual's ability to maintain simultaneous attention.

2.4 Automation and robotics in other industries

In other industries, automating various maintenance and inspection tasks has proven to be successful. For instance, the nuclear industry is particularly safety critical, but at the same time, hazardous and unsafe for human workers. B.L. Luk conducted a study in 2006, which found that robots could effectively handle a significant portion of inspections and maintenance tasks in a typical nuclear plant, although such robots require a substantial investment (B.L. Luk, 2006). Another example is the STRUM classifier, which is a robot designed to detect cracks on bridge decks. This robot enables the generation of large image datasets, which are automatically analyzed to rapidly assess the condition of the bridge (Prateek Prasanna, 2016).

A Norwegian scientific team led by Øyvind Netland (Øyvind Netland, 2013) conducted an experiment comparing the effectiveness of remote, robotic inspections to manned inspections. The study aimed to evaluate the differences in error detections found by students, posing as inspectors, using different methods: manned, teleoperated, and assisted remote inspection. The robot prototype used in the study was intended to be a permanent installation in a known area, specifically a wind turbine nacelle, to evaluate the effectiveness of inspections. The results indicated that remote inspections can be as effective as manned inspections, which has potential economic benefits for the operation and maintenance of offshore wind turbines. The team argues that the experiment provides a valid comparison between different inspection methods and notes that the participants themselves preferred the assisted remote method. This method allowed the participants to focus more on observation and inspections, rather than on controlling the robot, and was deemed the most successful.

2.5 Automation and maintenance in the railway industry

Several studies conducted by McKinsey (McKinsey, 2020);(McKinsey, 2016) emphasize the potential benefits of optimizing railway inspections and maintenance, particularly by transitioning to condition-based and predictive maintenance approaches. According to these studies, maintenance expenses constitute approximately 50% of the total cost in the railway industry. This prompts the need to explore strategies for optimizing the activities and processes.

Lidén proposes that prescheduling minor possessions into train-free slots, like major possessions, may be advantageous in providing access to infrastructure with sufficient intervals (Lidén, 2015). And as previously mentioned, both Peng and Budai promotes more focus being laid in the scheduling the preventive maintenance (Budai, 2004);(Peng, 2011). The distribution of time slots enables the coordination of various activities, resulting in reduced load on capacity planning and increased predictability of traffic situations. The development of these time patterns should consider the required maintenance volumes, track sectioning, work hours, coordination with traffic and other facilities, as well as any operational limitations beyond the work area (Lidén, 2015). Furthermore, Peng also proposes the importance of long-term planning to optimize the number of inspections teams and to balance the workload throughout the year (Peng, 2011).

To streamline long term planning and optimizing the number of inspections the infrastructure manager in the UK, Network Rail, has recognized that the implementation of robotics, automation, and artificial intelligence (AI) could represent a significant advancement in the management of data and the performance of infrastructure inspections and maintenance tasks (Network Rail, 2019). This implementation aims to decrease the frequency of disruptions in the network, but its primary objective is to enhance the safety of the workforce (Network Rail, 2019). Simultaneously, Network Rail contends that an enhancement in the precision and accuracy of collected data, through the integration of data analytics and the reduction of human bias, will enable improved repeatability and reproducibility, making it more economically viable to conduct frequent inspections and maintenance tasks. This would consequently result in improved knowledge about the asset condition, allowing for easier adjustment of maintenance intervals based on asset condition (Network Rail, 2019).

As previously mentioned, there is a drive to improve the existing infrastructure, fleets, recourses, and processes within the railway industry. Passenger track utilization, measured as passenger-kilometers per track kilometer, has increased by 75% between 2000 and 2016 at a global level. However, this growth has been primarily concentrated in China, India, Japan, European Union, and Russia, accounting for 90% of rail activity worldwide (IEA, 2019).

The Office of Rail and Road in the UK expects Network Rail to carry out the maintenance and operations 17% more efficiently by 2019, and to be able to reach these efficiency saving targets Network Rail will have to reduce to number of working staff on maintenance by 8% (National Audit Office, 2015). Parallel to this, Vithanage et al states that robotics and automation (RAS) are becoming more economical and feasible due to advancements in manufacturing and technology, referring to World Robotics 2014 data, which shows the adjusted price for industrial robots has dropped down nearly 80% in the US, UK, and EU, making robotization more feasible. (Randika K.W. Vithanage, 2019). The combination of these two facts points toward that an implementation of robotic and autonomous systems in maintenance and inspections should be discussed. Vithanage et al further states that out of 65 authentic studies done on development of robotics and autonomous systems in railway maintenance are distributed mainly toward the rolling stock (56%) and rail track maintenance (28%), the rest of the research are evenly distributed between bridges, tunnels, power transmission making out the remaining 16% (Randika K.W. Vithanage, 2019).

The inspection of rolling stock and track is both safety critical, expensive, and labor intensive, leading to an increase of automation of certain tasks. Examples of this are wayside detectors, cameras mounted on the undercarriage, and automated inspection tasks in the maintenance depots. The wayside detectors could continuously track the condition degradation of the wheels and bearings which in most cases were responsible for derailments, the implementation led to a decrease of derailments of 50%. Researchers have also successfully exploited the recent development of machine vision and classification algorithms to develop RAS in tail track maintenance activities, especially for inspections and monitoring by systematically scan rolling contact fatigue cracks on the rail to provide more detailed information on the cracks sub surface size (Rowshandel H, 2013).

Another relevant study was done by SINTEF (2020) on sensors for a robot performing inspections. The study describes and values different tasks for which the sensor package is to be designed. The assessment of method/comment has been considered in consultation with experts from BaneNor. From these documents, general sensor tasks have been linked to each individual inspection task where this is valued possible to achieve. Some tasks are valued not possible to be performed with the robot, with the limiting reasons specified. The inspection tasks are sorted into three use cases: cuttings and embankments, overhead contact line systems, and tunnels. Estimated applicability of the general sensor task to the specific inspection task, are indicated with either “direct applicability”, “potential with some research” and “difficult or impossible with the proposed sensor package”. However, the main finding is that visual inspections and measurements are valued as direct applicable in this report (SINTEF, 2020).

2.6 Overview of the maintenance market

A study published by DNV looked at the distribution of 700 accidents that occurred in 23 different countries and the results showed that 37% of these were rolling stock related and 36% infrastructure related (Papaelias, et al., 2016). The remaining accidents were due to operational failure and "other". These statistics shows that maintenance is critical for a safe and reliable service. Maintenance tasks are costly, but inevitable. According to McKinsey's analysis on the European rail maintenance, the costs of maintenance and renewal already exceed €25 billion a year across Europe and rising (McKinsey, 2020).

In the literature, maintenance work is usually divided into 4 different subcategories (Xie, 2020):

- Corrective maintenance
- Preventive maintenance
- Condition based maintenance
- Predictive maintenance

According to Xie et al the most desirable strategy is predictive maintenance since it reduces track failure rates while minimizing the maintenance costs by extending the life of track components thus allowing operators to plan maintenance ahead (Xie, 2020). The introduction of condition monitoring of components by more frequent inspections, will contribute the transition into condition-based maintenance where the components and facilities are maintained just in time.

Another study done by McKinsey, looked at the combined efficiency gain through condition based and predictive maintenance and found that the railway sector could be expected to gain around 15-25%. The McKinsey team estimated the global maintenance market shares to be around €45-50 billion and that this number should remain steady in the upcoming years (McKinsey, 2020). The team found that condition-based maintenance could reduce the maintenance costs with 10-15%, and with predictive maintenance an additional 5-10% cost reduction (McKinsey, 2016).

One notable issue that merits further attention is the recurring problem of maintenance backlog within railway networks (BaneNor, 2017);(Trafikverket, 2022). This refers to the accumulation of maintenance and repair tasks that have been deferred over time, leading to a significant backlog of work that must be addressed to ensure the safe and efficient operation of the railway system. This issue can have significant impacts on the overall reliability and safety of railway networks (Jernbanegruppa, 2011), highlighting the need for effective maintenance strategies and planning to prevent the accumulation of deferred tasks.

The McKinsey capacity study showed that infrastructural related train delays could be reduced by 35% if the maintenance backlog would be addressed (Isacsson, 2020). Assuming that this is true, further research were made to estimate the socioeconomic benefit of investing in prioritizing these tasks. The findings of these studies indicate that the consumer of train services can benefit significantly from the reduction of train delays and maintenance costs. Specifically, the socioeconomic benefit associated with reducing train delays was estimated to be 26 billion SEK, while the benefit associated with the reduction of maintenance costs was estimated to be 106 billion SEK over a 40-year period, assuming that the maintenance backlog work is addressed at a constant rate. Alternatively, if all reinvestment needs are met and all backlog is addressed, the socioeconomic benefits increase to 88 billion SEK and 180 billion SEK, respectively, even though the cost of this alternative was 233% higher. The author, Isaccson, concludes that both strategies are beneficial, but it is more advantageous to reduce the backlog at a constant rate rather than addressing all backlog since the ratio of the reduction of maintenance costs in relation to the discount rate is less than one. (Isacsson, 2020).

2.7 Norway

BaneNor, the Norwegian rail administration, has projected the cost of their maintenance backlog to be approximately 23 billion NOK for the period spanning from 2022 to 2023. The company views the maintenance and oversight of less critical tasks as crucial to ensure safety. (BaneNor, 2017).

In BaneNor’s maintenance handbook, (BaneNor, 2017) four elements are presented as the most important reaching improvement of maintaining the infrastructure:

- Analyzing root causes of frequent and/or critical faults to pinpoint weaknesses for preventive maintenance, instructions, or design.
- Planning, communicating, and implementing good practices
- Finding the optimal timing of renewal or quality enhancing measures connected to reduced quality

- Optimizing maintenance intervals for the preventive maintenance activities by continuously updating value and parameter reliability and costs of maintenance and the consequences of infrastructure failure.

A recent report conducted by the Jernbanedirektoratet (2020), the Norwegian railway directorate charged with the planning, development, and coordination of railway transport in Norway, presented a range of strategies for the maintenance of railway infrastructure in the upcoming years. The strategies were designed to ensure maximum safety while optimizing system punctuality.

The year 2017's punctuality record is being used as a benchmark for future goals and aspirations (Jernbanedirektoratet, 2020).

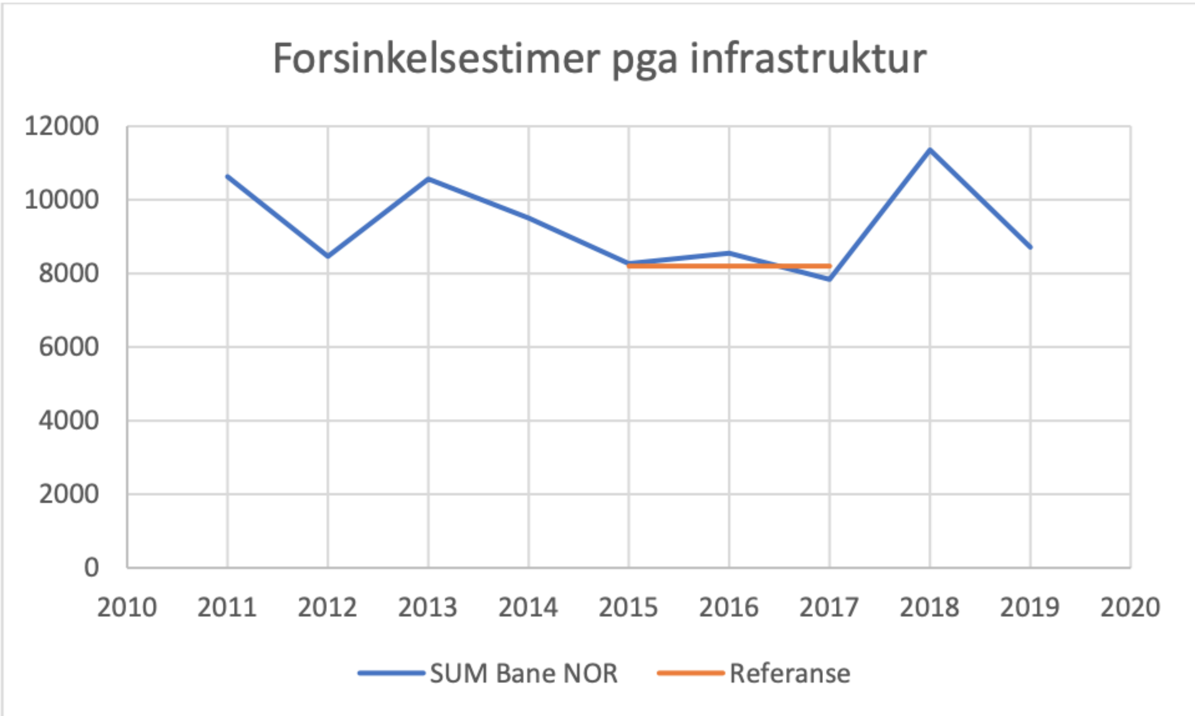


Figure 2, Diagram showing the difference in number of delayed hours over time due to infrastructural failures I Norway

In the study, the projected baseline costs for maintenance and operation over the next decade are expected to amount to approximately 10 billion NOK per annum. This baseline cost is defined as the level of maintenance work required to maintain a state of equilibrium, such that the annual maintenance backlog and infrastructure condition remain constant (Jernbanedirektoratet, 2020). The report also indicates that there is no direct correlation between preventive and corrective maintenance in the short term. Specifically, it is noted that investing 1NOK in preventive maintenance does not necessarily result in 1NOK saved in corrective maintenance. This is due to the historical underinvestment in preventive maintenance relative to the increase in traffic flow over time. Moreover, despite investments in preventive maintenance, the age and condition of the infrastructure will likely necessitate corrective maintenance during the same period. (Jernbanedirektoratet, 2020). In the long term, the preventive maintenance will affect the amount of corrective maintenance needed. This will lead to focus being laid at the backlog from previous years that have been under-prioritized.

According to “The railway group” in Norway one of the biggest challenges facing the railway industry are that the components which are used are described as “to old” and are “dimensioned for past flows of traffic”, meaning the components are under-dimensioned for the magnitude of today’s traffic (Jernbanegruppa, 2011). Furthermore, the deterioration of these core and safety critical components will lead to an increase of the maintenance backlog, which usually is taken care of by closing entire sections for a longer period. These measures stand opposed to BaneNor´s goal to offer the costumers a reliable service as well as it affects the train operators economically, since they are responsible for financing alternative transportation and complaints following the lockdown (Jernbanegruppa, 2011).

A paper on how preventive maintenance activities should be scheduled was done by Budai et al (2004). In this paper the preventive maintenance problem is discussed, whereas the problem is described to be that the preventive maintenance tasks are poorly scheduled and that these activities should be clustered together in the aim to minimize the expenditures on track possessions. This would be a step toward reducing the maintenance costs without reducing the maintenance itself (Budai, 2004).

2.8 Sweden

In The Swedish rail administration, maintenance plan for 2022-2025 (Trafikverket, 2022) it is stated that for 2022 base maintenance of the 14.200km railway includes the following and has a total cost of 7.5 billion SEK for 2022:

Table 1, Trafikverket 2022 base maintenance groups

Groups	Includes
Base maintenance contracts	34 basic maintenance contracts including materials, developer costs and evacuation and clearing
Maintenance activities in addition to the basic maintenance contract	Quality fees, station management, as well as smaller agreements such as for surveillance, pumping stations and technology houses
National maintenance contracts, electric power, signal and construction works	Non-line-bound power supply, information to users, detectors, etc.
National maintenance contracts, track	Condition assessments, rail grinding, chemical weed control and more
Damages	A historic four-year average
Less action and reinforced maintenance	Reinforced maintenance such as replacement of parts in a track system
Operating costs	Electricity, supply line, operable bridges and an investment in security guards

The same maintenance plan (Trafikverket, 2022) states that also the economic resources of Trafikverket for maintaining the railway infrastructure have been insufficient to meet the total needs. The infrastructure has deteriorated faster than it could be maintained, resulting in a maintenance backlog.

National maintenance contracts include corrective and preventive maintenance, just like the basic contracts, but within a specific technical area. It includes, for example, non-line-bound power supply, detectors, traffic information, pumping stations, rail grinding, weed control, and measurement vehicles. Within the preventive part of the maintenance of the national maintenance contracts, Trafikverket plans to focus on reinforcement of track substructure, increased rail grinding, weed control, and increased condition measurement.

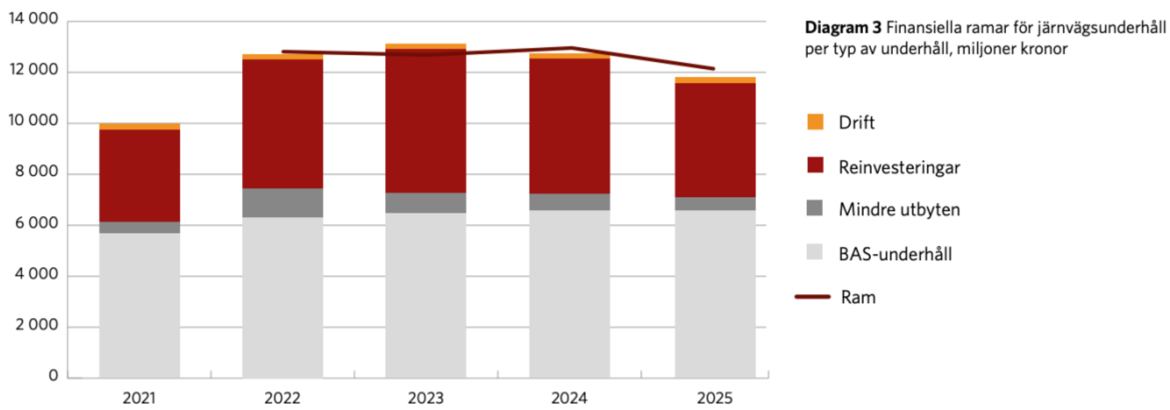


Figure 3, diagram showing the financial boundaries for railway maintenance in Sweden per type of maintenance, million SEK. Categories from top to bottom: Operation, reinvestments, lighter substitutions, base maintenance, boundary.

At present, there is no cost database available presenting various activities related to the operation, maintenance, and reinvestment of the railway network. Overall, there is limited information regarding specific maintenance actions and where they will be carried out. A larger sample of specific contracts needs to be studied to find average unit prices for different actions. Costs will vary depending on which sections the maintenance contracts cover, which is why a geographic breakdown of the contracts is necessary to study average unit prices. Prices will, of course, also vary depending on the procurement structure, but given a certain structure, average unit prices for different sections of the tracks can be studied. A structure that involves maintenance contracts with costs for specific maintenance actions, is according to a report done by VTI (2011) clearly preferable in a socio-economic analysis model for the operation, maintenance, and reinvestment of railway infrastructure (Andersson, 2011).

2.9 Cost of turnout maintenance and inspections

As per the 2021 annual report of the Swedish Transport Administration, the total cost of maintenance activities for turnouts was 460 million SEK, while the reinvestment cost for turnouts was 163 million SEK (Trafikverket, 2021). The railway system in Sweden encompasses a total of 11,000 to 15,000 turnouts, with approximately 12,000 owned by the state (Trafikverket, 2022); (Trafikverket, 2023); (Hedström, 2019). Adding maintenance activities and reinvestment together, the combined costs of maintaining and reinvesting in turnouts amount to 623 million SEK, implying a cost of approximately 52,000 SEK per turnout in 2021.

Via email with Swedish turnout expert and track technician Arne Nissen, it was noted that calculating a mean value for the cost savings in turnout inspections may not be particularly relevant. Instead, Nissen provided cost estimates for different types of turnouts (A. Nissen, personal communication, Mars 31, 2023).

For turnouts in sidetracks and stabling tracks (approximately 3,700 turnouts), the maintenance cost is estimated to be around 20,000 SEK per year. However, for the remaining 7,300 turnouts operating in the main track, the maintenance costs range from 40,000 SEK to over 200,000 SEK per year (Nissen, 2023). According to Nissen, inspections are carried out 1-7 times annually by a team of two individuals within approximately an hour. Corrective maintenance, which occurs on average once per year, can vary between 0.2-5 faults annually. The time required for corrective maintenance is typically the same as the inspection duration. However, due to the urgency of corrective maintenance, the travel time from the office to the track is set to be between 2.5-3 hours

Furthermore, the most expensive components to substitute are presented in table 2.

Table 2, Most expensive components to substitute with price of component and of work, according to Nissen

Component	Cost of component	Cost of work
Crossing	200.000 SEK	50.000 SEK
Tunganordningshalva	125.000 SEK	40.000 SEK
Point Machine	300.000 SEK	30.000 SEK (unsure)
Gear box	40.000 SEK	10.000 SEK

Apart from these larger and more costly repair works, there are also lighter maintenance tasks involving adjustments, controls, and replacements of smaller components like the electrical point detector. The number of inspections remarks typically varies between 5-10 in the main track. Some switches and crossings may require additional servicing based on factors such as the amount of traffic the turnout is serving, the age of the turnout, the climate where the turnout is located, and the initial conditions will affect in what degree the turnout will need inspections and maintenance (Nissen, 2015).

Trafikverket has defined different objects and sections of the network regarding traffic load and speed limit on the section (see figure 6). Engineering students at Lund's University studied the railway inspections in Sweden (Thomasson, 2013), where different statistics on turnouts are presented.

Relevant for this thesis are the amount of safety inspections per year per turnout priority, which showed that there are 1,3,4,6 and 6 inspections on turnouts within the priority class B1, B2, B3, B4 and B5 respectively (Thomasson, 2013). Section and facility inspection priority is visualized in figure 6. Furthermore, the study presented statistics on inspection remarks delivered by the inspectors between the year 2008 and 2012. Results showed most remarks on freight stations with a high number of turnouts. The thesis analyses the remarks on different facilities thoroughly and pinpoints 72% of the total remarks down to turnouts in the studied area.

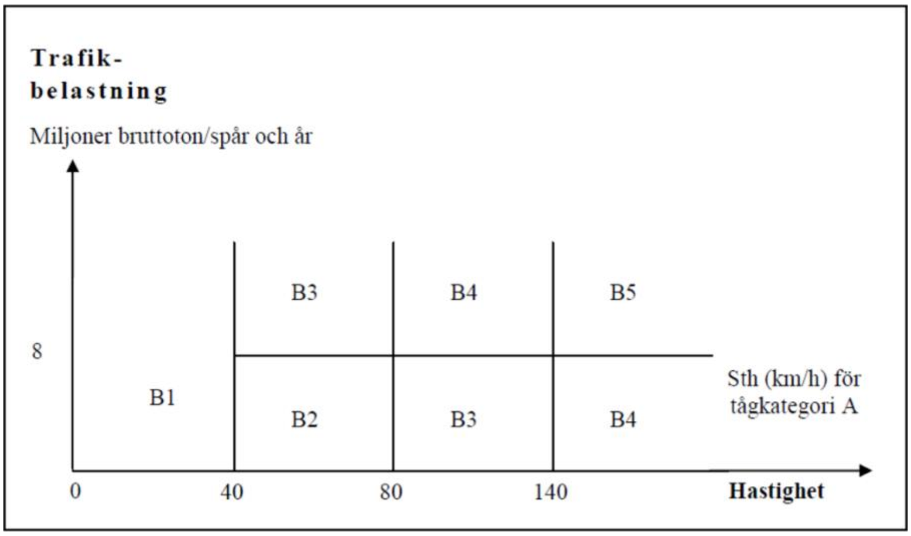


Figure 4, Section/facility inspection priority (million gross tons per track and year in relation with the speed limit)

The study will also pose a good comparison on the timespan an inspection takes, and how many inspections are done per year, which also estimates the costs for these inspections in the specific geographical location as well as the specific contract. The results showed an estimate of 1.7 million SEK per year in the Malmö region for inspections. The authors purposed a tool which easily could measure turnouts automatically by defining 10 parameters, these could include which type of turnout or crossing is to be measured as well as the tolerances of the measurements. This would enable the inspector to stay out of the hazardous areas for the most part of the inspection as well as inspecting the turnout parts while the measurements progress. This would according to the authors reduce the amount of time in the track as well as the amount of working days and nights, which would reduce the estimated price to 0,89 million SEK.

The Norwegian railway administration (Jernbaneverket, now BaneNor) performed a study estimating which factors or reinvestments of different components or facilitates in the railway network, and how these affect the annual maintenance costs. The sections studied were chosen based on which were highly representative in relation to the entirety of the system. The study also only investigates the corrective and preventive maintenance activities. The results however, showed that a marginal change in the number of turnouts on a section would increase the maintenance costs by 2.51 percent of the original cost level per year. This results an increase of maintenance costs by 533,000 nominal NOK per year evaluated on average for annual maintenance costs by increasing the number of turnouts by one unit, with all other things staying equal. Evaluated with an average in 2011, an increase of one turnout will result in an increase in annual maintenance costs of 615,000 nominal NOK (Jernbaneverket, 2016).

These two references demonstrate that the costs associated with railway turnouts are intricate due to the intricate nature of the turnouts themselves. While maintenance activities, referred to as "turnout maintenance," account for approximately 8% of the total maintenance costs per year over the last three years, a turnout, especially a poorly maintained one, can also contribute to increased maintenance requirements for the surrounding facilities that interface with it.

3 Method

3.1 Interviews

The interviews were conducted with individuals who have extensive experience working on the track. The interviews were conducted in aim to get an understanding on the current processes surrounding railway maintenance and especially turnout inspections and maintenance, and the associated safety risks. The answers from the interviews were also used in the calculations for time and cost savings. The idea-based interview approach as defined by Paulson, 2020 was adopted. This approach is recommended to get a deeper understanding about the subject, the weakness however, the interviewer can be affected by factors that have nothing to do with the interview itself.

The questions from the conducted interviews are presented in table x, which also distinguishes which questions that were asked to answer the different research questions:

1. What is the potential cost and time benefits of automation or robotization of turnout inspections and maintenance, and how can these be quantified?

3. What are the current processes for inspecting and maintaining railway turnouts, and what are the associated safety risks?

Table 2, Questions from interviwes

Research Question	**Question asked**
1 and 3	How often turnouts are inspected annually
1	Which safety measures that are taken
1	What the normal injuries during work in the track are
3	How the budget of turnout maintenance is distributed between the different activities
3	The time used to inspect the turnouts
3	Duration of the activities surrounding the inspections
3	How the more prioritized turnouts are defined
3	How long the typical inspection takes
3	How long the logistics of a turnout inspection take
3	How long the documentation takes
3	The number of turnouts in the Oslo area

The answers of the interviews are presented in the result chapter as well as in the appendices of this thesis.

3.2 Field Studies

A field study was conducted in collaboration with an experienced track technician at Ski station, and Hauketo station. During the field study a demonstration of geometrical measurements in a single turnout with a movable frog and a crossing was performed. In addition to this, a demonstration of VUL measurements, which involves continuous measurements of the track position in an external reference system was performed. The main purpose of conducting this study was to firsthand investigate the current practices and record the duration of these activities for further calculations. In addition to this, participation, and observations of the safety preparations prior to the work being put out was recorded.

The field studies also resulted in natural conversations with the technicians were an implementation of a track robot and its possible advantages were discussed.

3.3 Data Analysis

A data base analysis was conducted in the aim to get a reference from the inspections and maintenance being carried out for two Swedish stations Lund C and Alingsås. These were selected because of them being relatively easy to analyze, and the fact that they have different inspection priorities (see chapter 2.9). The databases being used are described below.

In aim to get an overview on the current work related injuries, the database for work-related injuries provided by the Swedish Work Environment Authority statistics database was used.

3.3.1 Databases used

The Swedish Work Environment Authority Statistics Database is a centralized repository of data and information related to work environments and occupational health and safety in Sweden. It is maintained and managed by the Swedish Work Environment Authority (Arbetsmiljöverket), which is responsible for promoting safe and healthy working conditions in Sweden.

Trafikverket uses two databases, Ofelia, and Bessy, to report actions and measures made in turnout maintenance and inspections. BIS which is a database where the different components and facilities are documented was also used to get an overview over the stations.

BESSY is a system used by the Swedish Transport Administration (Trafikverket) for documenting and monitoring inspections of its fixed railway installations. Access to the system requires authorization provided by Trafikverket. The system can be accessed via a computer, and the information can be transferred to a handheld device. The handheld device is used by inspectors during inspections in the railway environment. Any observations made during an inspection are then stored in BESSY for documentation (Trafikverket, 2023).

Within the system Ofelia, track contractors or fault handlers report the actions undertaken in response to a fault symptom that has been registered by traffic management. The fault handler provides details on the actual fault, its cause, the action taken, and subsequently completes the fault report (Trafikverket, 2021).

4 Results

4.1 Field Studies

The field study consisted of geometrical measurements of a turnout as well as performing measurements of the displacement between track and powerline poles (VUL-Measurements). During the turnout inspection, the technicians use a spirit level (figure 1) and a form to record their measurements with pen and paper (figure 2). The form includes the limit values and points of interest in the turnout. The spirit level is placed on top of the rails to measure the track gauge and the difference in height between the rails. Once the defined points have been measured, the turnout is repositioned, and the same points are measured again. The VUL-measurements were demonstrated by walking along the track and performing measurements between the outer rail and the closest point from the powerline pole using a laser (figure 3). The measurements are in this task normally documented digitally after each measurement. This time however, the digital documentation program was not working properly. The technician therefore had to resort to pen and paper and implied that he was not happy about the current documentation system being used.

The field study was valuable for several reasons. It gave a firsthand understanding of the tasks involved in maintenance and inspections, which provided a deeper insight into the challenges and complexities of the job. Mainly however, by observing the workers and participating in the tasks, as well as recording the time it took to complete the tasks and the number of times they had to bend over to make the measurements at least 2 times per measurement point (table). These observations can be used to calculate the efficiency of maintenance and inspection procedures.

Table 3, Table with results from the field study

Component	Inspection time	Bends
Single switch with moveable frog	25 minutes	26
Crossing	75 minutes	104
VUL-Measurements	60 minutes	8

Another observation made during the field study was that the work is always carried out by two certified workers. Prior to commencing any work at a construction site, safety analyses must be conducted by the workers involved, and was therefore also performed by us prior to the demonstration. This involved filling out a form that specified the location, activity, and facility of the work was to be carried out. Standardized additional information on the risks associated with the tasks were also discussed by the working team. For example, while performing geometrical measurements in the turnout, the team identified risks such as falling from the same level, pinch points, and the possibility of being struck by moving equipment such as working vehicles or trains. Before beginning work in the area, the safety manager and other workers are informed, and the work area is marked with flags to indicate the boundaries.

When asked about common physical strain experienced by track workers, the service professional indicated that injuries to the knees and ankles from walking in the ballast were the most common. This is an important consideration as it suggests that efforts should be made to minimize the impact of this strain on the body.

Furthermore, the accuracy of measurements using a spirit level and folding rule can vary depending on the quality of the tools, the skill of the person using them, and other factors such as environmental conditions. Generally, spirit levels are designed to provide measurements within a few millimeters, while folding rules are typically accurate to within a few centimeters.

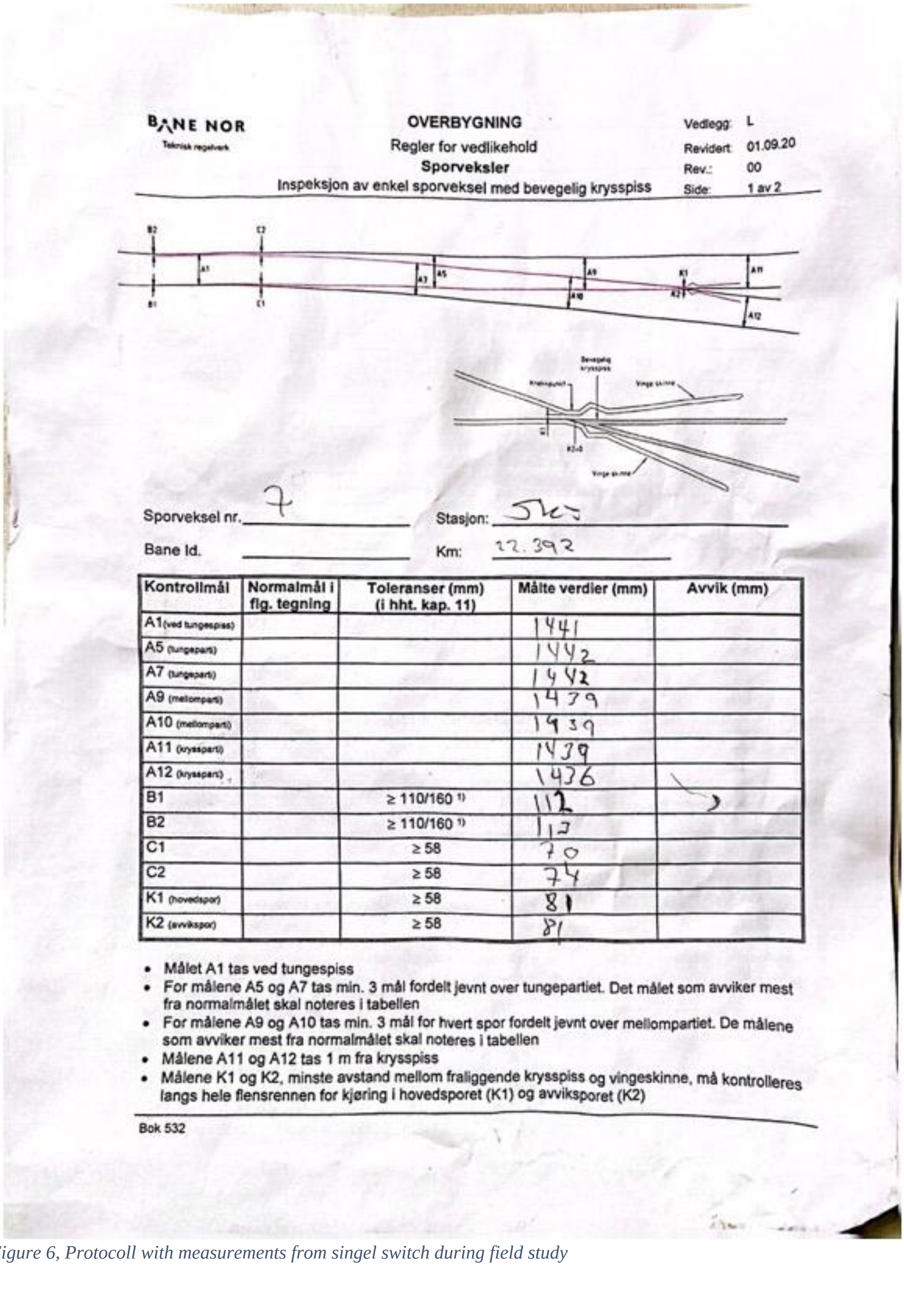
The acceptable margin of error for these measurements would depend on the specific application and requirements of the task. In some cases, even a small error could have significant consequences, while in other cases a slightly larger margin of error may be acceptable. It is important for the person performing the measurements to be aware of the required accuracy and take appropriate steps to ensure that the measurements are as precise as possible. It is important to ensure that the person doing the measuring is properly trained and has the necessary skills to ensure accurate measurements.

A preprogrammed robot performing the measurements, however, would not be subject to personal variations in the way measurements are taken. The robot would be programmed to take measurements in a consistent and accurate way, following a pre-determined set of rules and procedures. This would eliminate the potential for human error or inconsistencies and provide a more reliable and precise measurement result. Additionally, the sensors on the robot could be calibrated to a high degree of accuracy, further reducing the potential for measurement errors.

While there may be some leniency in regulations and margins for errors, it is still important to strive for precision in measurements for several reasons. Firstly, precision can help ensure the safe and efficient operation of the railway system, as even small deviations from the ideal position of track components can accumulate over time and lead to larger issues. This procedure took about 20-30 minutes. Second, precise measurements can help identify potential issues before they become significant problems, allowing for proactive maintenance and repairs. Finally, frequent, and precise measurements can help improve the overall quality and longevity of the railway infrastructure, reducing the need for costly repairs and replacements in the long run.

Overall, the field study was a valuable experience that provided insights into the tasks, time required, and potential for automation in railway maintenance and inspections. These insights can be used to improve the efficiency and effectiveness of maintenance and inspection procedures, ultimately leading to safer and more reliable railway infrastructure. The service professional also stated that VUL-measurements could be an additional task that a robot could perform.

Figure 5, Crossing measurement during field study with spirit level



BANE NOR
Teknisk regelverk

OVERBYGNING
Regler for vedlikehold
Sporveksler
Inspeksjon av enkel sporveksel med bevegelig krysspiss

Vedlegg: L
Revidert: 01.09.20
Rev.: 00
Side: 1 av 2

Sporveksel nr. 7
Stasjon: [illegible]
Bane Id.
Km: 22.392

Kontrollmål	Normalmål i fig. tegning	Toleranser (mm) (i hht. kap. 11)	Målte verdier (mm)	Avvik (mm)
A1 (ved tungespiss)			1441	
A5 (tungeparti)			1442	
A7 (tungeparti)			1442	
A9 (mellomparti)			1439	
A10 (mellomparti)			1439	
A11 (krysparti)			1439	
A12 (krysparti)			1436	
B1		≥ 110/160 [1]	112	
B2		≥ 110/160 [1]	112	
C1		≥ 58	70	
C2		≥ 58	74	
K1 (hovedspor)		≥ 58	81	
K2 (avvikspor)		≥ 58	81	

- Målet A1 tas ved tungespiss
- For målene A5 og A7 tas min. 3 mål fordelt jevnt over tungepartiet. Det målet som avviker mest fra normalmålet skal noteres i tabellen
- For målene A9 og A10 tas min. 3 mål for hvert spor fordelt jevnt over mellompartiet. De målene som avviker mest fra normalmålet skal noteres i tabellen
- Målene A11 og A12 tas 1 m fra krysspiss
- Målene K1 og K2, minste avstand mellom fraliggende krysspiss og vingeskinne, må kontrolleres langs hele flensrennen for kjøring i hovedsporet (K1) og avvikssporet (K2)

Bok 532

Figure 6, Protocoll with measurements from singel switch during field study


Figure 7, VUL-Measurement during field study

4.2 Interviews

The main findings of the interviews were the estimated times for the logistics and documentation in terms of the results of this study and are presented in the table 4.

Table 4, Activity time, logistic time, and documentation time for different activities

Activity	**Description**	**Activity time**	**Logistics time**	**Documentation time**
Inspection ***Single rail switch***	Regular visual inspection of rail switches/crossings to identify any damage or defects	30-45min	30min	10 min
Inspection ***Crossover***	Regular visual inspection of rail switches/crossings to identify any damage or defects	60-70 Min	30min	10 min
Inspection ***Un-symmetrical double switch***	Regular visual inspection of rail switches/crossings to identify any damage or defects	60-70 min	30min	10 min
Inspection ***Rail crossing***	Regular visual inspection of rail switches/crossings to identify any damage or defects	60-70 min	30min	10 min
Inspection ***Movable crossing point***	Regular visual inspection of rail switches/crossings to identify any damage or defects	60-70 min	30min	10 min
Lubrication	Lubrication of moveable parts in turnout	10 min	30min	5 min
Cleaning	Cleaning the turnout for optimal operation	10min	30min	5 min

Furthermore, a time estimate from both interviews with track technicians in Norway and Sweden, the turnout inspections were said to take approximately one hour for two people to perform, depending on the complexity of the turnout. However, the combined result from the field study and the interviews the time 25 minutes will be used for further calculations due to the majority of turnouts on the studied stations being single switches (see chapter 3.3).

Other answers from the interviews are presented in Appendix A.

4.3 Database analysis

In this chapter the main findings of the conducted database analyses are presented and analyzed.

4.3.1 Work related injuries in Sweden

In Sweden work-related injuries are well documented and easily accessible on the Swedish Work Environment Authority statistics database (Arbetsmiljöverket, 2023).

By filtering the work-related injuries to railway and metros the following causes of injuries are documented:

- Material fell, collapsed, burst, or exploded
- Vehicle accident, collision, hit, injured by object, machine, tool, or animal
- Hit something or stepped on something sharp
- Threat or violence, chock, fear
- Electricity, explosions, or fire
- Dust, gas, smoke, or liquids
- Falling accident
- misstep, miss lift or other overload injury
- other

From figure 2, the main observations are that the reported injuries from the railway work are related to categories named:
- Vehicle accident, collision, hit, injured by object, machine, tool, or animal (35%)
- Falling accidents (29%)
- Misstep, miss lift or other overload injuries (17%)

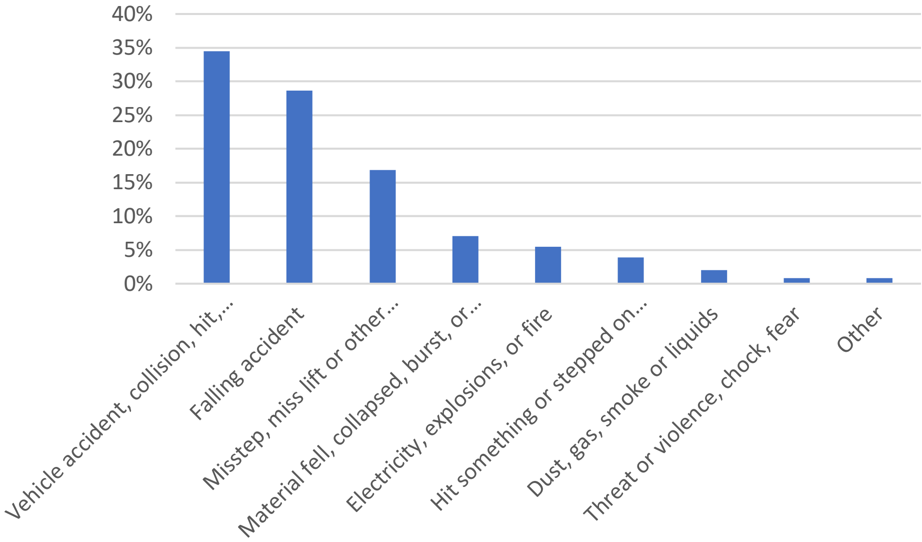


Figure 8, Main causes of accidents in the railway industry

When looking at the injuries over the last 5 years, the mean value of reported injuries related to railway or metro work is 50 reports per year.

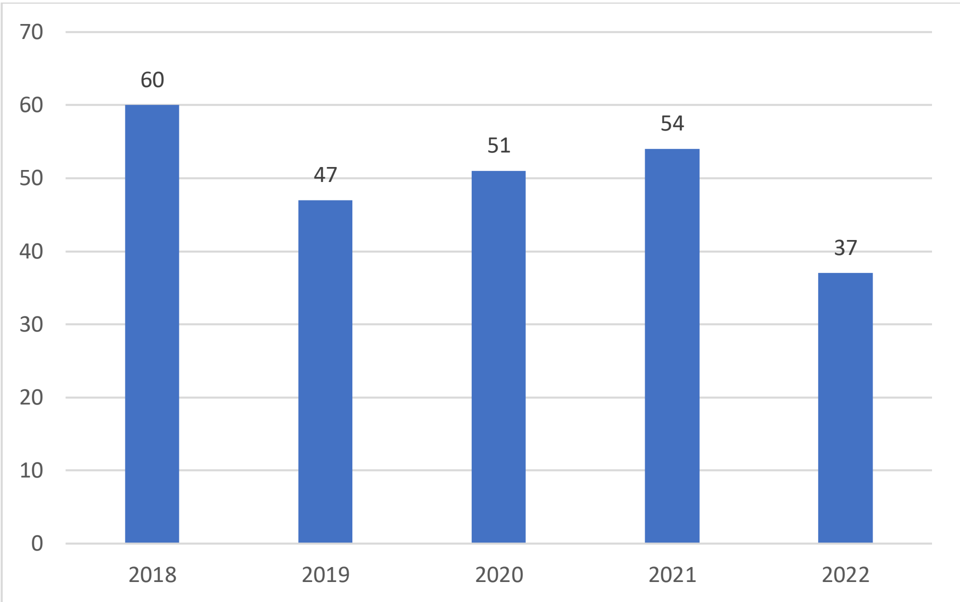


Figure 9, Reported injuries in the railway industry

4.3.2 Calculations on Lund C and Alingsås station

By analyzing Lund C and Alingsås station in regards to both the inspections classification, the time estimates for the different switches and crossings, estimates of documentation times of the work, a comparison between todays practices can be made with a robot.

According to the remarks found in Bessy, Lund C predominantly has the inspection priority B5, and Alingsås B3. Meaning that turnouts in Lund are inspected 6 times every year and turnouts in Alingsås are inspected 4 times a year. The most common turnout type is the single switch EV-UIC60-300-1:9. Specifically 36% of the turnouts in Lund are this type and 24% of the turnouts in Alingsås. (see figures 7 and 8). The switch takes according to both the interview subject and the field study 25-30 minutes to inspect, which is why this is the estimated time for further calculations.

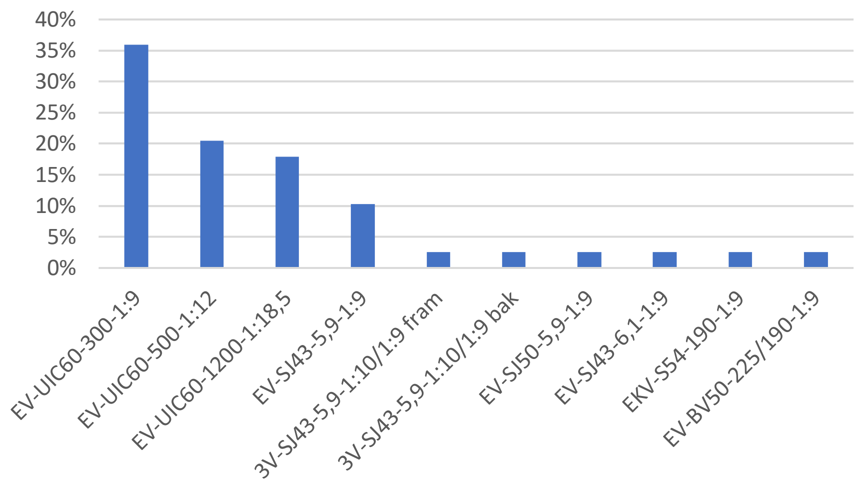


Figure 10, Percentage of turnouts per type Lund C

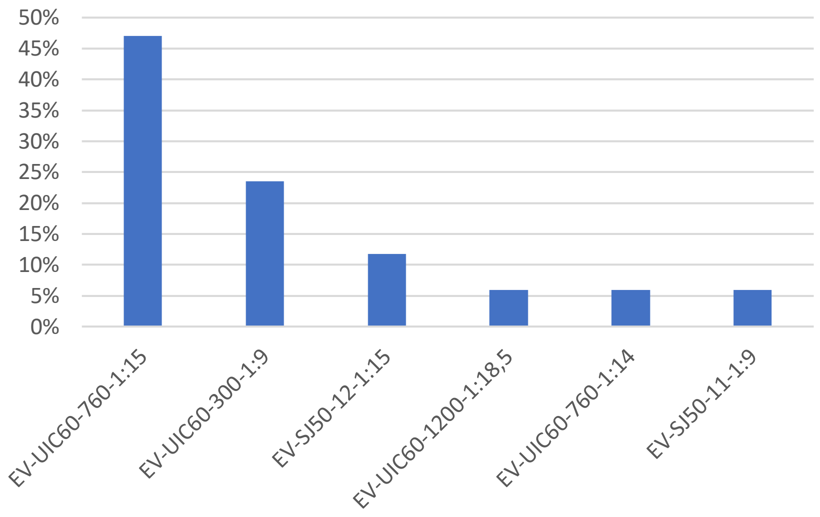


Figure 11, Percentage of turnouts per type Alingsås

Figure 9 shows the different activities prior, during and after an inspection of 4 single switches. The durations of the geometrical measurements and documentation of the work are based on the interview answers from the track technician. The other time estimates are done by me with some help from my supervisor. However, the duration of the geometrical measurements and the documentation times are the times being used in the calculations and are therefore marked in yellow (figure 10). The time for the geometrical measurement is set to 25 minutes, and the time for the documentation is set to 40 minutes (10 minutes per switch).

Geoemtry measurement						
Inspection of track	Resource	Daytime/Nighttime	#People in work team	Limits train traffic	Duration	Manhours
Apply for track access	Work planner	Daytime	1	No	0,25	0,25
Prepare for 1 day/night's work incl. SJA	Service personnel	Daytime	2	No	0,50	1,00
Travel from office to site (near track)	Service personnel	Nighttime	2	No	0,50	1,00
Prepare for work/unload car/get access	Service personnel	Nighttime	2	Yes	0,25	0,50
Transport from car to switch (in track)	Service personnel	Nighttime	2	Yes	0,25	0,50
Establish security measures on location	Service personnel	Nighttime	2	Yes	0,20	0,40
Perform geometry meauserments	Service personnel	Nighttime	2	Yes	0,42	0,83
Remove established security measures	Service personnel	Nighttime	2	Yes	0,20	0,40
Move to next switch	Service personnel	Nighttime	2	Yes	0,10	0,20
Establish security measures on location	Service personnel	Nighttime	2	Yes	0,20	0,40
Perform geometry meauserments	Service personnel	Nighttime	2	Yes	0,42	0,83
Remove established security measures	Service personnel	Nighttime	2	Yes	0,20	0,40
Move to next switch	Service personnel	Nighttime	2	Yes	0,10	0,20
Establish security measures on location	Service personnel	Nighttime	2	Yes	0,20	0,40
Perform geometry meauserments	Service personnel	Nighttime	2	Yes	0,42	0,83
Remove established security measures	Service personnel	Nighttime	2	Yes	0,20	0,40
Move to next switch	Service personnel	Nighttime	2	Yes	0,10	0,20
Establish security measures on location	Service personnel	Nighttime	2	Yes	0,20	0,40
Perform geometry meauserments	Service personnel	Nighttime	2	Yes	0,42	0,83
Remove established security measures	Service personnel	Nighttime	2	Yes	0,20	0,40
Transport from switch to car (in track)	Service personnel	Nighttime	2	Yes	0,25	0,50
Load car (near track)	Service personnel	Nighttime	2	No	0,25	0,50
Documentation work	Service personnel	Nighttime	2	No	0,67	1,33
Travel from site to office (near track)	Service personnel	Nighttime	2	No	0,50	1,00
Documentation verification	Work planner	Daytime	1	No	0,67	0,67
				∑	**7,65**	**14,38**
Total manhours 4 switch measurements/night	14,38					
Total hours of railtrack occupancy 4 measurements	4,32					

Figure 12, Calculations of time being used on manual inspections single switch

In Figure 10, the times for geometrical measurements have been discussed with a robot manufacturer, where the estimates for a single switch inspection is set to 2 minutes (5 minutes for a crossing). Furthermore, the documentation of the work is done simultaneously due to the robot being connected to the cloud via IOT. Another result from the calculations is that the time of rail track occupancy for 4 single switch measurements (one shift) is reduced with 1,5 hours.

Geoemtry measurement						
Inspection of track	Resource	Daytime/Nighttime	#People in work team	Limits train traffic	Duration	Manhours
Apply for track access	Work planner	Daytime	1	No	0,25	0,25
Prepare for 1 day/night's work incl. SJA	Service personnel	Daytime	2	No	0,50	1,00
Travel from office to site (near track)	Service personnel	Nighttime	2	No	0,50	1,00
Prepare for work/unload car/get access	Service personnel	Nighttime	2	Yes	0,25	0,50
Transport from car to switch (in track)	Service personnel	Nighttime	2	Yes	0,25	0,50
Establish security measures on location	Service personnel	Nighttime	2	Yes	0,20	0,40
Perform geometry meauserments	Service personnel	Nighttime	2	Yes	0,03	0,07
Remove established security measures	Service personnel	Nighttime	2	Yes	0,20	0,40
Move to next switch	Service personnel	Nighttime	2	Yes	0,11	0,22
Establish security measures on location	Service personnel	Nighttime	2	Yes	0,20	0,40
Perform geometry meauserments	Service personnel	Nighttime	2	Yes	0,03	0,07
Remove established security measures	Service personnel	Nighttime	2	Yes	0,20	0,40
Move to next switch	Service personnel	Nighttime	2	Yes	0,11	0,22
Establish security measures on location	Service personnel	Nighttime	2	Yes	0,20	0,40
Perform geometry meauserments	Service personnel	Nighttime	2	Yes	0,03	0,07
Remove established security measures	Service personnel	Nighttime	2	Yes	0,20	0,40
Move to next switch	Service personnel	Nighttime	2	Yes	0,11	0,22
Establish security measures on location	Service personnel	Nighttime	2	Yes	0,20	0,40
Perform geometry meauserments	Service personnel	Nighttime	2	Yes	0,03	0,07
Remove established security measures	Service personnel	Nighttime	2	Yes	0,20	0,40
Transport from switch to car (in track)	Service personnel	Nighttime	2	Yes	0,25	0,50
Load car (near track)	Service personnel	Nighttime	2	No	0,25	0,50
Documentation work	Service personnel	Nighttime	2	No	0,00	0,00
Travel from site to office (near track)	Service personnel	Nighttime	2	No	0,50	1,00
Documentation verification	Work planner	Daytime	1	No	0,67	0,67
				∑	**5,48**	**10,04**
Total manhours 4 switch measurements/night	10,04					
Total hours of railtrack occupancy 4 measurements	2,81					

Figure 13, Calculations of estimated time after implementation of robot inspection

Table 5, Work capacity and stations sizes

Work capacities and station sizes	
Capacity/Speed	4 swithes/shift
Lund C	39 switches
Alingsås	17 switches

Table 12 presents the calculations made with a description of how the calculations were made.

Table 6, Calculations of time savings after transition to robotized inspections

	Lund C (B5)	Alingsås (B3)	**Description**
Number of inspection per year	234	68	Number of switches * Number of inspections related to priority classification
Number of shifts per year	59	17	Number of inspections per year/switches inspected per shift (4)
Current time spent per year (h)	448	130	Total duration of shift (Figure 9) * Number of shifts
Hours spent with robot per year	321	93	Total duration of shift (Figure 10) * Number of shifts
Hours saved with robot per year (h)	127	37	Current time - Time spent with robot

The main result is that there are potentially 127 and 37 hours to be saved annually by performing geometrical measurements in turnouts with robot.

Finally Figure 12 shows the calculations of the time savings during a year on a station with a similar number of turnouts as the ones studied, and with the inspection classification B3 and B5 (4 inspections and 6 inspections annually).

In an interview conducted by the Norwegian website utdanning.no, a track technician was asked about her salary (Delmas, u.d.); (Anon., u.d.). By combining the insights from this interview with statistics on average annual pay for track technicians in Norway, an estimate of the labor costs associated with manual inspections can be derived. According to the statistics, the average pay for a track technician is 544,000 NOK, while the interviewee reported an annual salary of 520,000 NOK. Additionally, the interviewee mentioned the availability of benefits such as overtime pay and allowances, which typically amount to an additional 150,000 NOK per year. The interviewee also stated that she served as a trainee for 1.5 years, and according to salary statistics, trainee track technicians earn approximately 329,000 NOK per year. Over a five-year period, including the education phase, a track technician would earn approximately 2,850,000 NOK. These figures represent the remuneration paid by the contractors to their employees. However, the fees charged by infrastructure managers to the contractors vary depending on factors such as geographical location, climate, traffic load, and type of traffic.

5 Discussion

The findings of this study demonstrate that the integration of robotics and automation in railway maintenance processes offers notable advantages in terms of safety and time efficiency. The adoption of these technologies has the potential to enhance both worker safety and operational efficiency.

Regarding cost analysis, obtaining precise estimates for the current costs associated with manual maintenance tasks proved challenging. However, the calculations presented in this thesis indicate significant time savings achieved through the implementation of robotics and automation. Moreover, existing studies suggest that transitioning to more predictive and condition-based maintenance practices can lead to substantial cost savings. The utilization of robotics and automation facilitates this transition by enabling more efficient data analysis and allowing for increased inspection frequency due to reduced task durations.

While the focus of this thesis has primarily been on the geometrical measurements of turnouts, other maintenance activities such as lubrications and VUL-measurements have also been mentioned in passing.

An implementation of a track robot that also can perform measurements and continuous localization measurements of the track position seemed to have several advantages. Firstly, it would mitigate the physical strain on workers' bodies caused by bending over to take measurements and walking on ballast. This could lead to reduced injuries on the knees and ankles and reduced physical strain in the back. Second, the risk of pinching injuries during repositioning of the turnout would be mitigated because the measurements would be done by the robot, eliminating the need for workers to be in the turnout. Finally, by removing the workers from the track area during the measurements which normally takes a lot of time, this reduces the risk of being hit by vehicles.

One significant challenge highlighted by the participants in the interviews was the limited availability of track time for conducting maintenance and inspections. The calculations performed in this study revealed that work shifts in the track can be reduced by 1.5 hours, addressing this challenge, and potentially increasing productivity/frequency.

5.1 Limitations

A limitation of this study is the inability to provide an accurate cost estimate for the implementation of robotics and automation and the subsequent cost benefits. However, the estimations presented in this thesis, based on information provided by robot manufacturers.

To enhance the validity of the findings, future research could involve direct comparisons between robotic and manual measurements of turnouts in terms of time and accuracy. This empirical approach would provide a more accurate benchmark for evaluating the performance of robotic systems, complementing the estimates and projections utilized in this study.

6 Conclusions

In conclusion, the findings of this thesis demonstrate a growing willingness within the railway industry to embrace the robotization and automation of inspection and lighter maintenance tasks. The potential benefits, both in terms of time and cost savings, are widely recognized, given that maintenance expenses account for a significant portion of operational costs. By implementing robots for turnout inspections, considerable time savings can be achieved, allowing for increased frequency and improved maintenance practices. The automation of associated processes streamlines documentation and analysis, enhancing overall efficiency and enabling a shift towards preventive and condition-based maintenance strategies.

The robotics and automation industry are well-positioned to support the adoption of these technologies, with industrial robotics becoming more feasible than ever before. The calculations from the data analysis showed that 127 hours in this example Lund, and 37 hours in this example Alingsås could be saved by robot inspections, and the double of that in terms of manhours.

Field studies provided valuable insights into the challenges faced by railway personnel and highlighted the potential for improved ergonomics and reduced safety risks through robotization. By minimizing physical stress and reducing the risks associated with accidents and machinery, robots can create safer working environments for the service personnel.

Overall, the implementation of robotized turnout inspections presents a significant opportunity to optimize maintenance practices and enhance operational efficiency. It is crucial for the railway industry to carefully evaluate the costs associated with implementation and maintenance while considering the long-term benefits and potential return on investment. With the right strategies and proper utilization of robotics and automation, the industry can achieve safer and more efficient maintenance practices, leading to improved infrastructure performance and service delivery.

Significant cost savings can potentially be achieved through the increased utilization of condition-based maintenance and condition monitoring practices. By adopting these approaches, expenses related to the replacement of expensive components that have been excessively worn out and not adequately maintained discussed in chapter 2.9 can be reduced. Moreover, the overall costs of maintenance work can be optimized. Emphasizing condition-based strategies allows for a more targeted and efficient allocation of resources, resulting in financial benefits and improved cost-effectiveness.

7 References

Anon., u.d. *Utdanning.no.* [Online]
Available at: https://utdanning.no/yrker/beskrivelse/banemontor

Arbetsmiljöverket, 2023. *Arbetsmiljöverket.* [Online]
Available at:
http://webbstat.av.se/QvAJAXZfc/opendoc.htm?document=accesspoint%5Carbetsskadestatistik.qvw&host=QVS%40vmextapp02-hk&anonymous=true&sheet=SH_Avancerad
[Använd 20 Maj 2023].

B.L. Luk, K. L. A. C. D. C. S. C., 2006. *Tele-operated climbing and mobile service robots for remote inspection and maintenance in nuclear industry,* u.o.: u.n.

Baddeley, A., 2010. *Working memory,* u.o.: u.n.

Delmas, B. H., u.d. *Utdanning.no.* [Online]
Available at: https://utdanning.no/tema/yrkesintervju/banemontor

Budai, D. H. a. R. D., 2004. *Scheduling Preventive Railway Maintenance Activities,* u.o.: u.n.

Hassankiadeh, S. J., 2011. *Failure Analysis of Railway Switches and Crossings for the purpose of Preventive Maintenance,* u.o.: u.n.

IEA, 2019. *The future of Rail,* u.o.: u.n.

Jernbaneverket, 2016. *Estimering av kostnadsrivere for vedlikehold på jernbanen,* u.o.: Jernbaneverket.

Lidén, T., 2015. *Railway Infrastructure Maintenance - A Survey of Planning and Coducted Research,* u.o.: u.n.

Liu, B. L. a. K., 2006. *Tele-operated climbing and mobile service robots for remote inspection and maintenance in nuclear industry,* u.o.: u.n.

McKinsey, 2016. *Huge value pool shifts ahead – how rolling stock manufacturers can lay track for profitable growth,* u.o.: McKinsey.

McKinsey, 2020. *using analytics to get European rail maintenance on track,* u.o.: Mckinsey.

National Audit Office, 2015. *A Short Guide to Network Rail,* u.o.: u.n.

Papaelias, M. o.a., 2016. *Online condition monitoring of rolling stock wheels and axle bearings,* u.o.: University of Birmingham.

Peng, F., 2011. *Scheduling of Track Inspection and Maintenance Activities in Railroad Networks,* u.o.: u.n.

Prateek Prasanna, K. J. D. N. G. B. B. B. H. M. L. M. I. R. S. L. a. H. P., 2016. *Automated Crack Detection on Concrete Bridges,* u.o.: u.n.
railwaysignalling, 2017. *Corrective, Preventive and Predictive maintenance for railway applications.* u.o.:u.n.

Randika K.W. Vithanage, C. S. H. a. A. K. D., 2019. *Importance and Application of Robotic and Autonomous System (RAS) in Railway Maintenance Sector: A Review,* u.o.: u.n.

Ronny Salim Lim, H. M. L. Z. S. a. W. S., 2011. *Developing a Crack Inspection Robot for Bridge Maintenance,* u.o.: u.n.

Rowshandel H, N. G. D. C. R. C., 2013. *An integrated robotic system for automatic detection and characterisation of rolling contact fatigue cracks in rails using an alternating current field measurement sensor.,* u.o.: u.n.

SINTEF, 2020. *Sensorvalg BaneRobot Rapport,* u.o.: SINTEF.

Trafikveket, 2019. *Handledning Besiktningsplan,* u.o.: u.n.

Trafikverket, 2021. *Trafikverket.se.* [Online]
Available at: https://bransch.trafikverket.se/tjanster/system-och-verktyg/forvaltning-och-underhall/Ofelia/

Trafikverket, 2023. *Trafikverket.se.* [Online]
Available at: https://bransch.trafikverket.se/tjanster/system-och-verktyg/forvaltning-och-underhall/Bessy/
[Använd 2023].

Yaguchi, H., 1995. *Robot introduction to cleaning work in the East Japan Railway Company, Advanced Robotics,* u.o.: u.n.

Øyvind Netland, G. J. H. M. S. a. A. S., 2013. *An Experiment on the Effectiveness of Remote, Robotic Inspection Compared to Manned,* u.o.: u.n.

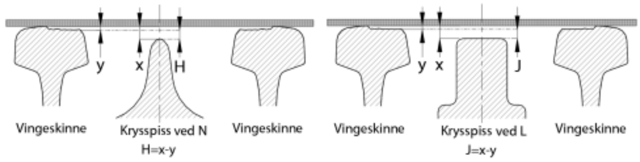
8 Appendices

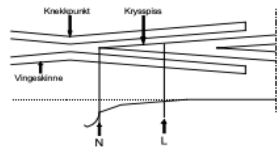
How many times are turnouts inspected?	The frequency of turnout inspections and the routines for these, it was found that the frequency varied depending on the traffic load, but generally turnouts were inspected twice a year with some being inspected three or four times per year.
How is an inspection normally carried out?	The routines involved visual inspections, lubrication, and measurements.
What is the biggest challenge during your work?	Gaining access to the track was the biggest challenge. Additionally, if the track was not fully cast and that some smaller tasks sometimes was given less attention.
How do you ensure that the facilities are maintained in time?	weekly updates are provided on tasks and activities. The regulations set by BaneNor decide on the intervals for inspections and maintenance.
How is safety in the ensured?	through the allocation of resources, the appointment of a safety manager, and the rule that a minimum of two people should be present during each task. Before any work is carried out in a “new” area, or if the conditions on a familiar area has changed, a “safety work analysis” is carried out to evaluate the possible risks of safety.
How is the data of the facilities used and how is the communication between contractor and administrators?	information is used during the activities, and the state of the facility is updated and sent back to the

	administrators after the work is carried out.
What are the typical fault that comes of too few inspections?	neglected drainage, pits, and vegetation.
How does inspections in tunnels differ from inspections in the regular tracks?	largely similar, but smaller leaks and ice problems in the tunnels could result in difficulties. Additionally, escape routes, signs, and lighting were present in tunnels and not in regular track inspections. The frequency of inspections was not reported to differ in tunnels.

Appendice A

BANE NOR Teknisk regelverk	**OVERBYGNING** Regler for vedlikehold **Sporveksler** Inspeksjon av enkel sporveksel	Vedlegg: b Revidert: 01.06.22 Rev.: 5 Side: 1 av 2





Sporveksel nr.____________________ Stasjon: ____________________________________

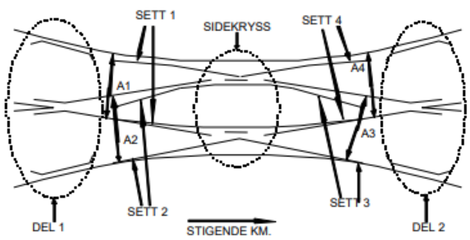
Bane Id. ____________________ Km: ______________________

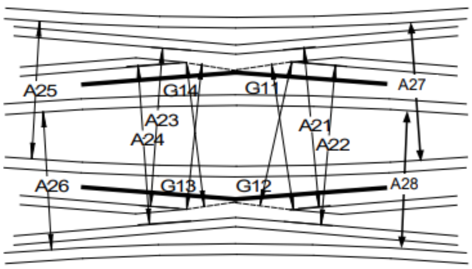
Kontrollmål	Normalmål i flg. tegning	Toleranser (mm) (i hht. kap. 11)	Målte verdier (mm)	Avvik (mm)
A1 (ved tungespiss)				
A5 (tungeparti)				
A7 (tungeparti)				
A9 (mellomparti)				
A10 (mellomparti)				
A11 (kryssparti)				
A12 (kryssparti)				
B1		≥ 110/160 [1)]		
B2		≥ 110/160 [1)]		
C1		≥ 58		
C2		≥ 58		
G1				
G2				
F1		≤ 1370		
F2		≤ 1370		
F3		≤ 1370		
F4		≤ 1370		
H				
J				

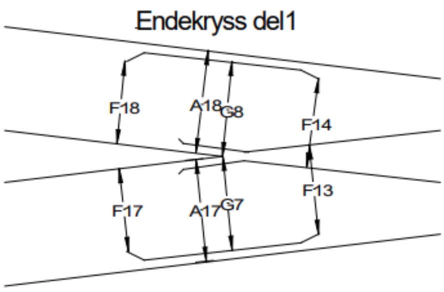
Bok 532

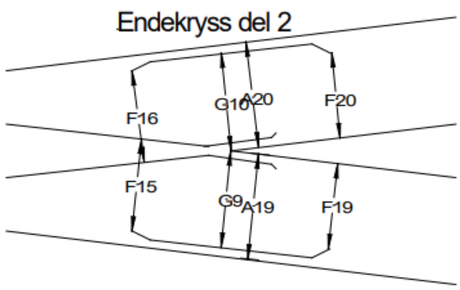
Appendice B

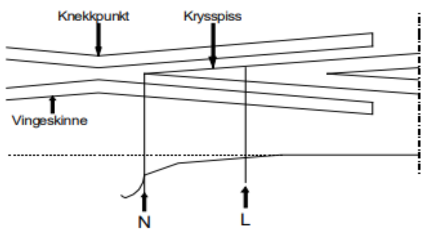
BANE NOR Teknisk regelverk	**OVERBYGNING** Regler for vedlikehold **Sporveksler** Inspeksjon av kryssveksel	Vedlegg: Revidert: Rev.: Side:	c 01.09.21 5 3 av 4

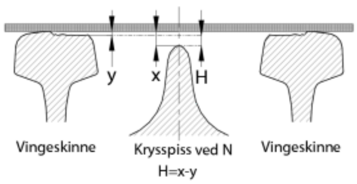


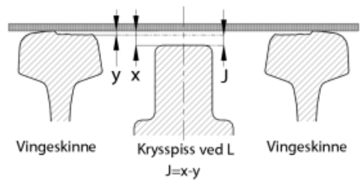












Appendice C