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# Investigating the Effect of Trackwork on Punctuality of Swedish Railways

Master's thesis in Project Management

Supervisor: Nils Olsson

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## SUMMARY

Railways are one of the important modes of transportation and providing punctual and reliable services is the main quality factor of railway industries. In order to improve competitive advantages in the rapidly changing transportation market and to obtain a well-functioning transportation system, study of different variables influencing the punctuality of trains will need to be undertaken.

The main purpose of this study is to develop an understanding of the relation between trackwork and train punctuality.

To compile and upgrade the existing knowledge and experiences regarding the effect of trackwork on punctuality of railways both qualitative and quantitative approaches have been followed through reviewing the literature and analysing the punctuality and historical data. The study is also a pilot on combining railway traffic data and maintenance data for analytical purposes. This type of analysis can later show how different types of trackwork influence punctuality.

Previous studies on this subject have mainly utilised causes of delay data. In this study, we have found methods to complement such analyses also by taking into account the high-resolution data available from registered records of train movements. The current study illustrates how such time data can be utilised in order to enhance the decision support system for maintenance.

A data processing method is used to identify trains and line sections exposed to trackwork. A search engine is designed in order to correlate the two datasets (including train traffic data and trackwork data) and to extract the required data for the analysis. Through the overlap between the duration of trackwork and the delay in departure time, it is demonstrated that it is possible to combine railway infrastructure data with train traffic data.

As a result of this analysis, it is discovered that for railway traffic, in general, trackwork is related to 14.8% of all causes of delays. However, a relatively large share of the trackwork was related to train delays. Another important finding from this study is that, when trackwork are conducted, it is a high probability that there will be delays in train schedules and these delays are relatively large.

Apart from the result, it has been experienced that there is a need for more investigation with sufficiently updated data and some suggestions have been mentioned in the further research to

evaluate the railway system more precisely. Nevertheless, this thesis, provides the readers general view regarding the analysing different datasets and their strength and weaknesses which will aid in more efficient analysis.

### **Keywords**

punctuality analysis, railway timetable, maintenance trackwork, influencing factors



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The study was initiated after a former specialization project with the same topic. there was abundant room for further investigation and progress in determining the effect of trackwork on train punctuality in the work which has been carried out as a specialization project.

Herewith, I would like to express my gratitude to my supervisor Professor Nils Olsson, for the inspiring guidance, continues support, useful comments and contributions during the course of carrying out this research.

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## Abbreviation

<b>GPS</b>	Global Positioning System
<b>IM</b>	Infrastructure Manager
<b>MCs</b>	Maintenance Contractors
<b>NPV</b>	Net Present Value
<b>PIMS</b>	Punctuality Improvement Method System
<b>PRC</b>	Passenger Ride Comfort
<b>TOCs</b>	Train Operating Companies
<b>TSR</b>	Temporary Speed Restrictions
<b>TTC</b>	Train Traffic Control



# 1 INTRODUCTION

## 1.1 Background and motivation

The Swedish national railroad system consists of many different and connected parts, which is used for freight and passenger transportation in which political and social considerations including the safety and environmental impact, public demands for safe as well as reliable and cost-effective transportations should be taken into account Åhrén and Parida (2009).

Important stakeholders of the Swedish railway are train operating companies (TOCs), infrastructure manager (IM) who is in charge for train traffic control (TTC) and the timetables scheduling, the maintenance contractors (MCs), the customers and public subsidisers Nyström (2009).

The increasing demand for transportation makes railways attractive. However, railways face a challenging situation with the need for infrastructure maintenance and increased traffic. Also, in order to remain competitive in the transportation business, the railway industry needs to be cost-effective and provide reliable service. The reliable service is to a great extent entwined with train punctuality and regularity. punctuality is known as a key performance indicator. It relatively indicates to what extent the transportation system manages to deliver transports on time according to the timetable. to this aim, specified performance characteristics should be provided Granström (2005).

The railway infrastructure consists of a large set of interdependent systems and components including tracks, switches, signalling and power distribution and overall, there is a need for continuous improvements in the infrastructure. According to Li et al. (2013), appropriate infrastructure leads to more accessibility of trains, longer operating hours, and achieving better punctuality. At the same time, reducing the available infrastructure may decrease the precision of the originally planned timetable which constitutes one of the major train timetabling problems.

Trackwork plays an important role in the punctuality of trains. This view is supported and investigated by Åhrén and Parida (2009) who developed an approach for analysing the factors influencing the performance of railway infrastructure. On the one hand, carrying out the maintenance (the trackwork) may be a cause of delay, it can also result in avoiding future delays. There is, therefore, a definite need for more investigation regarding punctuality influencing factors with the aim of effective scheduling.

Several key features can be investigated to determine how trackwork affect train punctuality. Unpunctuality may arise as a result of different factors including reduction in speed Van der Kooij et al. (2017), disturbances from train movements supplying the trackwork and situation in which the entrepreneur is not ready in time or timetable is not fully adjusted to the trackwork Parbo et al. (2016).

There have been empirical analyses of train punctuality, such as the work by Palmqvist et al. (2017b), and work on trackwork, such as Lidén (2018). This study combines these two areas to investigate the effect of trackwork on train punctuality, with the aim of improving the train performance. As pointed out by Lidén et al. (2018), train services and maintenance tasks should ideally be planned together, for optimal capacity utilisation and operational predictability.

In general, there are two types of data for investigating railway punctuality empirically: time registration data and causes of delay data. In this study, the focus is on the time registration data. Time data is available in larger data volume and it is relatively high quality which shall not be underutilized. Most of the analyses, in general, are based on delay causes data which are somewhat less accurate than time registration data. Sørensen et al. (2017) observed notable differences between these two types of data. Registration of time is automatic while the delay registration is performed manually, and it is based on the registrar judgement, not to mention the existence of inevitable human errors. Moreover, the registration of delays is often accompanied by the information regarding the responsibility of delay, the matter that has been always a controversial issue.

Previous studies on this subject have mainly utilised causes-of-delay data (Olsson and Haugland 2004, Mattsson et al. 2007, Peng et al. 2007, Jiang et al. 2010). In this study, we have found methods to support such analyses also by taking into account the high-resolution data available from registered records of trains arrivals and departures. The current study illustrates



how such time data can be utilised in order to enhance the decision support system for track maintenance.

## **1.2 Problem Definition and Objectives**

The main purpose of this study is to develop an understanding of the relation between trackwork and delays. The study is a pilot on combining railway traffic data and maintenance data for analytical purposes. This type of analysis can later show how different types of trackwork influence punctuality.

One of the objectives of the current study is to propose a method for utilising high-resolution time data. This approach can also contribute to quality assurance and additional information for the delay cause registration.

This thesis addresses the following research questions:

1. What are suitable methods for analysing the relation between trackwork and train delay?
2. What is the distribution of delays in general, and how it is related to trackwork in particular?
3. What is the relationship between trackwork and delays (of the studied line section)?
4. What is the magnitude of delays related to trackwork?
5. What is the share of different types of trains?

In order to answer these questions, the research focuses on three areas:

1. The connection of timetable and trackwork datasets based on scrutiny of the required data to distinguish the trains expose to the trackwork
2. Exploration of statistical analysis and data visualization for line sections in order to give a holistic picture of the influencing factor on punctuality.
3. Evaluation of the types of trains to develop an understanding of the database and the relation between delays and the types of trains.

## **1.3 Scope and limitations**

This thesis focuses on the duration of train traffic and maintenance activities and therefore, it is less concerned with the effect of the maintenance type and the detailed cause of delay on the train punctuality. These are of course equally important fields of study. Since railway systems, consists of mutual interactions between the different and complex sub-systems, there are a complicated collection of different factors which affect the overall performance of the system. investigating one variable without considering the effect of other

influential factors cannot provide a comprehensive review of the system. Therefore, not all the improvements in the punctuality can be related solely to the trackwork. However, another potential problem is that the scope of the thesis should not be too broad. Besides, limitation of time and data always influence the results of researches.

In terms of database, this study is limited by the lack of information about stations in trackwork data. Therefore, investigating the exact location of trackwork is beyond the scope of this study.

Despite the fact that the data base used in this study contains comprehensive amount of data, it is however limited to a specific geographical location. Therefore, caution must be taken, as the findings might not be directly transferable to all countries. The findings are probably most relevant to regions with a mix of urban, regional and long-distance trains, and integration of passenger and freight traffic.

#### **1.4 Thesis structure**

In the following chapters, the structure of the thesis is organized as follows: Chapter 2 explains the various theoretical concepts associated to train punctuality. Chapter 3 provides a literature review regarding the challenges and improvements in train punctuality and maintenance. The methodology of the current study is explained in Chapter 4. Chapter 5 is dedicated to the results and discussion. The final conclusions are presented in Chapter 6 followed by suggestions for further research.

## 2 Theoretical concepts

In this chapter the fundamental theoretical concepts as well as the accurate definition of some technical terms associated to the study of train punctuality are explained. These concepts include punctuality and delay, timetable, cancelled train, and time plan graph.

### 2.1 Delay and Punctuality

Delay and punctuality are two interchangeable terms which present measures of precision in the train traffic. Both factors are based on deviations of actual train arrival/departure data from the planned timetable.

Delay is an important factor which has considerable impacts on customer satisfaction and reduction in delay has always been the main concern for train operators Barron et al. (2013). In general, delay happens when the task is performed later than the Planned timetable, in other words, it is the time difference between the scheduled and actual travel time Dingler et al. (2010). According to Olsson and Haugland (2004), delay can also be measured by calculating the negative deviation from the timetable in minutes or any time unit. For instance, if actual departure is later than planned departure, this negative deviation from planned departure is considered as delay.

In contrast to punctuality, delay can also be measured along the track as well as in the final destination. It is worth mentioning that train can apply a higher speed on specific parts of its journey. So, train might be punctual in the final destination in spite of having delay along the path Nicholson et al. (2015).

Delay can be divided into two main types: primary delay and secondary delay. Primary delay is a deviation from a scheduled time caused by disruption within the process whereas secondary delay is the delay caused by waiting for other delayed trains or conflicting train paths Goverde (2005). From the explanations above, it can be concluded that the secondary delay is influenced by the primary delay.

Other important terms related to delay which are frequently used in the literature, are departure and arrival delay. Departure delay is computed as the difference between the measured departure times and the scheduled departure times according to the train timetable. Arrival delay is defined as the difference between the measured arrival times and the scheduled arrival time in a similar way.

Punctuality is a measurement of operational reliability and is one of the most important quality indicators in railroad operations (Nyström 2009, Parbo et al. 2013, Palmqvist et al. 2017b). Hansen (2001) defines punctuality as the percentage of trains passing, arriving or departing at given locations of the railway network no later than a certain time in minutes.

According to Veiseth et al. (2011), the punctuality of railway systems increases the satisfaction of railway customers. Olsson and Haugland (2004) define punctuality as percentage of punctual trains which is measured by dividing the number of punctual trains by the total number of trains in which cancelled trains are not included.

Different railways have different definitions of punctuality. For instance, railway authorities sometimes define punctuality for departure and arrival separately, and punctuality as the share of trains within the defined tolerance. The tolerance varies between countries and even the length of travel Nyström (2008). For example, the threshold for delay in many European railway systems is 5 minutes while it is only 3 minutes in the Netherlands. The delay the delay limit in Japanese train system might be down to seconds and not even minutes.

While a variety of definitions of the term “punctuality” has been suggested, this study has been focussed on definition presented by Olsson and Haugland (2004) and other time deviation measures like statistical standard deviation and average. It worth to mention that calculating the average of all scheduled stops also gives a holistic picture of punctuality.

Zakeri and Olsson (2017) demonstrated that the departure punctuality is strongly correlated to delays and punctuality in the Norwegian railways' network.

## **2.2 Timetable**

One of the main planning tasks on the tactical level is train scheduling. A timetable is defined by Van Aken et al. (2017) as arrival and departure times at stations and some important locations such as junctions which are connected by a set of dependencies. It represents train running times and infrastructure constraints. In timetables, train services are usually repeated on a periodic basis. The timetable is the schedule that describes where and at what time a specific transport is to be located. Timetable can be seen as a sort of agreement between the train operators and the infrastructural manager Granström (2005).

Finalizing yearly timetable is a time-consuming process. Requests need to be integrated from multiple and sometimes competing operators. Freight and passenger trains are mixed, and the infrastructure permits traffic in both directions. there is a lack of capacity on the tracks during peak-hours and the traffic must be planned differently there Andersson et al. (2011).

## 2.3 Time Plan Graph

Scheduled train traffic at different stations/intersections represented schematically on Time Plan Graph on Trafikverket webpage. Graphical route diagrams are used for monitoring the operations. The vertical axis describes distance on the line, the horizontal axis describes time along the line. The diagram also shows the train number and the train path (Figure 1). This visual representation of scheduling aids train controllers to monitor and manage daily operation activities and it eases to check all changes in the schedule.

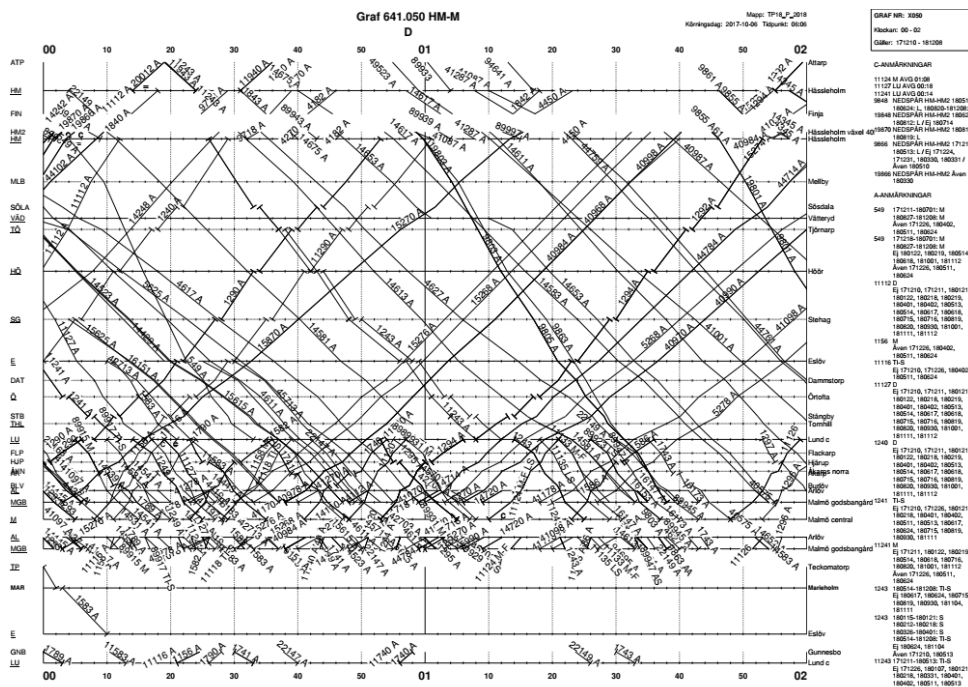


Figure 1: Time Plan Graph (Trafikverket, 2018)

## **2.4 Cancelled trains**

The term ‘cancelled train’ simply means, the train not travelling its planned route. In other words, a cancelled train is a train that does not reach on the final destination. A cancelled train is not recorded as a delayed train. The cancellation of a train may affect the schedule of another following train.

It is important for infrastructure maintainers to know when train operating companies (TOCs) cancel the trains. So, maintainers have the advantage of having longer, continuous track access Nyström (2005) which leads to improvement in track availability.

## **2.5 Maintenance**

Maintenance refers to the combined technical and managerial actions during the life cycle of an object Granström (2005). Two main categories of maintenance are corrective maintenance and preventive maintenance. Preventive maintenance (PM) is divided into predetermined maintenance and condition-based maintenance. Corrective maintenance is performed after detecting fault. In contrast, preventive maintenance is performed before recognising the fault to prevent its consequences.

Although one of the ways of improving punctuality is to perform maintenance on different items in the railway system, maintenance may also cause delays and lead to unpunctuality. It happens when maintenance is performed in an incorrect way or if maintenance of the infrastructure disturbs the traffic Nyström (2008).



### **3 Literature review**

There is a growing literature on how different factors influence train punctuality. Maintenance is one important factor that is desirable to include in such analyses. Here, a literature review on the subject has been performed, the results of which are generally classified under theoretical concepts as well as challenges and improvement in punctuality and maintenance.

#### **3.1 Punctuality; Influencing factors and improvement**

The first part of literature review section provided a brief overview of the theoretical concept, it then goes on to develop an understanding of various factors that influence punctuality and then this thesis will focus on previous studies related to challenges and improvement in punctuality and maintenance.

A considerable amount of literature has been published focussing on the train punctuality to see how different factors affect punctuality in railway traffic. Such factors include passenger, cancellation, weather, rolling stock, timetable, infrastructure, temporary speed restrictions (TSR), operational priority rules and trackwork, (Van der Kooij et al. 2017, Palmqvist et al. 2017b). For instance, according to Aryal and Olsson (2015) number of passengers and occupancy ratio might have an inversed relationship with the punctuality, as punctuality reduces as the number of passengers increases. Another example of punctuality influencing factor is Temporary speed reductions (TSR), railways lines have defined maximum speed, which varies along the line. When the line is not in an appropriate condition, speed is frequently reduced. These reductions in speeds are sometimes demonstrated as one of the major causes of delays. A good example concerning the railway construction work is about the trains which often get delayed during the modification period or extension of railway lines due to lack of enough signalling and information regarding the nature of new railway lines. Obviously, trains are less punctual during constructions period. The increased capacity also leads to enhance punctuality. Due to uncertainties and complexity of the realistic environment of train operation, analyses of how different factors relate to punctuality is a major area of interest within the field of the railway.

There are several studies of factors influencing train punctuality, including (Olsson and Haugland 2004, Palmqvist et al. 2017b). In a Chinese high speed context, Jiang et al. (2010) the main causes of train delays are attributed to locomotive/train factors, and infrastructure factors. Other studies of punctuality influencing factors include Gorman (2009) who studied



which factors contributed the most to delays for freight trains in the US. He pointed out that congestion was the primary cause for delays because the number of meets, passes and overtakes consistently had the highest impact on punctuality.

Investigating the causes of low punctuality of trains is an essential step for improving the punctuality. Improvement of punctuality is mostly the same as the improvement of any other aspect of quality. The challenges of punctuality in practical and scientific perspective were expressed by Veiseth et al. (2011), they proposed a method to organize and accomplish punctuality improvement. Nyström (2005) demonstrated the actions to reduce the causes of delay including stable indicators on punctuality and maintenance as well as using historical data as a rear mirror approach.

Different strategies could be obtained in order to improve the quality of punctuality data. One is to make the causes of delay data system more transparent through motivating and training the people who register the information. Another way is to use additional data sources, e.g. linking the information from different databases Van der Kooij et al. (2017). Palmqvist et al. (2017a) also suggested that the quality of punctuality data could be improved by connecting it with infrastructure databases.

Veiseth et al. (2011) represent that data availability for benchmarking and performance measurement is a common challenge of improvement in punctuality.

In another study, Lusby et al. (2011) discussed the problem of train routes “track allocation” from a strategic, tactical, and operational perspective and reported that effective coordination of the movement of trains on a railway network is a major part of the railway planning process.

Ceder and Hassold (2015) investigated New Zealand rail-network operations. The results demonstrated that the efficiency of operations could be improved by using different crew schedules and accurate passenger demand estimation. It is also noted that there exists a strong correlation between delays and the time of day for each line.

Landmark et al. (2017) focused on analysis related to the line, time and selected trains to show relevant dimensions as alternatives for visualisation and analysis of railway punctuality data in order to identify punctuality improvement measures.

Veiseth et al. (2011) examined a systematic collection of methods called PIMS (Punctuality Improvement Method System) comprise techniques and tools to support the

implementation of a joint method for punctuality improvements in the Norwegian railway sector.

Lidén (2014) reported that some countries like Sweden might allow maintenance work to be carried out on a parallel track if the train traffic meets the defined speed limitation. In addition, Palmqvist et al. (2017c) pointed out that, in terms of infrastructure maintenance, metropolitan lines are heavily utilized in Sweden. Nevertheless, more research on maintenance and railway infrastructure is still needed for more capacity utilization of railway lines.

Veiseth et al. (2011) assumed that several quality improvement work related to punctuality has been carried out in different countries, but not all this work has been published. Famurewa et al. (2015) presented the application of risk matrix as a maintenance analysis method for the identification of track zones that are bottlenecks in the Swedish network which limit operational capacity, punctuality and quality. With the aim of continues improvement in punctuality and railway infrastructure performance, a synthesised system of indicators relevant for maintenance has been presented as the result of their study.

Forsgren et al. (2013) address the challenges related to scheduling and timetable revisions including handling a network with both single and multitrack lines, to allow trains to be rerouted or cancelled, considering different running times depending on train stops. they applied an appropriate approach to solve the scheduling problem.

Granström (2005) demonstrated that the main tool of achieving punctuality is maintenance and that maintenance improvement can be achieved by condition monitoring systems.

### **3.2 Maintenance and Trackwork; Challenges and improvements**

When it comes to trackwork, there exists a wide body of research on railway track deterioration in which many parameters affecting track deterioration are demonstrated. Guler (2013) suggests the developed decision support system in which there exists a possibility to develop planned maintenance and renewal management systems by using measuring systems instead of corrective maintenance and renewal. Stenström et al. (2013) argue for performance indicators and terminology who proposed standardised indicators to find the most essential indicators for the value drivers and for estimation of the net present value (NPV).

However, wrong data from malfunctioning sensors or due to wrong tags is generally seen as a factor related to the decision support system. Before proceeding to improve train maintenance, it is necessary to evaluate the data quality. For this purpose, data cleaning is needed, Thaduri et al. (2015) reported that systems may store the wrong data from

malfunctioning sensors or due to wrong tags like time stamps, GPS, etc. and wrong decisions may be taken based on them. Therefore, new tools and methodologies must be used in order to establish meaningful associations.

As the purpose of developing maintenance performance, various approaches and methods have been used. Simson et al. (2000) argue that track maintenance costs can be reduced by 5 to 10 percent through improved planning.

Al-Douri et al. (2016) reported the increasing trend in traffic which has led to more rapid deterioration of the railway track that has also a profound impact on enhancing maintenance costs. Holmgren (2005) identified maintenance related losses and causes at the Swedish Railway. The findings indicate that maintenance related causes represent 30% of all rail and track related accidents in the database. About 80% of the maintenance related accidents occur during the execution phase. Incomplete communication between the maintenance personnel and operators which lead to lack of information is the most common cause of maintenance-related accidents. The second major causes are rule violations and a lack of permission to accomplish maintenance work on the track.

Lyngby et al. (2008) have mentioned that degradation affects comfort, safety, track quality, reliability, availability, speed, as well as overall railway performance. In order to reduce these effects in their study, proactive solutions have been used which includes analyses based on the calculated values to understand the process of track degradation and required action to improve maintenance decisions.

Related to the optimization of maintenance in the rail industry, Vatn (2008) discusses grouping of maintenance activities into maintenance packages in order to reduce the setup costs. For the aim of optimization of maintenance cost Lidén and Joborn (2016) define quantitative measures which also are applicable for comparing contradictory capacity requests from infrastructure maintenance and traffic operations on railway networks.

Norrbin et al. (2016) hold the view that in the railway industry, most maintenance approaches are based on “specified conditions” while “unfavourable conditions” may occur from either natural or operational causes.

A considerable amount of the literature on railway maintenance pays particular attention to the condition monitoring system. The use of appropriate condition monitoring and maintenance management techniques can create significant improvements in efficiency and directly increase profitability. The efficiency of maintenance depends on the correct decisions

of the key personnel (Granström (2005)). Famurewa et al. (2013) proposed a performance monitoring system. Also, presented a framework to facilitate the implementation of performance-based railway maintenance.

The railway is a twisted system used for both freight and passenger and maintenance is one of the ways to achieve railway reliability, but the inferior maintenance may also cause accidents.

Karakose et al. (2018) proposed a method for fault detection on railway components and condition monitoring through using camera placed on the bottom and the top of the vehicle.

According to Zhang et al. (2018), much of the available literature on railway deal with the integrated optimization of train scheduling and railway maintenance planning with the focus on a small region and the optimization model is formulated at the microscopic level. Their study is much more concerned with long distance railway and large range regular maintenance which is formulated at a macroscopic level.

While it is a common understanding that maintenance is needed for punctuality and a well-functioning railway in the long run, this paper studies how maintenance and trackwork in particular is related to the punctuality in the short run, when it is carried out.

Sadeghi et al. (2017) develop a new railway track geometry conditions index by developing a new algorithm for prioritizing and scheduling maintenance activities, which also takes into account passenger ride comfort (PRC) and required level of track safety.

Regarding the inspection of railway components, Camargo et al. (2011) reviewed condition monitoring systems. They studied visual inspection methods and traditional methods in the United States in which inspections were labour intensive and recording data and monitoring of trend was not easy. with the goal of the emerging technologies in inspection processes, increasing the safety of railway operation and preventive maintenance approach they demonstrated the potential to enhance the inspection of railway infrastructure.

## 4 Methodology

This study is based on combination of railway traffic dataset and trackwork dataset. To begin with, the study shows how punctuality is related to trackwork. By utilising time registrations, we include all delays, including those that have not triggered a Registration of a delay cause. The study solely focuses on trackwork and does not take into account other potential influencing factors. Trackwork and punctuality data have been analysed to some extent elsewhere (Veiseth et al. 2007, Famurewa et al. 2015) , however, there still is a potential to perform further studies in order to algorithms that combine these two types of data and extract additional information from it useful for operational excellence.

### 4.1 Data sets

In order to utilize time data, the present study combines two main datasets, which are the maintenance dataset and the punctuality dataset. The data of the study is provided by the Swedish National Transport Administration. Trackwork data for selected lines in southern Sweden have been collected and made available. Punctuality data originate at Swedish National Transport Administration. The trackwork data originates from IT-system used by train dispatchers to manage train access to different line sections. All performed trackwork in the studied period on the studied lines have been included, both those planned long in advance, and those planned and executed on short notice. All hours of the studied days are included.

The empirical data consists of a dataset containing a record of more than 4500 trackwork registration, and more than 1,156,168 train movements in Sweden during the year of 2015. The study period is 5 months, from the beginning of February to the end of May.

The punctuality data contain arrival and departure of the trains for the same time period and line sections in Sweden, and the maintenance data contains information on trackwork data. These two datasets have been analysed and correlated to each other which is explained below.

Railway lines in southern Sweden were the major area of interest. The tracks in the South Traffic Zone have been categorized into different line sections. This study has included 8 line sections that are listed below.

List of all included stations is shown in Table 1.

Table 1: Studied railway line sections in southern Sweden

<b>Line section</b>	<b>Station</b>
<b>HM</b>	Bjärnum-Hässleholm/Mellby-Hässleholm/Attarp-Hässleholm/Finja-Hässleholm
<b>ALLU</b>	Tornhill (Gunneshö) -Lund c-Flackarp-Hjärup-Åkarps norra-Åkarp-Burlöv-Arlöv
<b>BRON</b>	Hyllie-Lernacken/Svågertorp-Lernacken/Peberholm-Lernacken
<b>ÖVN</b>	Jordholmen-Skytts Vemmerlöv-Trelleborg-Lockarp-Hyllie-Lockarp-Malmö Godsbangård-Jordholmen-Malmö Persborg-Fosieby-Östervärn
<b>LUHM</b>	Lund c-Tornhill-Stångby-Örtofta-Dammstorp-Eslöv-Stehag-Höör-Tjörnarp-Vätteryd-Sösååla-Mellby
	Teckomatorp-Eslöv-Stehag-Höör-Tjörnarp-Vätteryd-Sösååla-Mellby
<b>LUHB</b>	(Flååie)-(Gunneshö)-(Teckomatorp)-Kåvlinge-Dösåebro-Håljarp-Landskrona Östra-Glumslöv-Rydebååck-Helsingborg godsåbangård
<b>HMAV</b>	Hååssleholm-Båållingslöv-Mosselund-Hååstveda-Osby-Tunneby-Killeberg- Åålmhult-Diö Söådra-Diö-Enerýda-Vislanda-Blåååååge-Alvesta
<b>HBHD</b>	Kungsbacka-Lekarekulle-Ååsa-Frillesåå-Våårö-Varberg-Hamra-Týllered- Torebo-Falkenberg's personstation-Heberg-Bråånnarp-Biskopstorp-Furet- Håålmstads c-Håålmstad Rangeråångård-Kistinge-Eldsberga-Lååholm Vååstra- Bååstad Norra-Åångelholm-Vegeholm-Helsingborg c

Figure 2 shows a simplified map of the studied area in southern Sweden. We highlighted the lines that are included in the study and listed in Table 1 but also indicated some of the other lines in the region. The actual network is relatively complex in this region, therefore, a simplified model of it is presented here (Figure 2) which is easier to understand. In this figure, the abbreviations are those explained in Table 1, and the dashed lines indicate the sections that are not included in the current analysis.

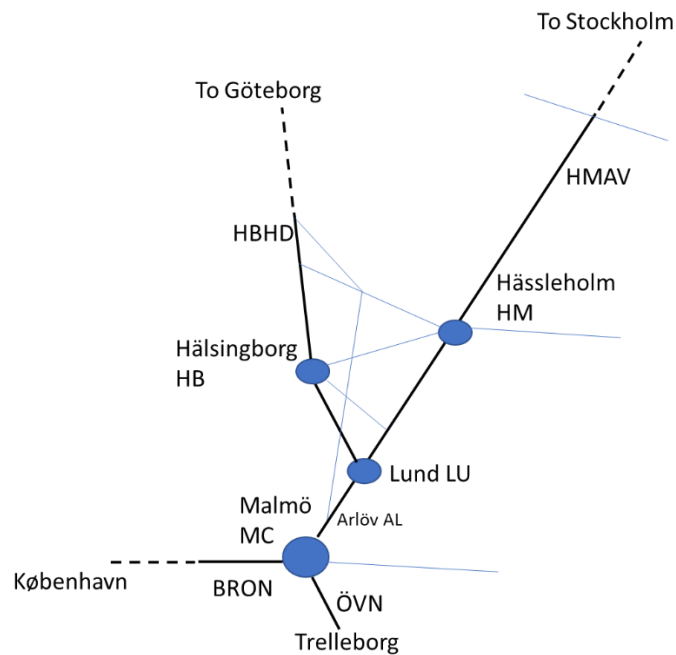


Figure 2: Simplified map of the studied line sections in southern Sweden.

#### 4.2 Identification of trains that are affected by trackwork

For the purpose of preprocessing of data for the analysis, an algorithm is introduced in order to connect the two datasets (train timetable data and trackwork data). The purpose of the algorithm is to identify trains that have passed a line section in the time period that trackwork has been undergoing on that particular line section. In the analysis, then punctuality and delay for trains exposed to trackwork are compared with other trains on the same line section that have not been exposed to trackwork. It should be noted that cancelled trains are not included in the calculations.

Line sections contain a set of stations (between 2 and 23). Punctuality for the trains being directly exposed to trackwork or running close to trackwork has been investigated. Four situations have been identified when a train is defined as being exposed to trackwork. These four situations have been investigated in the algorithm illustrated in Figure 3 and explained below:

1. Trackwork start before planned departure and finish before or at the time of actual departure

2. Trackwork start and finish between planned and actual departure
3. Trackwork start after planned departure and finish after the actual departure
4. Trackwork start before planned departure and finish after the actual departure

Not to mention that if it ends or begins outside the area it does not relate to that particular train.

In order to find the trackwork which is related to delayed departures, the data related to actual departure, planned departure and trackwork have been sorted in a new database. It is then checked whether or not a delay in departure and trackwork has been occurred at the same date and time interval based on aforementioned conditions. If so, the primary key of the trackwork is assigned to that particular departure. Thus, if at least one of the situations is met, a delay in departure related to trackwork is registered.

In other word, in a station, a train is defined as being exposed to trackwork if at least one of the four situations above occur and that the trackwork has been undertaken on that particular line section when the train passed it. Examples of different situations are shown in appendix A.

The logic of the algorithm illustrated in a graphical timetable. Showing both planned and actual time for a train (Figure 3).

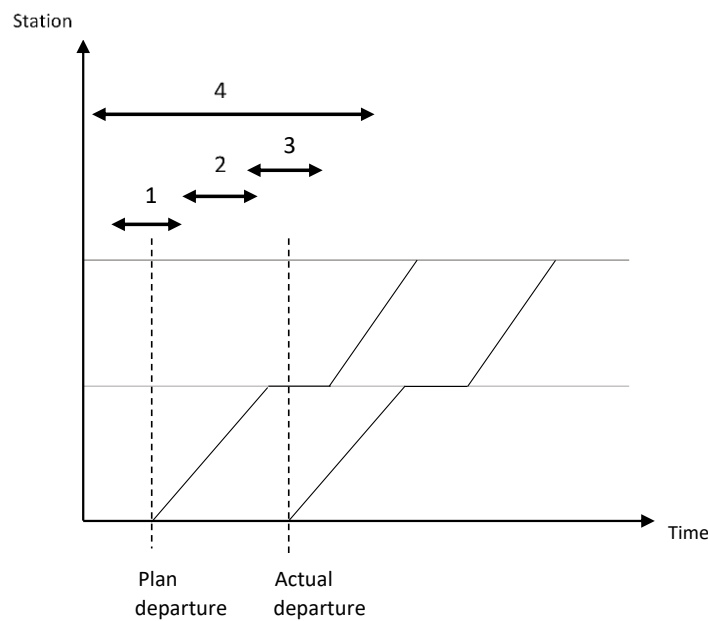


Figure 3: Schematic of the logic of the algorithm

The structure of the proposed algorithm is briefly outlined in Figure 4.



**Proposed algorithm**

**Sort** the train departures by their actual and planned departure times, respectively.

**Sort** the trackwork by their finish and start times, respectively.

**Assign** a primary key to each trackwork.

Start from the first departure.

**While** *all the train departures are not checked* **do**

**If** *the train departure is not delayed*, **Then**

**Go** to the next train departure.

**Else**

Start from the first trackwork.

**While** *all the trackwork are not checked* **do**

**If** *the trackwork and the train departure are related to the same line section*, **Then**

**If** *the trackwork start-time is before or exactly at the planned departure and finish time is after planned and before or exactly at the actual departure*, **Then**

**Assign** the primary of the trackwork to the train.

**Record** the start and finish-time of the trackwork.

**Calculate** the trackwork duration.

**Calculate** the delay duration.

**Exit** the current while loop.

**ElseIf** *the trackwork start-time is after the planned departure and finish time is before or exactly at the actual departure*, **Then**

**Assign** the primary of the trackwork to the train.

**Record** the start and finish-time of the trackwork.

**Calculate** the trackwork duration.

**Calculate** the delay duration.

**Exit** the current while loop.

**ElseIf** *the trackwork start-time is after or exactly at the planned departure and before or exactly at actual departure and finish time is after the actual departure*, **Then**

**Assign** the primary of the trackwork to the train.

**Record** the start and finish-time of the trackwork.

**Calculate** the trackwork duration.

**Calculate** the delay duration.

**Exit** the current while loop.

**ElseIf** *the trackwork start time is before the planned departure and finish time is after the actual departure*, **Then**

**Assign** the primary of the trackwork to the train.

**Record** the start and finish time of the trackwork.

**Calculate** the trackwork duration.

**Calculate** the delay duration.

**Exit** the current while loop.

**Else**

**Go** to the next trackwork.

**End If**

**Else**

**Go** to the next trackwork.

**End If**

**Wend**

**Go** to the next train departure.

**End If**

**Wend**

Figure 4: Outline of the proposed algorithm

### 4.3 Statistics on trains exposed and not exposed to trackwork

Statistical analysis has been used in order to provide a holistic picture of the influencing factor.

Aiming at developing an understanding of the effect of trackwork on the punctuality, the punctuality criteria has been defined as trains departing from stations with a delay. The overall average and standard deviation of daily punctuality are calculated accordingly based on this definition.

The available data has relatively low-resolution regarding the location of trackwork. The data shows that trackwork has been going on at a line section, typically consisting of a limited number of stations. With this dataset, we do not have the exact location, but we know that trains passing the whole section have been exposed to the trackwork somewhere along this line section.

#### 4.3.1 Developing histograms

In order to analyse the deviations from planned departures, a histogram chart is applied for all line sections. To this aim, the range of efficient deviation and the length of the bin should be determined. Therefore, mean of sample ( $\bar{X} = \frac{\sum_{i=1}^N d_i}{N}$ ) and then standard deviation of sample ( $S = \frac{\sum_{i=1}^N (d_i - \bar{X})^2}{N-1}$ ) are calculated. Worth noting that  $N$  is the number of departures and  $d_i$  is the deviation of  $i^{th}$  departure from its planned time is calculated and the deviation in the range ( $\bar{X} - 3S, \bar{X} + 3S$ ) are analysed. Additionally, according to Scott (1979), the length of bins which is applied to draw a histogram is decided by Equation (1): Scott's normal reference rule. The negative and positive values of the bins indicate earliness and lateness from planned departures, respectively. The empirical values are briefly outlined in Table 3. According to the large size of our samples also based on the shape of the histogram, deviation from planned departure is approximately distributed normally and  $\bar{X}$  and  $S$  are in fact the unbiased estimators of the normal distribution parameters  $\mu$  and  $\sigma$ , in a row ( $f(d) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{d-\mu}{\sigma}\right)^2}$  where,  $d$  is deviation from planned departure and  $\mu$  and  $\sigma$  are mean and standard deviation, respectively Miller and Miller (2014).

$$\text{Length of bins} = \frac{3.5 S}{\sqrt[3]{N}} \quad (1)$$

More details can be found in the result section.

## 5 Results and Discussions

This chapter is divided into three main sections, which present the results and discussion relating to the research questions. The results in this Chapter indicate statistics on trains affected and not affected by trackwork. Then, in order to gain more insights into the database, share of different types of trains are investigated. The next section, therefore, moves on to discuss the findings which emerged from the statistical analysis

### 5.1 Statistics on trains affected and not affected by trackwork

The data that is extracted from the database and further used in the analysis can be categorized as:

- Total number of delayed departures and duration (this is a collocated measurement that shows the overall performance of the railway system)
- Duration of delayed departures due to trackwork
- Total number of trackwork and the duration.
- The overlap between punctuality data and delay due to trackwork
- Total number of trackwork leading delayed departure and duration
- Average and standard deviation and some other related parameters corresponded with the aforementioned items
- Comparison of types of trains

Table 2 present simple statistical analysis of line sections which will be discussed in the forthcoming section.

In Table 2, the averages of delayed departures are related to the positive delays, in the other word early departures have not been considered as unpunctuality.

Table 2: Statistics of the line sections

Line	HM	ALLU	BRON	ÖVN	LUHM	LUHB	HMAV	HBHD	Sum
No. of departures	23191	308401	22499	26152	228425	105481	204935	237084	<b>1156168</b>
No. of delayed departures	10658	145565	9767	12408	110025	44736	99150	109072	<b>541381</b>
No. of trackwork	204	280	313	966	1033	414	632	695	<b>4537</b>
No. of trackwork leading to delayed departure	124	207	227	747	812	328	546	627	<b>3618</b>
No. of delayed departures due to track work	552	7942	818	4244	13331	5562	12586	30591	<b>75626</b>
Total duration of delayed departures (minutes)	127883	1334839	119059	269054	1610483	211165	1889417	936669	
Total duration of delayed departures due to trackwork (minutes)	14917	242275	26919	154208	558397	30794	594513	438925	
Average duration of delays in departures (minutes)	12	9	12	22	15	5	19	9	
Standard deviation of duration of delays in departures (minutes)	51	38	46	69	53	15	60	38	
Average duration delayed departure due to trackwork (minutes)	27	31	33	36	42	6	47	14	
Standard deviation of duration of delayed departure due to trackwork (minutes)	88	101	103	103	111	21	114	63	
Total duration of trackwork (minutes)	14396	31555	46813	163275	142521	67264	73026	110150	
Average duration trackwork (minute)	71	113	150	169	138	162	116	158	
Standard deviation of duration of trackwork (minute)	174	120	129	265	119	314	155	161	
Total duration of trackwork leading to delayed departure (minutes)	11311	24062	34374	131411	102178	50771	58754	95912	
Average duration of trackwork leading to delayed departure (minutes)	91	116	151	176	126	155	108	153	
Standard deviation of duration of trackwork leading to delayed departure (minutes)	210	126	131	283	117	290	141	160	

## 5.2 Histograms and related analysis

Table 3 shows empirical values for the complete data set, and **Error! Reference source not found.** illustrate the extreme values. Histogram chart is applied for all line sections, as shown in Figure 5.

Table 3: Empirical values for histogram of the deviations from planned departures

No. of departures:	1,156,168
Mean ( $\bar{X}$ ):	2.31
Standard deviation ( $S$ ):	35.97
Range ( $6.S=205.36$ ):	(-100.46, 104.90)
Length of bins:	1.20
No. of bins:	191

The most frequent bin is the 90<sup>th</sup> bin with 300,466 departures (25.9% of all departures) in which deviations in the interval (-0.05, 1.15] are included. Moreover, the bins 90 to 93 (i.e. deviations in the interval (-1.25, 3.55]) occupy 65.13% of all departures. Hence, it is expected that 34.87% of departures are either more than 1.25 minutes earlier or more than 3.55 later than the planned time. It is worth mentioning, 99.14% of the departures are included in the  $6.S$  range (i.e. (-105.61, 110.23)) and the other deviations out the range are considered as outliers which rarely happen.

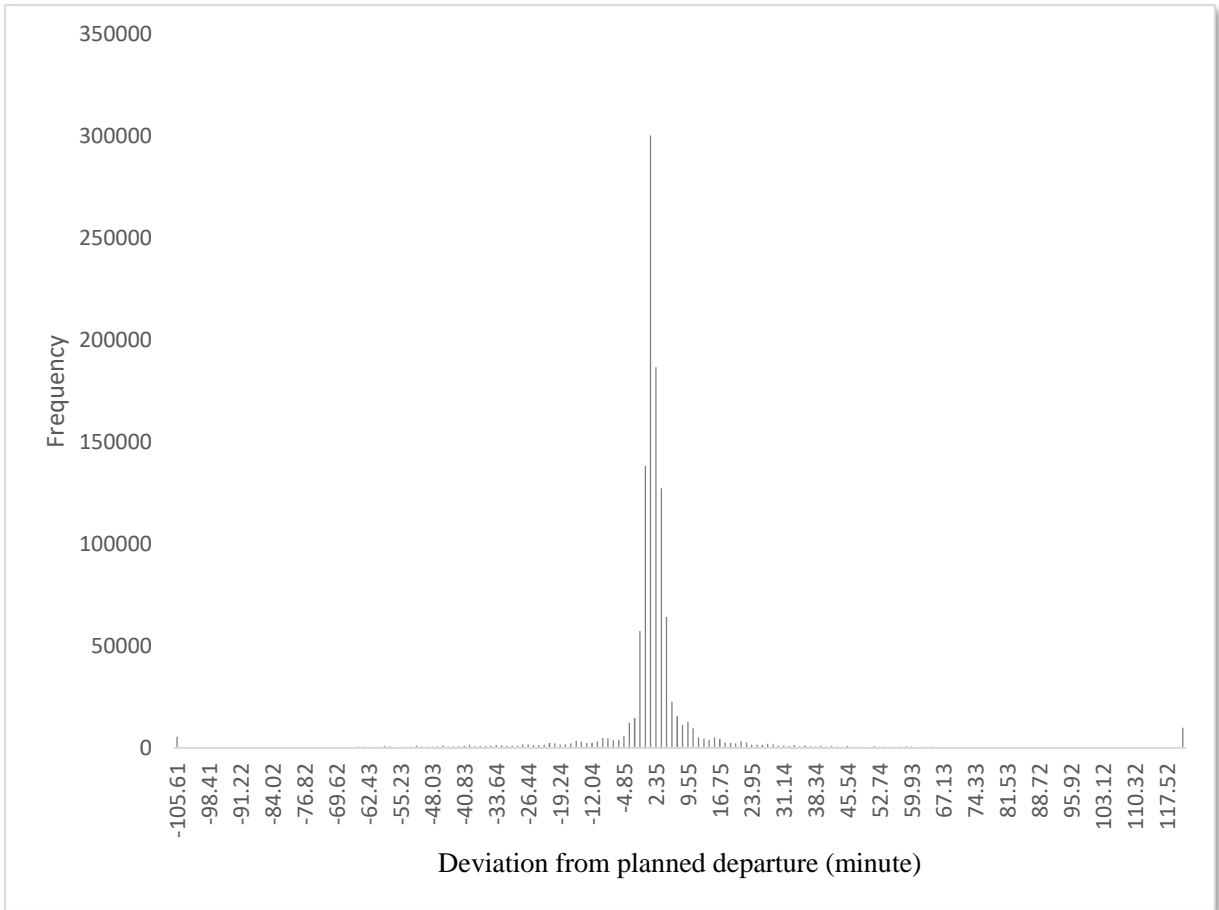


Figure 5: Histogram of the deviations from planned departures

As shown in Figure 6, the histogram diagram is also applied to analyse the influence of trackwork on the delayed departures (i.e. the delayed departures due to trackwork). Therefore, the mean and standard deviation are calculated, and the delays are analysed in the range (0, 6.S). Additionally, the length of bins is calculated by Equation 1. The empirical values are briefly outlined in Table 4.

Table 4: Detailed data for histogram of the delayed departures related to trackwork

No. of delayed departures due to trackwork:	75626
Mean ( $\bar{X}$ ):	27.25
Standard deviation ( $S$ ):	89.64
Range ( $6.S=979.94$ ):	(0, 537.82)
Length of bins:	7.42
No. of bins:	73

Accordingly, the most frequent bin is the first bin with 51240 delayed departures due to trackwork (67.7 % of the delays due to trackwork) in which delays due to trackwork in the interval (0, 7.42] are included. Hence, it is expected that 32.25% of delays due to trackwork exceed 7.42 minutes which shows the necessity of taking the causes into consideration and reducing the unplanned trackwork as much as possible. It is worth mentioning, 99.22% of the delays due to trackwork are included in the  $6.S$  range (i.e. (0, 991.26]) and the longest delay due to trackwork is 1439 minutes later than the planned departure is related to the ALLU, HMAV, LUHM, OVN line sections. The longest duration of trackwork is for the line section ÖVN with 163,275 minutes.

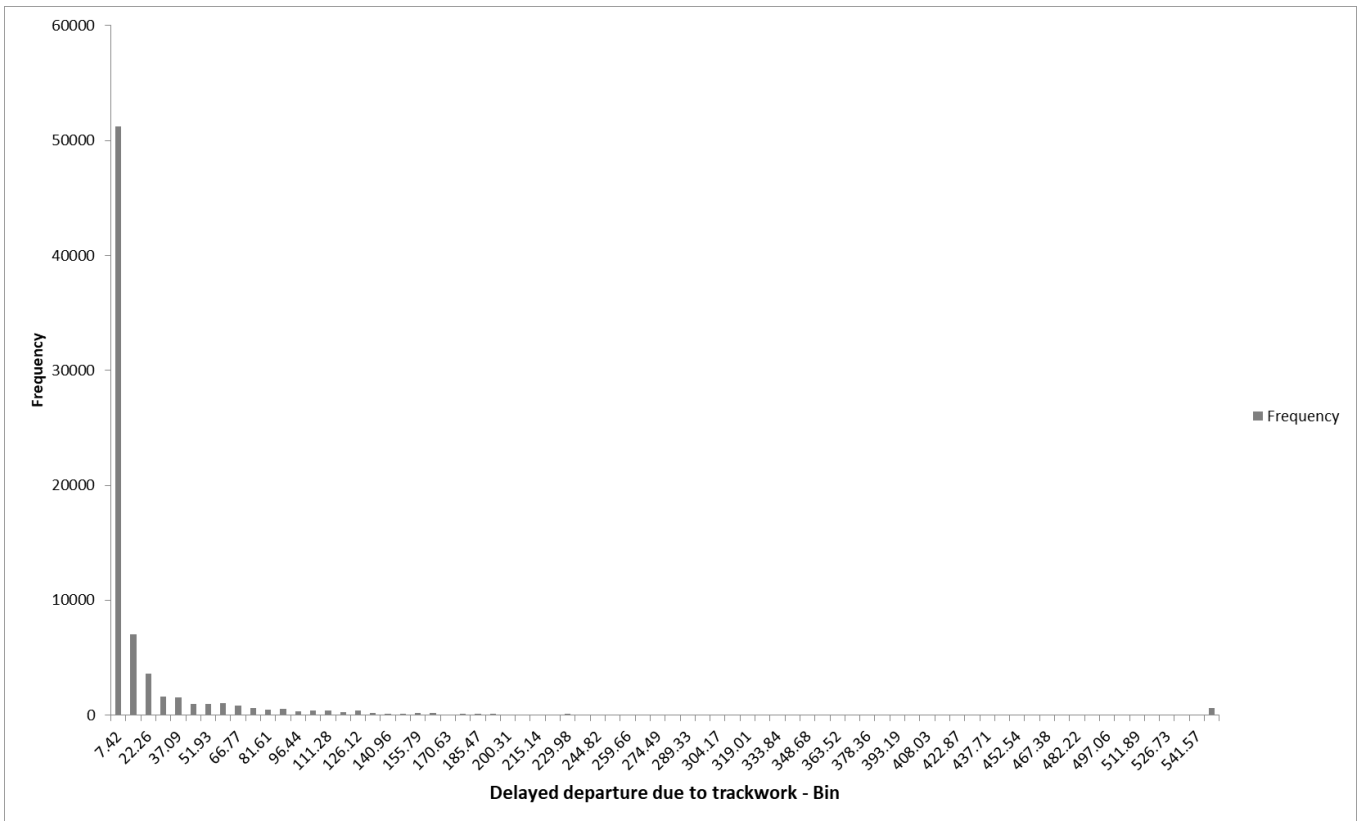


Figure 6: Histogram of the deviations from planned departures due to trackwork

## 5.2 Type of train

In general, a high percentage of departures are related to passenger trains (70% on average). The rate of freight trains and work trains are 24% and 7% respectively. The details of these ratios can be seen in Table 5.

A comparison of the number of delayed departures for one type of train and the number of departures for that particular train and line section also reveals passenger trains have also the highest portion of delay departure in their own group (6% on average). the detailed percentage of each line section and other types of trains are presented in Table 6.

Table 5: Percentage of departures based on type of trains in each line section

Type of train	HM	ALLU	BRON	ÖVN	LUHM	LUHB	HMAV	HBHD	Average
<b>Freight Train (GT)</b>	22%	14%	24%	48%	26%	1%	39%	15%	<b>23.6%</b>
<b>Passenger train (RST)</b>	74%	82%	70%	27%	71%	95%	57%	81%	<b>69.6%</b>
<b>Work train (TJT)</b>	4%	4%	6%	25%	3%	3%	4%	4%	<b>6.9%</b>

Table 6: Percentage of delayed departures due to trackwork in each line section

Train type	HM	ALLU	BRON	ÖVN	LUHM	LUHB	HMAV	HBHD	Average
<b>Freight Train (GT)</b>	2%	4%	4%	8%	8%	4%	7%	6%	<b>5%</b>
<b>Passenger train (RST)</b>	2%	2%	3%	18%	4%	5%	4%	13%	<b>6%</b>
<b>Work train (TJT)</b>	1%	3%	4%	8%	3%	4%	4%	7%	<b>4%</b>

This Percentage for each line section is a comparison of number of delayed departures for one type of train and the number of departures in that particular train and line section



### 5.3 Discussion

The result of this study is summarised and presented in Table 7. The ratio between the number of total delayed departures and the number of delayed departures related to trackwork gives that despite various delays, trackwork has been the cause of a small portion of delays, 14.81%. To begin with, small delays are common in the whole sample. The ratio between the number of delayed departures and the number of departures further reveals that about half of all departures have more than or equal to one-minute delay. The result is remarkably stable for different line sections, only varying between 42% to 48%, with an average of 46 %.

The ratio between the average duration of delayed departures and the average duration of delayed departures due to trackwork (minute) shows that the average duration for delays related to trackwork is more than the average duration of the delayed departure. For all line sections, the delays related to trackwork were between 1.11 and 3.39 times longer than other delays. The results are generally reliable even if long and short delays (delays more than 180 minutes and less than 5 minutes) are filtered away. The results obtained from the preliminary analysis of the lines, thus convey that trackwork in fact, represents a small part of all delays (14.81%), and on average, it is not the main cause of delays. However, when there exist delays due to trackwork, they are longer than general delays, also when there is trackwork, there is a high risk of delay.

The comparison of the number of trackwork and number of trackwork leading to delayed departure indicates that a relatively large portion of the trackwork (77 %) were related to train delays.

Table 7: Summary Comparison Table

	HM	ALLU	BRON	ÖVN	LUHM	LUHB	HMAV	HBHD	Average
$\frac{\text{No. of delayed departures}}{\text{No. of departures}}$	46%	47%	43%	47%	48%	42%	48%	46%	<b>46%</b>
$\frac{\text{No. of delayed departures due to trackwork}}{\text{No. of delayed departures}}$	5.18%	5.46%	8.38%	34.20%	12.12%	12.43%	12.69%	28.05%	<b>14.81%</b>
$\frac{\text{No. of trackwork leading delayed departures}}{\text{No. of trackwork}}$	61%	74%	73%	77%	79%	79%	86%	90%	<b>77%</b>
$\frac{\text{Average duration of delayed departure due to track work}}{\text{Average duration of delays in departures}}$ (minutes)	2.25	3.39	2.74	1.65	2.86	1.11	2.49	1.59	<b>2.26</b>
$\frac{\text{Standard deviation of duration of delayed departure due to track work}}{\text{Standard deviation of duration of delays in departures}}$ (minutes)	1.72	2.67	2.23	1.49	2.11	1.41	1.89	1.67	<b>1.90</b>

In terms of the type of trains, we may have more delays in freight trains, but the calculations just consider those delays which are related to trackwork.

Dispatchers adjust the plan based on the priority and their decision depends on multiple factors, for instance sometimes the train dispatchers decide to let the freight train wait and part of delays in passenger trains may be covered by freight trains, or early departures can be permitted in some circumstances like for freight trains but it might be difficult to investigate the possible scenarios.

## 6 Conclusion

In this study, quantitative analysis is used to gain insights into the effect of trackwork on the punctuality of Swedish railways and answer a set of research questions. One research question addressed the methods for analysing the relation between trackwork and train delay. In this study, “time registration data” was chosen for investigating railway punctuality. In order to extract the required data for the analysis, an algorithm is proposed to connect the train timetable dataset and trackwork dataset.

The second question in the study was about the distribution of deviation from planned departure, and how it is related to trackwork. According to the data analysis in this study, 65.13% of all deviations from planned departure are between -1.25 and 3.55 minutes where the negative sign means earlier than the planned departure, while 67.7% of the delays from planned departure due to trackwork are in the interval of (0 – 7.42] minutes.

To address the third and fourth questions of the thesis which relates to the relationship between trackwork and delays as well as the magnitude of trackwork delays, the study indicates that, although trackwork is not the biggest problem in the railway industry (14.81% of delays on average); when trackwork is conducted it is a high probability that it will be related to delay (77% on average), and these delays are more than 2 times of average duration of delayed departure. Regarding the last question of the report which relates to the type of train, most of delays in each line section, are related to passenger trains (6% on average).

## 7 Proposed Future Work

Although this study was not based on a small sample, caution must be applied, as the findings might not be directly transferable to all countries. The findings are probably most relevant to regions with a mix of urban, regional and long-distance trains, and integration of passenger and freight traffic.

There is abundant room for further progress in determining the effect of trackwork on punctuality. This study was limited by the lack of information about stations in trackwork data. Therefore, one possible area of future research would be to investigate the exact location of delays, another area of future research is related to investigating the detailed cause of delay and how does it effect on the train punctuality.

More research is needed to better recognize what is the most efficient way of carrying out trackwork in terms of the type of trackwork, the place, time and procedure in which the trackwork needs to be done.

Not only delays but also earliness is a lack of precision. Since early departures can be permitted in some circumstances like for Freight trains, a further study with more focus on separating freight and passenger trains in the analysis is suggested.

Departing exactly on time is not achievable due to various natural variations in operations. Most countries have decided threshold values for assuming the train on time. Depending on the way punctuality is measured, different threshold values for when the train is on time, various information can be extracted.

The study focused on delayed trains and check if there had been trackwork going on on the line sections where there were delays. Further studied could investigate the change of delay, measured as the difference between delays while train entering and exiting the trackwork area. Moreover, Further research should be done to investigate the relationship between trackwork and cancel trains of the studied line sections.

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## **APPENDIX A: Example of different situations**

As it is mentioned in the methodology Chapter, if at least one of the situations is met and the trackwork has been occurred on that particular line section when the train passed it, delay in departure is registered as delay related to trackwork. for making the explanations more explicit, an example of all situations is given below:

### **Trackwork type 1:**

In the ALLU line, the train number 11110 was supposed to leave the Arlöv station to Burlöv at 23:12 in 7-Feb-2015; however, a trackwork activity was started at 23:08 and lasted for 6 minutes. The trackwork finished at 23:14 and eventually, the train departed from Arlöv at 23:22. Therefore, in this case a 10-minute delay happened due to trackwork type I.

### **Trackwork type 2:**

In the BRON line, the train number 44737 was supposed to leave the Svågertorp station to Lernacken at 12:05 in 3-Feb-2015; however, the train didn't depart on time and after 20 minutes a trackwork activity started at 12:25. The delay to start the trackwork can presumably be due to preparing for maintenance (e.g., calling for required skills, spare parts and logistics, etc.) which shows the importance of supportability issue in the operation and maintenance planning. The trackwork lasted for 21 minutes and finished at 12:46. Eventually, the train departed from Svågertorp at 12:52 (i.e., 6 minutes after the trackwork was finished). Therefore, in this case a 47-minute delay happened due to trackwork type 2.

### **Trackwork type 3:**

In the HMAV line, the train number 44530 was supposed to leave the Hässleholm station to Ballingslöv at 22:56 in 23-Apr-2015; however, the train didn't depart on time and after 22 minutes a trackwork activity started at 23:18 which lasted for 14 minutes. The train departed from Hässleholm at 23:23, while the trackwork was still under progress and finished at 23:32 (i.e., 9 minutes after the train departure). Therefore, in this case a 27-minute delay happened due to trackwork type 3.

### **Trackwork type 4:**

In the LUHM line, the train number 40973 was supposed to leave the Stehag station to Eslöv at 01:45 in 19-May-2015; however, the train didn't depart on time due to a trackwork activity which was already under progress at that time started at 00:25. The trackwork lasted for 217

minutes and finished at 04:02. The train departed from Stehag station at 02:25, while the trackwork was still under progress. Therefore, in this case a 40-minute delay happened due to trackwork type 4.

