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Towards cost-conscious management of engineering track access

A study of railway maintenance and renewal procurement from a contractor perspective

Master of Science Thesis in Civil and Environmental Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover:
Engineering crew on the work site (Infranord AB)

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Abstract

Railways operate under the conflicting desired outcomes of minimizing the infrastructure costs while continuing to provide sufficient services. In recent years in Sweden increased rail traffic and reduction of track kilometers have raised traffic densities and reduced track access time for maintenance and renewal (M&R) work, while the safety requirements for maintenance work increase. The demands on quality and capacity have increased in the railway sector, leading to more trains and higher travelling speeds with higher axle loads. Heavier, wider, and longer trains running on the railway results in higher degradation of railway assets and consequently higher maintenance need and cost. Long time functional life span is one of the important aspects of railway infrastructure which is highly dependent on the maintenance and renewal strategy used during its life cycle.

The Swedish Traffic Administration is fully outsourcing M&R to maintenance contractors under the public procurement law. In outsourcing maintenance, the contractual relationship between the client and supplier is of great significance. The general objective of the study is to provide a basis for ongoing collaboration between client and supplier towards a cost-effective M&R strategy. Specifying track access time in a contract has shown to be a difficult task due to the complexity of the railway system. Nevertheless, contractors need input in the tendering phase to give a realistic price and coordinate resources for their services in advance. A high level of information uncertainty related to track access in the tendering phase and project phase may result in serious implications for the maintenance contractor and potential problems for future railway conditions.

The research study highlights various key issues to consider when managing track access conditions for railway maintenance, from the time of procurement to the time of project execution. By analyzing engineering track access for 2010 it is concluded that few possessions between 4-9 hours are reserved in the long-term plan. It results in difficulties for service suppliers to estimate costs of maintenance. The study provides concepts to be used for infrastructure managers and railway contractors to simplify and understand the railway system and how track access uncertainty influence the contractor organization.

Key words: M&R, Maintenance, Contract, Track Possession, Railway, BAP, BUP

I dedicate this work to my parents, Zari and Hosein, who taught me to enjoy hard working.
I would like to express my deepest appreciation to my wife Mahboubeh and our beloved daughter Ava, who always support me through my academic journey.

You always bring inspiration, meaning and purpose to my life.

Saeid Azmoudeh
July 2011

I dedicate this work to the memory of my mother Birgitta.
I especially wish to thank my father Jean-Michel for decades of encouragement in my academic journey.

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July 2011

Content

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Abbreviations

APP: Annual Possession Plan (Banarbetsplan, BAP)
ATT: Annual Train Timetable
DG: Daily Graph (Train time table graph)
IM: Infrastructure Manager
M&R: Maintenance and Renewal
NS: Network Statement
PPP: Periodic Possession Plan (Banutnyttjandeplan, BUP)
PSB: Major engineering works
STA: Swedish Transport Administration
STS: Swedish Transport Agency
TCE: Transaction Cost Economics

1 Introduction

The Swedish railway infrastructure is a complex system including assets and various stakeholders, such as the government, passenger operators, freight companies and service suppliers. It has been observed that the growth in the traffic volume has been positive while the punctuality has decreased (Åhren & Parida, 2009). The demands on geometric quality of tracks are increasing. Heavier, wider, and longer trains are running on the rail network, increasing the need for maintenance and renewal (M&R).

In Sweden, the Swedish Transport Administration (STA) is the government body responsible for long-term planning, construction and maintenance of government owned infrastructure assets. Since early 1960's, the Swedish railway industry has experienced a gradual shift from a protected regulated monopoly to a competitive market. In 1988, the Swedish government decided that Swedish Railway (SJ) was going to be separated into three parts: SJ (rail operator), Swedish Railway Administration and Rail inspectorate. In 1998, Banverket Produktion was created as an in-house contractor to the Swedish Railway Administration (Banverket) and SJ was divided in a series of companies, i.e. SJ AB, Green Cargo AB, Jernhusen AB etc (Espling & Kumar, 2008). Since 2011, rail infrastructure M&R is fully outsourced to service providers and in-house contractor functions have been privatized. The new market structure aims to increase flexibility and reduce M&R costs through competitive tendering.

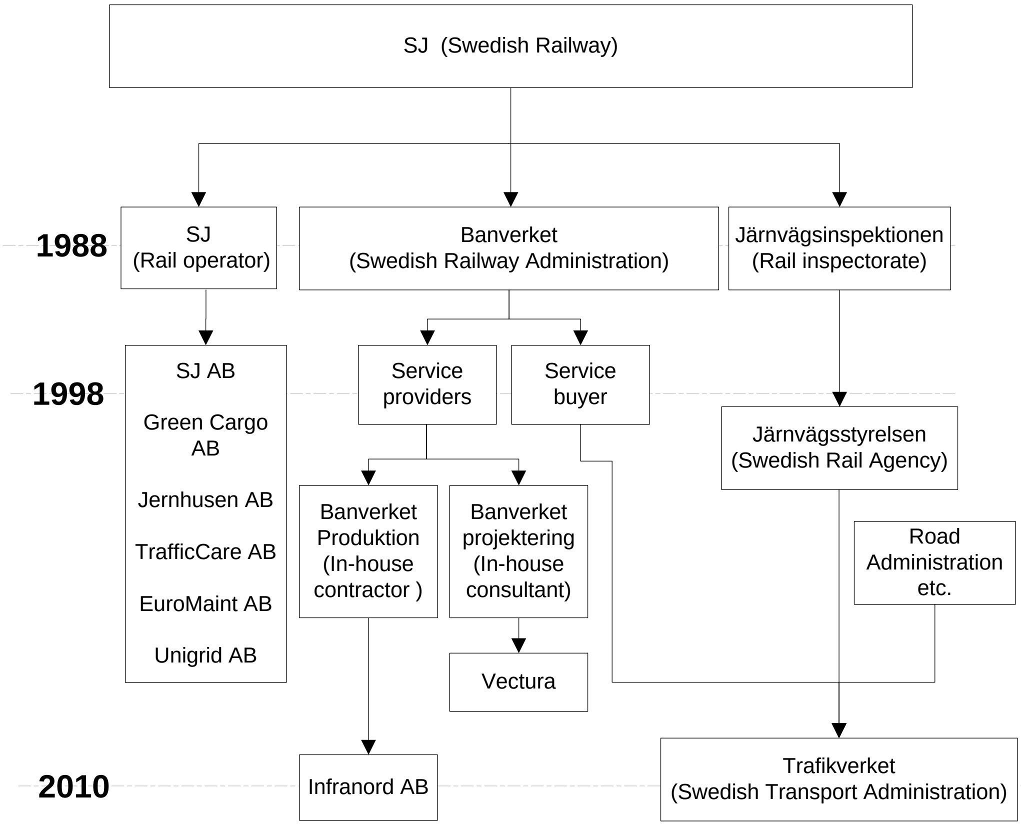


Figure 1. Organizational change of the Swedish railway sector since 1988.

Infranord is a railway contractor with focus on railway engineering services and construction based in Sweden. The company is the largest Nordic railway contractor and has about 3,000 employees and technicians with expertise in track, electrical, signal and telecom engineering. In 2010, Infranord issued a project to investigate how engineering track access affected their organization in terms of costs and relationship to their largest client Swedish Transport Administration. It laid ground to the current study carried out by two students at Chalmers University of Technology.

1.1 Problem Description

In the new market situation, the contractual relationship between the client and its maintenance contractor is of great significance. Outsourcing has great potential but includes various risks such as loss of critical skills, loss of functional communications and loss of control over a supplier (Al-Turki, 2009).

In the tendering phase, the contractor needs inputs in terms of technical specifications and track access conditions. Tender sums will vary strongly depending on track availability and on how this is defined in the tendering documents. Short possessions have been recognized to give output per worker of only a fraction of a longer possession (Mercer Management Consulting, 2002). Work night-time instead of day-time results in higher costs. Additional costs will have to negotiated if track access requirements changes from what is agreed upon *ex-ante*.

Incomplete contracts have substantial influence on the economic relationships. Even though standard contractual agreements give contractor legal right to compensation for late changes and additional costs, the contractor may be viewed as greedy by the client when variations later arise in the project. Negotiation is time-consuming and may result in disputes. Further, highly incomplete contracts may leave more room for opportunism by both parties and lead to a greater likelihood of misunderstandings regarding the roles of each party in the exchange (Crocker & Reynolds, 1993).

The complexity inherent in the railway system results in high information uncertainty. In fact, maintenance activities are highly uncertain and are often interrupted. Maintenance tasks can be divided into different subtasks, each of them with own requirements and different activities linked to each other in terms of precedence or priority.

Corrective maintenance is often urgent and is scheduled with short notice. However, scheduling of preventive or predictive maintenance activities on the rail network is challenging since many constraints are to be considered, i.e. safety regulations, disruption of train operation and the length of track possession (Budai-Balke, 2009). Train traffic must wait until the maintenance activity is completed. There are safety regulations that stipulate the clearance time needed between one train leaving and next opposing train entering to the segment (Albrecht et al., 2010). In case of disruption there are few re-routing options for trains and delayed trains will inevitably interfere with pre-planned maintenance activities (Higgins, Ferreira, & Lake, 1999).

There seems to be two main problems in maintenance work scheduling: finding required time slots for work and allocating required resources to it. Finding time slots involves requesting track possession from the infrastructure manager and acquiring approval for it (the capacity allocation process). Resource allocation, however, is the problem of allocating a set of resources to be able to carry out a sequence of tasks (Cheung et al., 1999). In a privatized railway, the service agent faces both. The maintenance contractor operates as a service business and needs to deal with issues such as scheduling maintenance tasks (Murthy & Jack, 2008).

1.2 Research Questions

The general objective of the study is to provide a basis for ongoing collaboration between client and supplier towards a cost-effective maintenance and renewal (M&R) strategy.

The thesis has two research questions:

- *How is the current system for planning and scheduling track access in railway M&R projects managed in Sweden?*

- *What are the consequences of contracts with high level of incompleteness in track possession specification on a contractor's strategies and costs?*

1.3 Significance of the Study

The study could help stakeholders in the railway market to realize the connection between M&R cost-effectiveness and track access conditions. Additionally, it will afford the management in the Infrastructure Manager's (IM's) organization to know the contractor's requirements and key issues in design of maintenance contracts. Mathematical models and conceptual frameworks presented in the study can be used by suppliers to illustrate or quantify requirements in terms of diagrams or numbers. The study will contribute to ongoing efforts in development of effective and efficient infrastructure asset management. Finally, we believe that the study will eventually help to improve contractor-client relationships in railway M&R projects.

1.4 Scope and Limitation

Engineering work on railway tracks can be carried out under different conditions, either on a fully closed section for train operation, or under restricted speed restrictions for train operation. In this thesis we have only considered the first case, when work must be planned in advance and the track section must be closed for operation (also called possession). The study covers the contractor's business in the west of Sweden and offices in Gothenburg.

1.5 Thesis Structure

In Ch. 2 we present literature related to current study. We also provide the conceptual framework and explanations of terms and variables used in the paper.

In Ch. 3 we present used methodological research methods and instruments.

In Ch. 4 we present track possession allocation procedures on strategic and tactical level.
We present findings from interviews and a cost-sensitivity analysis of one project. We also present graphs from the statistical analysis of possession plans.

In Ch. 5 we present a discussion of different topics related to current study.

Finally in Ch. 6, conclusions and recommendations are presented.

2 Frame of Reference / Theoretical Framework

2.1 Related Literature and Studies

2.1.1 General Aspects

The study of operational research models for scheduling railway infrastructure maintenance by Budai-Balke (2009) has provided definitions of related railway maintenance terms relevant to present study, in particular categorization of different possession categories. Previous European studies and literature of cost-effective track maintenance, eg. Bente and Lüking (2001), has provided reference for possession duration data and cost-effectiveness. Especially important for the present study has been the concept for optimal possession interval calculation and dependency between capacity, substance and quality provided by Putzalla and Rivier (2003). Further relevant European literature on outsourcing (Vatn et al., 2003; Veit, 2003) has provided references on the significance of clear information.

Previous literature on informational asymmetry (PA-theory) and incomplete contracts (TCE-theory) has provided explanations of relationship specific problems arising from information uncertainties. The concept of moral hazard and adverse selection forwarded by PA-theory will serve as examples of the problems arising from asymmetrical information before and after entering into contract. The paper by Murthy and Jack (2008) has significant relationship to the present study because the authors' forward the issue of informational asymmetry from both sides. Martin's (1997) paper on contracting out maintenance provides recommendations on how contractors could respond to contract complexity.

Operational research on scheduling maintenance (Albrecht et al, 2010; Peng et al., 2011; Lake et al., 2002; Cheung et al., 1999; Higgins et al., 1999; Zante et al., 2007) provides mathematical representations of railway networks and variables related to maintenance cost-effectiveness. Literature above likewise relates to present study as they will serve as examples of possible ways to schedule maintenance tasks with higher efficiency and effectiveness than current practices in Swedish railway industry.

2.1.2 Summary of Scheduling Maintenance Literature

Track maintenance scheduling methods should be flexible in order to reduce probability of train operation disruptions (Albrecht et al, 2010). Recent research optimizes and increases flexibility of scheduling using computational methods. Major objectives are to minimize total travel costs, disruption of train operation, set-up and take-down time and amount of night activities to increase work safety. Peng et al. (2011) present a mathematical model to solve the track maintenance scheduling problem. The model is applied for a large-scale maintenance project and the objectives are to minimize the total travel costs of crews and train disruption.

Lake et al. (2002) present a model for short-term scheduling of track maintenance activities after the activities and train-time table (see Figure 2) has been planned. The objective is to minimize the total maintenance costs including set-up and take-down time. Cheung et al. (1999) optimized the assignment of job requests based on priorities in order to schedule enough preventive maintenance during the remaining time of the operational period (19 hours) which is less than 5 hours.

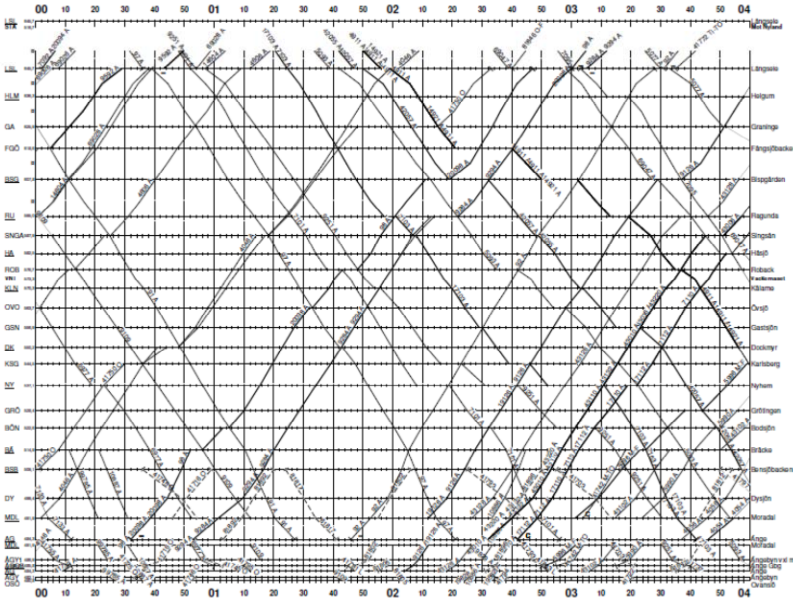


Figure 2. Daily graph (DG), planned train-time table (Swedish Transport Administration, 2011).

Budai-Balke (2009) presents a solution to the Preventive Maintenance Scheduling Problem. The problem concerns scheduling preventive maintenance activities such that the works are clustered together as much as possible to minimize the overall costs. Higgins et al. (1999) develop a mathematical model to minimize disruption of train operations by considering train-time table, crew travel time and budget constraints. Zante et al. (2007) provides a solution to a track maintenance scheduling problem in Netherlands with the objective to minimize the number of nights with planned maintenance in the schedule to decrease risk of accidents.

A project carried out by the Hong Kong Mass Transit Railway Corporation applied a knowledge-based expert system to automate the assignment of track possessions for engineering works (Cheung et al., 1999). A knowledge-based system incorporates human expertise into the computer system. In the project, researchers and human experts worked together for more than 1 year and collected technical knowledge that the experts had been used to construct the schedule manually. These, so called heuristics or “cognitive rules of thumbs”, were programmed into the computer system. Cheung et al. (1999) tries to solve the Railway Track Possession Assignment Problem by using heuristics solution techniques as constraint satisfaction. The system was applied and showed to be successful. It had a short run time (around 10 min for assignment of 150 jobs) and proved more efficient than manual methods.

Research shows that computational methods are advantageous compared to manual methods. They are faster and are able to find solutions closer to the optimal state. Albrecht et al. (2010) propose a method for integrating track maintenance and train timetable in order to produce schedules on demand. In Australia, train timetables on long-haul networks have been scheduled manually and require several weeks to find a practicable solution. It was found that the scheduling process was terminated when the first feasible solution was found and therefore, the solution was far from optimal (Albrecht et al., 2010).

2.2 Conceptual Frameworks

2.2.1 Stakeholders in Infrastructure Maintenance in Sweden

In Sweden, most of the infrastructure asset is owned by the government. Figure 3 presents different stakeholders in infrastructure maintenance that need to be considered.

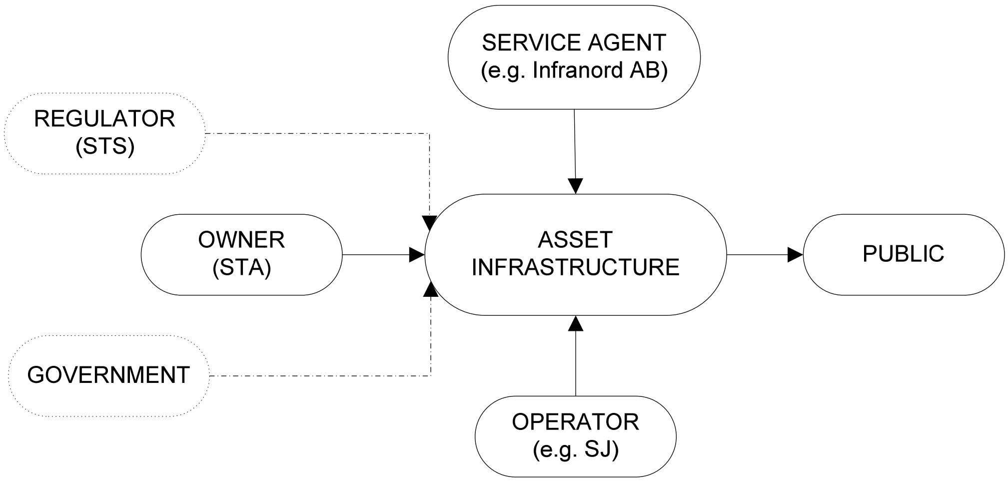


Figure 3. Stakeholders in infrastructure maintenance. Adapted from Murthy & Jack (2008).

Owner

The Swedish Transport Administration (STA) is the infrastructure manager (IM) responsible for long-term planning, construction and maintenance of government owned infrastructure assets (Trafikverket, 2011).

Regulator

The Swedish Transport Agency (STS) draws up regulations and exercise supervision over authorities, companies and organizations (Transportstyrelsen).

Operators

Railway undertakings operate the asset and provide services for the public (e.g. SJ AB, Green Cargo AB, Euromaint AB, etc).

Service agents

Maintenance is contracted out to maintenance contractors (e.g. Infranord AB, Balfour Beatty Rail, etc).

2.2.2 **The Infrastructure Asset Maintenance Process**

Asset maintenance can be divided into a set of different activities. The main ones are: work identification, work planning, work scheduling and work execution (Misra, 2008) (see Figure 4). Verification of the actual state of an asset can be done either by visual inspection or data recording. Collected data must be processed and analyzed. If the asset state is lower than set standards, work must be carried out to restore or replace components to their required functional condition. Once a need for maintenance is identified, work has to be planned. Work planning is a process to find a certain sequence of needed actions to retain the functionality of the technical system.

Scheduling involves exact allocation of a set of resources over time. It deals with finding a resource that will process a certain activity and further finding time for processing (Brusoni et al., 1996).

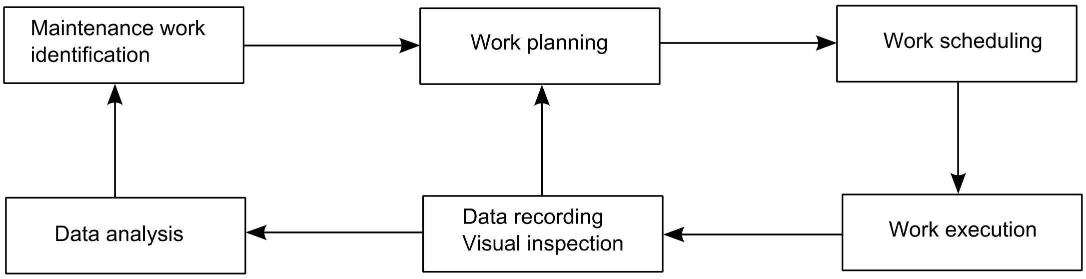


Figure 4. Asset maintenance activities. Adapted from Misra (2008).

The term infrastructure covers all the assets that are used for train operation (Improverail, 2002). Budai-Balke (2009) identifies those assets as:

- Tracks (rails, sleepers, fastenings, ballast), switches and crossings,
- Bridges and tunnels,
- Energy supply installations (catenary systems),
- Safety and telecommunication equipment (signaling systems).

2.2.3 **Optimal Possession Interval Calculation**

Putallaz & Rivier (2003) present a concept for optimal possession interval calculation (see Figure 5). The cost function for work is based on: the type of work to be undertaken, used technology, worksite organization and layout of the network in the work site region. The worksite cost, which depends on several factors such as work typology, work site length, machines and section characteristics, will decrease with an increase of possession interval. However, the capacity costs (due to re-routing of train, delays and service cancellations) will increase with an increase of possession interval.

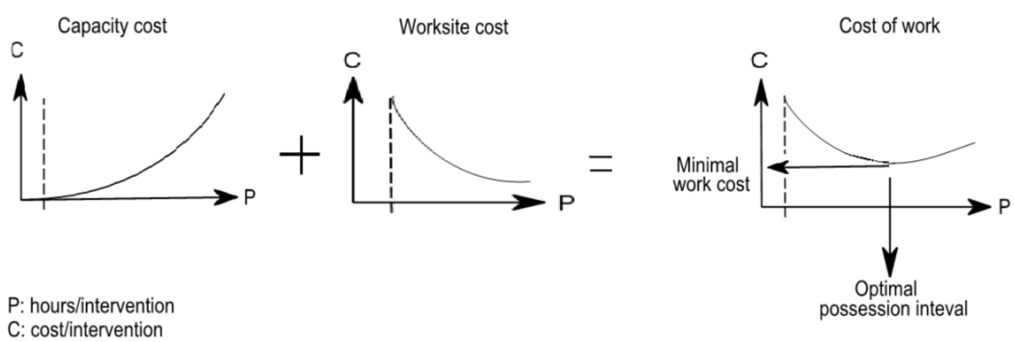


Figure 5. Optimal possession interval calculation. Adapted from Putallaz and Rivier (2003).

Thus, the basic concept is that the infrastructure manager has to choose the most optimal track possession interval in order to minimize the cost of work and possession intervals. The total cost of maintenance or renewal actions (work cost) is the sum of traffic alteration costs and engineering costs.

2.2.4 Conflict between Capacity Development and M&R Policy

Railways operate under the conflicting desired outcomes of minimizing the infrastructure costs while continuing to provide sufficient services. An increase of railway traffic and reduction of track length have resulted in an increase of traffic density and reduction of time available for maintenance activities, while the requirements of track maintenance have increased. All mentioned issues make scheduling of track maintenance activities more important for infrastructure managers. As showed in Figure 6 rail travel is the most economical and environmental way to travel while it faces for the smallest portion of the transport market (White paper, 2001).

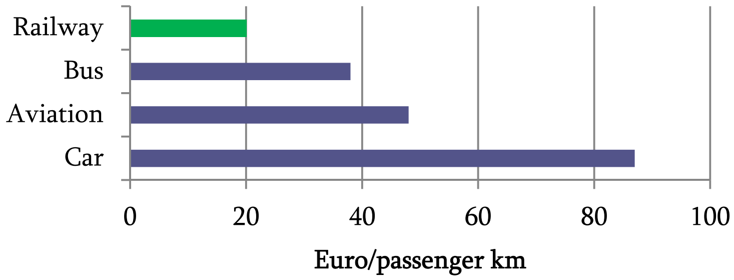


Figure 6. Costs of different travel modes. Railway is a cheap mean of transportation compared to car transport. This implies that railway travel will increase in the future (White paper, 2001).

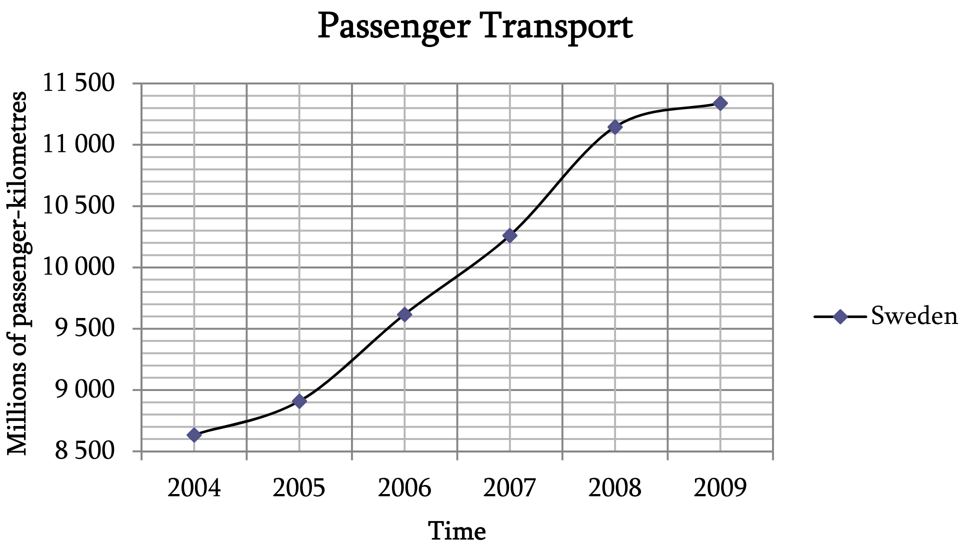


Figure 7. Growth of passenger transport between 2004 and 2009 (Eurostat, 2011).

The level of passenger travel in Sweden reached 11 billion passenger kilometers in 2009 (see Figure 7). With assuming a 4% annual growth, passenger transport is forecast to reach 18 billion passenger kilometers by 2021.

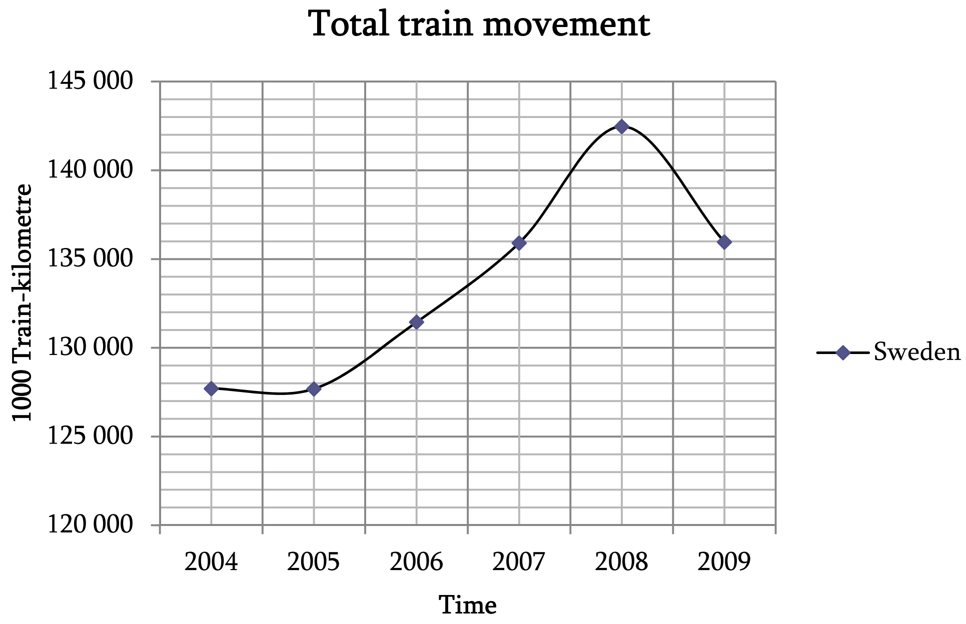


Figure 8. Growth of train movement between 2004 and 2009 in Sweden (Eurostat, 2011).

Consequently, higher level of passenger and goods transport results in more train movement on the systems. Total train movement in Sweden (see Figure 8) increased by 6% between 2004 and 2009 (i.e. 10% passenger train movement and -4% goods train movement). The economy crisis influenced goods train movements and resulted in a decline in total train movements in 2009. According to Eurostat, (2011) total train movement in Sweden reached 136 million train kilometers and is calculated to reach 153 million by 2021.

Development of track length in Sweden has increased 0.7 % between year 2004 and 2009 while total train movements have increased by 6 %. An increase of wearing out resulting from traffic growth will increase demand for maintenance. Track possessions used for maintenance, reduce capacity availability and therefore owners of infrastructure tend to prioritize availability instead of quality, and cut maintenance and renewal budgets (Putallaz & Rivier, 2003).

Figure 9 shows the dependence between three “macro” parameters of rail management. By adjusting these, rail network efficiency is accomplished.

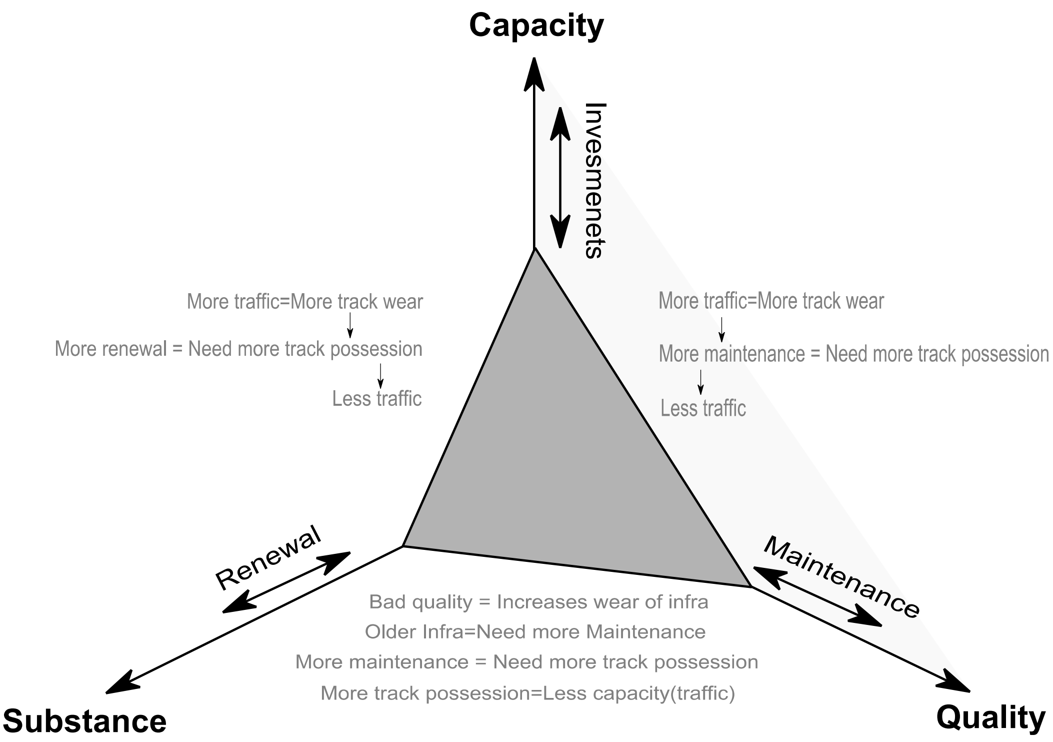


Figure 9. Three macro parameters of rail management. Adapted from Putallaz and Rivier (2003). The figure illustrates the interconnection between capacity, substance and geometric quality.

Rail network efficiency is accomplished by adjusting three parameters:

- Capacity of the network
- Substance of the infrastructure
- Geometric quality of the track

These three parameters cannot be adjusted independently because they are strongly linked to each other. Capacity of the network is closely related to network availability. A growth in traffic induces wear and increases maintenance needs, and in turn more track possessions are required. More track possessions lead to reduced network availability. An upgrade of signaling systems or construction of new track lines will allow more trains to operate on the network and will increase network availability.

Systematic maintenance tasks such as rail grinding and ballast tamping increase tracks geometric quality. The substance is highly influenced by the rail network components state. An old infrastructure has a low substance, i.e. the components remaining life-time is low and require more maintenance (Putallaz and Rivier, 2003). Component replacement decreases the average age of infrastructure (substance).

Infrastructure managers' knowledge on the relationship between rail usage, wear, maintenance needs and consequent cost is not optimal (BV, ECORYS Nederland, 2006). It is not easy for infrastructure managers to find the optimal balance between these three parameters. To achieve this balance, long-term strategic maintenance and renewal policy in required.

2.2.5 **Principal-Agent Theory**

In many commercial situations, there is a client (principal) that buy a services or goods from an external provider (agent). In the railway sector, such example is the relation between the infrastructure manager and a maintenance contractor. The infrastructure manager buys core competence by the maintenance contractor who performs work on behalf of the buyer.

Information asymmetry due to uncertainty will affect the overall outcome of the relationship between parties. There are various kinds of costs for both parties (Murthy & Jack, 2008). For example, costs for administration, communication, monitoring, collecting information and outcomes which are influenced by uncertainties. When investment of time and communications channels is insufficient from the principal, the agent will not follow the principal's intent due to lack of clarity and reliability in messages from the principal (Goggin et al., 1990). Complexity results in risks of a contract which depends on different aspects such as: possibility of defining the service formally, possibility to define the legal consequences (legal liability) and degree of mutual trust that can be formed (not covered by a formal contract) (Martin, 1997).

Problems from information uncertainty arise when two parties engaged in a contract have different goals and different level of information (Eisenhardt, 1989). The general assumption of goal conflict between principal and agent is that each party wants to maximize their own interest at the expense of the other. Different level of information influences the relationship between parties. In economics, informational asymmetry exists when one party in a transaction has more information than another and is unable or unwilling to share this information. As a consequence two Principal-Agent problems arise:

Adverse Selection: it occurs when one party acts opportunistically before entering into a contract. A classic illustration of this problem is the second-hand cars market problem modeled by Akerlof (1970). It is difficult for a buyer to identify a car with mechanical problems before purchase and therefore, the buyer may easily be exploited by opportunistic sellers. As a result the seller's behavior may lead to purchase of wrong product by the buyer.

Moral Hazard: the problem occurs when one party acts opportunistically after entering into a contract. A typical example of moral hazard problem appears in insurance transactions. After signing an insurance contract, there always exists a tendency to cheat and claim more than what is agreed in the contract from the insurance company.

Applications and Aim

The Principal-Agent Theory has several advantages. First, it has broad applicability. Secondly, the theory has great explanatory power. It gives logical predictions of what rational individuals should do in a Principal-Agent relationship. Eisenhardt (1989) states that: "*Principal-Agent Theory provides a unique, realistic and empirically testable perspective on problems of cooperative efforts*". Third, the Principal-Agent Theory is to solve problems, through answering the question of how a contractual agreement should be formed to make the agent act in the best interest of the principal, in order to increase efficiency of the relationship.

2.2.6 Incomplete Contracts and TCE

However, in many situations it will be hard to design a complete contract. Problems arising from incomplete contracts have attracted researchers for decades. Incomplete contracts have important implications for the long-term economic relationships (Williamson, 1985). In traditional construction contracts, frequent negotiations of contractual changes are an example of transactions costs (Kadefors, 2004). Hart and Moore (1988) define an incomplete contract as:

"*When drawing up a contract it is often impracticable for the parties to specify all the relevant contingencies. In particular, they may be unable to describe the states of the world in enough detail that an outsider (the courts) could later verify which state had occurred, and so the contract will be incomplete*".

Due to the complexity of describing a complete contract, unforeseen contingencies appear such as late changes and design variations. These are major reasons for claims and disputes in contractual relationships (Bajari & Tadelis, 2001). Negotiation sometimes gives rise to disputes between parties. Leaving a contract relatively incomplete may allows the parties more flexibility to deal with new contingencies as they arise. Conversely, highly incomplete contracts leave more room for opportunism by both parties and may lead to a greater likelihood of misunderstandings regarding the roles of each party in the exchange (Crocker & Reynolds, 1993). In maintenance, contract complexity can be large and therefore responsibilities should be explicitly separated between contractor and client (Martin, 1997).

2.3 Definitions of Terms and Variables

2.3.1 Maintenance and Renewals (M&R)

According to British Standard (1984) maintenance includes all actions necessary for retaining or restoring a system or an item in a state in which it can perform its required function. Maintenance involves servicing, replacement or repair and is necessary when a component or a system is likely to fail or fails to perform its required function (Kumar, 2008).

The approach to maintenance has changed by time and have since 1950 been driven by the rapid change of technology (Misra, 2008). Before, equipments or components were simple, reliable and easy to repair. Today, there are complex systems as the railway infrastructure consisting of several interacting subsystems, such as tracks, signaling and electrical systems. According to Budai-Balke (2009) renewals are often included in maintenance but are seen separately because of the general practice in the industry.

In the thesis, renewal includes work such as ballast, track and sleepers replacement while maintenance includes routine maintenance of railway infrastructure assets, e.g. rail grinding, ballast tamping and snow removal.

2.3.2 Track Possession

The term "*possession*" is used and is defined as follows (RailNetEurope, 2001): "*Non-availability of part of the rail network for full use by trains during a period of time reserved for the carrying out of works is called "possession". Possession is an operational arrangement that prohibits scheduled train movements, marshalling or shunting activities on the track*".

Budai-Balke (2009) describes three categories of possessions:

- Overnight possessions: include the time interval between the last scheduled passenger trains at night until the first train arriving next day.
- Sunday and weekend possessions: work done during weekends or Sundays.
- Daytime possessions: engineering track access during daytime and will usually cause major train disruptions, especially to passenger trains. Freight trains are easier to re-route.

2.3.3 Maintenance Tasks

A maintenance task consists of a set of maintenance activities performed in a specific order to accomplish maintenance of a component or a system. Maintenance tasks can be divided into three main categories (Budai-Balke, 2009):

- Corrective maintenance
- Preventive maintenance
- Predictive maintenance

Corrective or breakdown maintenance tasks include actions performed immediately (ad-hoc) after failure to restore a system or an item to its required state. It may involve repairs, replacement, or adjustments.

Preventive maintenance tasks include preplanned actions performed to minimize the probability of sudden events. These scheduled actions include adjustments, replacements, renewals and inspection of technical systems or components. Preventive maintenance is advantageous because regular maintenance and refurbishment can make the technical system or components to last longer and reduce the likelihood of such equipments becoming non-operational (Murthy & Jack, 2008). Preventive maintenance actions can be triggered based on periodic plans or the actual conditions of the component or system, also known as conditional-based maintenance (Misra, 2008).

Predictive or conditional maintenance tasks are direct monitoring methods used to determine status of items in the system. The objective is to predict sudden failures in the future and aims to achieve the most cost-effectiveness maintenance before failure in system occurs.

2.3.4 Engineering Work

Engineering works are technical works, including maintenance activities on the railway infrastructure assets. Engineering works can be divided into (Budai-Balke, 2009):

- Small works: consists of inspections and works which can be carried out manually or by small machines.
- Systematic maintenance: consists of large works which are performed by heavy machines and need to be planned in advance.

2.3.5 Outsourcing

In the literature on maintenance, the term "outsourcing" usually refers to the choice to contract out work, not included in the main business (Vatn et al., 2003). Different options for outsourcing track maintenance are (Veit, 2003):

- Outsourcing based on job specifications
- Outsourcing based on functional requirements

In the first option, the owner specifies when and what type of track work shall be carried out. The owner is responsible for all planning and controls the output of the maintenance work. In the second option, functional requirements are stated by the owner. The maintenance contractor decides when and what work needs to be carried out to fulfill the functional requirements. Outsourcing has advantages such as reduction of service costs, reduction in personnel and increased flexibility of the business. Negative effects have also been reported, such as loss of control, high transaction costs and less flexibility (Vatn et al., 2003).

2.3.6 Traditional Procurement Methods

The contracts used in outsourcing of maintenance services in Swedish railway sector are often traditional methods or "controlled" design-build. The traditional method is based on separation between design and construction, where the client prepares specifications with the help of consultants and the contractor procured to execute the work (Potts, 2008).

In the tender process, the price is calculated by the contractor. Often this calculation is based on a bill of quantities provided by the client in the tender documents. The client evaluates bids according to selection criteria such as technical-organizational ability, construction method and tender price, etc. Finally, the most economically advantageous tender is awarded the contract.

3 Methodology

This section presents scientific research methodology and explains the process of empirical data collection.

3.1 Research Design

We have chosen a mixed methods research defined by Onwuegbuzie & Johnson (2004) as “the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study.” The advantages of such a strategy can be illustrated from how military unites navigate and use multiple reference points to locate an object’s exact location. Similarly, by collecting different kinds of data bearing on the same single study, the accuracy of the researcher’s judgment can be improved (Jick, 1979).

The studies in the thesis have been made by two students. Multiple investigators have complementary insights from different perspectives and increase confidence through multiple observations (Eisenhardt, 1989). The study started with a problem identification which includes an assessment of current practices in the company. The aim was to understand the interaction between contractual agreement and engineering track access in the practical reality. When the problem was formulated we started to collect empirical data.

The study consists of following parts:

- Description of track access allocation procedures in Sweden (Basis: interviews and STA documents)
- Description of problems associated with possession information uncertainty for the contractor (Basis: interviews)
- Study of possession information availability (Basis: long- and short-term possession plans)
- One project case study of cost consequences of track possession during night or week-end as compared to day-time (Basis: project invoices)
- One project case study describing consequences of late possessions (Basis: interviews)

3.2 Location

The research has been based on M&R projects and routes located in West Sweden. See Appendix (I) for a complete map of routes in Sweden. The researchers were placed at the contractor’s office in Gothenburg, close to project managers and technical crews. The total route length of West Sweden rail network is about 1900 km which consist of 19% of the total state owned railway routes in Sweden.

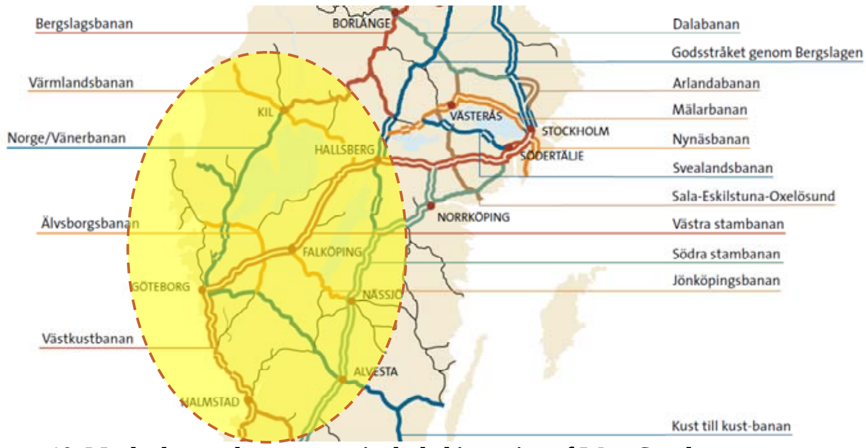


Figure 10. Marked area shows routes included in region of West Sweden.

3.3 Data Samples

The study of track access allocation and planning procedures has been based on written guidelines compiled by STA and participation in meetings with planners from the client's and contractor's organization. Project cost data were fetched from invoices sent from the contractor to the client. It was used to show the impact of possession conditions on final project cost for one project. The annual possession plan (APP) and the periodic possession plan (PPP) for 2010 has been used to analyze possession information. Table 1 shows routes in West Sweden which have been used for the analysis (see Figure 10).

Table 1. List of investigated routes and their length in West Sweden.

Route name	Route length(km)*	Share of Swedish rail
Norge/Vänerbanan	298	2,9%
Västra Stambanan	218	2,1%
Värmlandsbanan	212	2,1%
Kust till kust bana	212	2,08%
Bohusbanan	171	1,7%
Västkustbanan	150	1,4%
Älvsborgsbanan	131	1,3%
Gårdsjö – Håkanstorp	119	1,2%
Kil – Torsby	81	0,8%
Viskadalsbanan	80	0,8%
Kristinehamn – Persberg	55	0,5%
Värnamo – Halmstad	55	0,5%
Mellerud– Billingsfors	37	0,4%
Göteborg närställverksområde	37	0,4%
Munkedal – Lysekil	34	0,3%
Jönköping gbg – Vaggeryd	25	0,2%
Alvehem – Lilla Edet	14	0,1%
Total route length in region west	1935	19,0%

Source: (Banverket, 2004)

(*) only parts of the route that are included in the region of West Sweden are considered

3.4 Procedure

The research combines literature reviews, interviews and quantitative analysis. We began to identify the problem through discussions, literature exploration and observations. We composed a general description of the allocation process to understand how the system worked. It preceded the data collection through semi structured interviews and gathering of data from guidelines documents and invoices. In the next step, we formed a hypothesis and tested it through analysis of quantitative data and results from the interviews questions. Data analysis included a cost-sensitivity analysis and a comparative analysis of statistical data.

3.5 Instrumentation

Table 2 summarizes instrumentations for different research methodologies.

Table 2. Summary of methods used in the research. Adapted from Silverman (2005).

Instrumentation	Qualitative (Understanding)	Quantitative (Verifying)	Data sources
Interviews	Semi structured interview	-	Decision-makers, administrators
Observation	Understanding work culture	-	Meetings and discussions
Text and documents	Understanding the process	Statistical & cost-sensitivity analysis	Contracts, procedures, literature, invoices

Observations

We participated in one start and three follow-up meetings. The possession planning process, request of possessions and discussions between client and contractor was observed. An understanding of work culture has been gained.

Text and documents

We started to study literature and possession allocation procedures to understand track possession problems from the view of a contractor. Routines for the possession planning and allocation process have been examined.

Interviews

Semi-structured interviews were decided as suitable data collection method. The interviews took place between February and April 2011 with personnel from Infranord AB offices in West Sweden and STA's head quarter in Gothenburg. An interview guideline comprising about 15 questions was developed. The interviewees were 2 site managers, 1 possession administrator, 1 tender group-manager, 2 project managers from Infranord AB and 2 possession administrators from STA. Each interview lasted approximately 2 hours and was documented by notes.

3.6 Statistical Analysis of the Data

The data collection was compiled from possession plans and analyzed using Microsoft Excel. The interval was calculated for each possession. Each duration frequency between 1 and 24 hours was then estimated. A comparative analysis is then made between the annual possession plan and periodic possession plan for two various samples of routes: one for all routes in the region and one for only Western Main Line.

4 Results

4.1 Track access allocation procedures for M&R

In Sweden, the rules and conditions for allocation of train paths and engineering work on government owned railway are issued by the Swedish Transport Administration in the Network Statement. The Network Statement contains information about the available infrastructure and major engineering works planned by the infrastructure manager (Swedish Transport Administration, 2011).

Actions at the *strategic level* aim to transform overall system priorities into maintenance priorities of the infrastructure assets (see Figure 11). In the strategic level the infrastructure manager has to make decisions about future plans for maintenance of the infrastructure assets depending on several factors, i.e. asset condition, budget and predicted capacity usage from train operators.

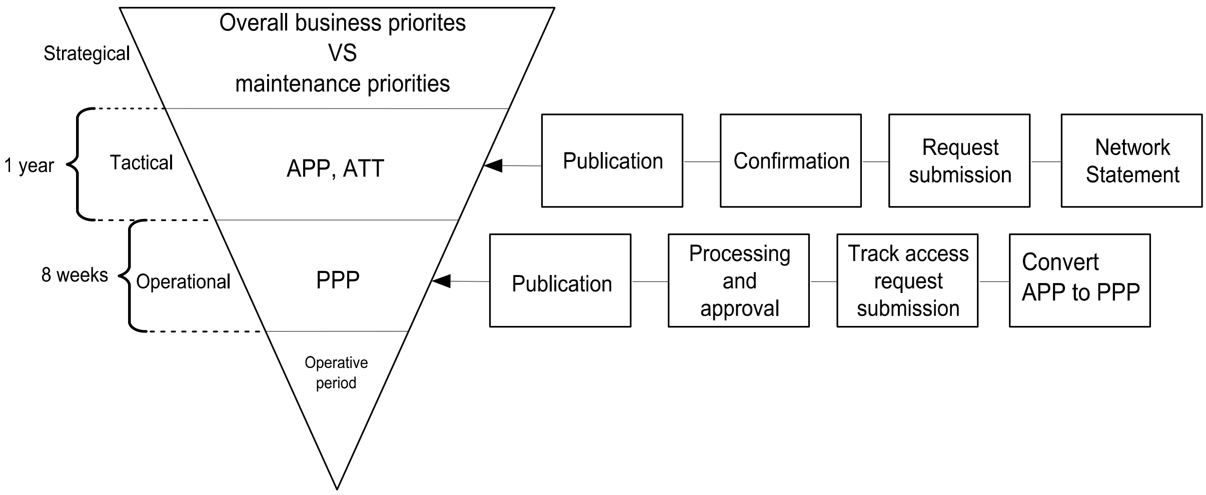


Figure 11. Different levels of railway maintenance planning and scheduling.

4.1.1 Tactical Level

Actions at the *tactical level* aim to produce a time table for maintenance activities. These actions involve allocation of capacity for train movements together with major engineering works. Only major engineering works are considered in the tactical planning level. Major engineering works are the works which fulfill some criteria depending on required work time, disruption level and traffic density on the track line stated in network statement. To be allowed to operate on the Swedish rail network, railway operators and maintenance contractors must request capacity from the Infrastructure Manager i.e. STA. On the tactical level, allocation for capacity for railway operators and track access for engineering work is a parallel process.

Figure 12 illustrates the capacity allocation process in the tactical activity level for annual timetable 2012 which consists of two main components:

- The Annual Train Timetable (ATT) is a detailed timetable for railway infrastructure used by operators to move rail vehicles (except work vehicles) from one place to another during a certain period of time (see Figure 12).

- The Annual Possession Plan (APP) is a detailed schedule of infrastructure capacity reserved to service agents for carrying out engineering work (see Figure 12).

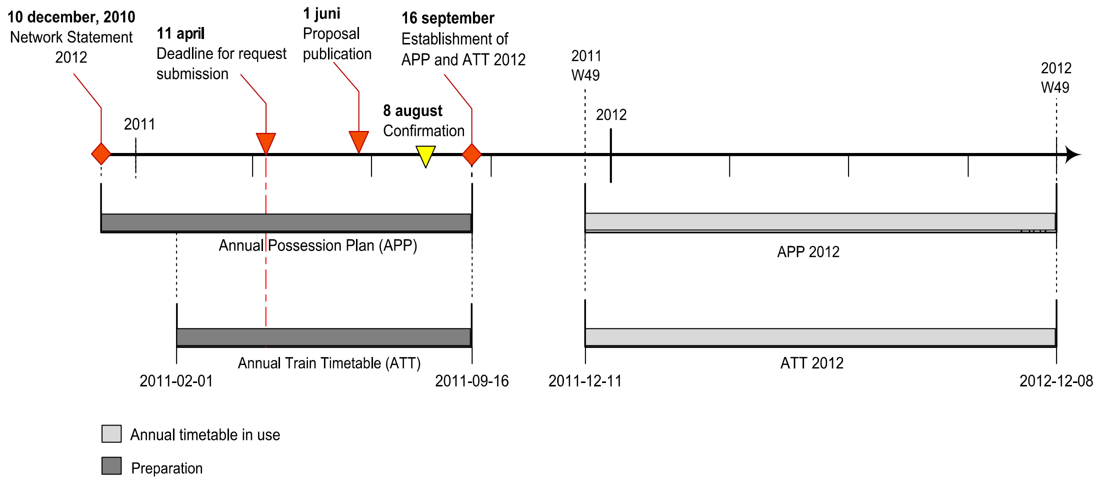


Figure 12. Illustrates the path allocation process for the annual possession plan. When the Network Statement 2012 is published a preparation phase begins where infrastructure capacity is allocated in a parallel process to train operators and service agents.

4.1.2 Operational Level

Actions at the *operational level* aim to ensure that engineering work is carried out in time and that re-scheduling is done if changes happen. All requests for capacity allocation are processed, confirmed and published within a specific period of time stipulated in Network Statement. In the operational planning level (see Figure 11) the annual possession plan (APP) will be converted to a more detailed periodic possession plan (PPP) with duration of 8 weeks (see Figure 13). If requested track possession is not included in APP, and affects train timetable, the submission of possession request should be done 13 weeks before the execution of work. In this situation, possessions are allocated on remaining capacity. The operative period is the time interval between the establishments of PPP until the next Sunday.

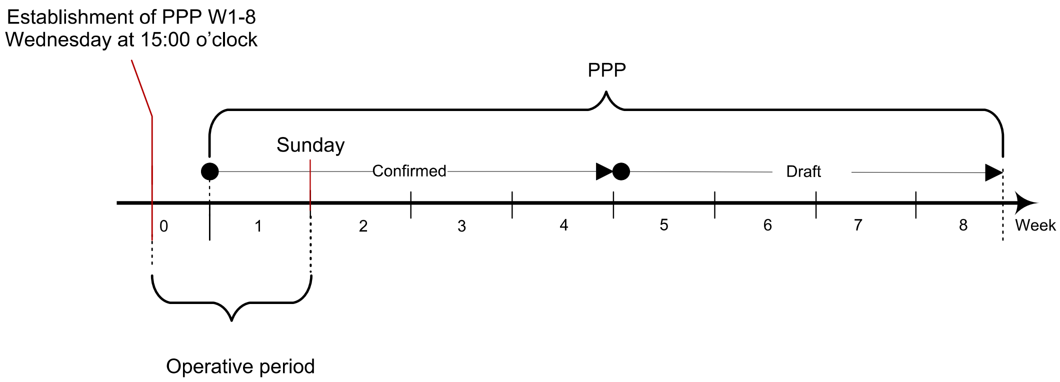


Figure 13. Illustrates the 8 weeks time horizon for the periodic possession plan.

4.2 Contractor's organization

4.2.1 Project Case 1: Cost Sensitivity Analysis

In this section, we present an analysis to show the impact of possession conditions on final project cost for Case 1. The project Case 1 involved electrical and signaling renewal on a specific track section in Gothenburg. Possessions were reserved in the long-term schedule in the beginning. However, the initial contract was a lump-sum contract but was later renegotiated into an admeasurement contract due to uncertain working conditions. Both client and contractor agreed to cooperate to meet a joint goal. Admeasurement payment allowed the contractor to calculate the price according to the actual usage of resources for a certain task. Unit prices were agreed on before-hand in a rate of schedule. Contractual problems were few and the client was reported to be satisfied with the final costs.

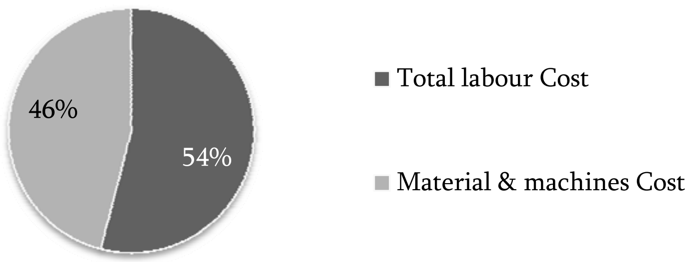


Figure 14. Share of labour and material & machines cost on total project cost.

A possession scenario includes the distribution of man-hours between two possession categories, i.e. daytime work and overnight or Sunday possession. Total project cost is estimated to 3,6 MSEK. As Figure 14 shows, according to our research 54 % of total project cost is related to labour cost (i.e. 1,8 MSEK). Depending on time conditions Infranord pay different rates of salary to workers. The range of average labour costs per hour in different possession categories is demonstrated in Figure 15.

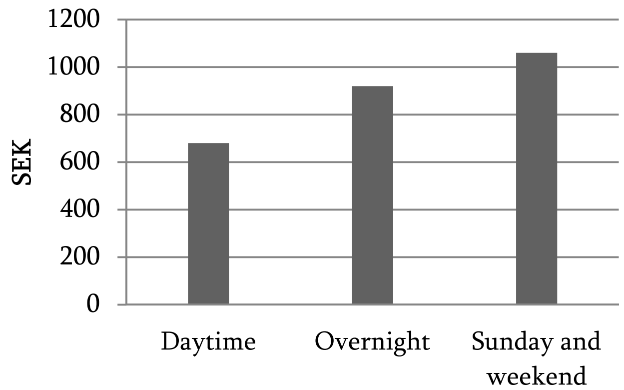


Figure 15. Average labour cost per hour in different possession categories.

In this project our research finds that 41% of the work is done during overnight or weekend possession (see Figure 16).

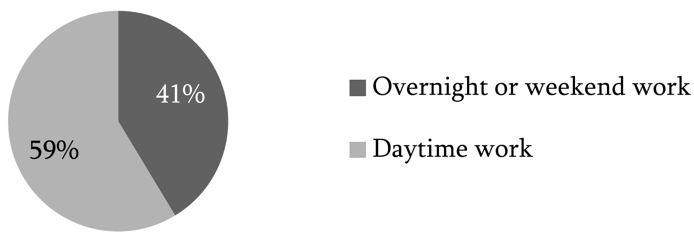


Figure 16. Share of possession categories.

The cost of these possessions (i.e. 920 hours work) constitutes 52% (see Figure 17) of the total labour cost due to higher salary rates during nights and weekends.

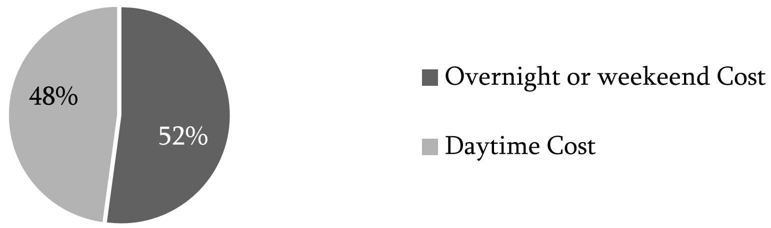


Figure 17. Share of total labour cost distribution in different possession categories.

In order to show the influence of different possession categories on total project cost we present 3 different hypothetical cases:

- **A.** Actual situation (i.e. 41% overnight/weekend possession and 59% daytime)
- **B.** When all work is carried out during daytime (100% daytime possessions)
- **C.** When all work is carried out during night or weekend (100% overnight or weekend possessions)

Table 3. Possession categories influence on total labour cost.

	(A)	(B)	(C)
Labour cost(SEK)	1853205	1586251	2338851
Share of total project cost	54%	44%	65%

As showed in Table 3 we assume that the total project cost is constant, i.e. is equal to actual project cost. The most expensive case is case C when the labour cost will increase by 26 % compared to the actual situation. It accounts for 65% of the total project cost. Case B results in a reduction of 14% of labour cost compared to case A and accounts for 44% of the total project cost.

Table 4 shows the change of total project cost (including material and machines) when switching between different cases. For example, switching from case A to case B will lead to a total project cost reduction of 7.5%.

Table 4.Possession categories influence on total project cost.

	A	**B**	**C**
A		-7,50%	13,50%
B	7,50%		21%
C	-13,50%	-21%	

The findings in this section support previous research by Bente and Lüking (2001) that identified human resources as dominant cost factor. It ranges between 44% and 65% of the total project cost in railway infrastructure M&R. In our analysis we assumed constant productivity and constant possession duration in all scenarios.

4.2.2 Project Case 2: Late Signed Contract

The project involves renewal of the signaling system on a specific track section in Gothenburg area. A lump-sum contract was signed with Swedish Transport Administration (STA). The contract sum was about 9 MSEK and estimated on conditions written in the tender specification. The available possessions were governed by the long-term schedule provided by the STA and referred to in the contractual documents. However, the contract was signed late and possessions in the long-term schedule could not be used.

Despite that track access was reserved in advance by client, a late signed contract caused problems. The contractor had to start negotiate possessions and coordinate production once more under new conditions. The work had to be carried out night and weekend possessions instead of regular daytimes which increased project costs for the contractor. The contractor was entitled for additional work arising from changed work conditions due to late contract signing by client.

4.2.3 Contractor Opinions

The most common view among the contractors interviewed was that the track possessions needed to be clearly specified in the contract. The main reasons why Infranord needs the right information about track possession time in advance or before entering into a contract are that:

- Resources have to be locked in advance for each project
- Different work types demand different possession intervals
- Different possession categories affect final project cost

In sum, they agreed that the absence of such information can affect their business activities as follows:

- Resource planning:
  - More administration cost due to complexity of resource planning
  - Creates uncertain environment for contractor
- Possession duration and productive time:
  - Installation and setting-up time consumes parts of possession time
  - Stress can be high and work safety low in short track possessions
- Possession categories and cost effectiveness:
  - Tiredness is a risk at night and reduces productivity
- Contractual issues:
  - Bad client-contractor relationship
  - Disputes may happen in the future

The results from interviews are based on transcriptions. A sample of answers of questions will follow:

Question	Answer
Which types of task demand careful planning of possessions the most?	Track maintenance is most dependent on track possession. It involves the use of resources which needs to be reserved in advance. Infranord owns also machines but on occasions they have to be rented which demand more planning. For example electrical works are more dependent on track possessions than signaling work.
What major problems are imposed by insufficient track possessions?	There are risks that certain procedures have to be neglected in order to finish in time. A short duration results in stressful conditions and may increase risks for errors and accidents.
Is there any risk for not receiving pay for additional work arising from inadequate track possession information?	Not receiving compensation is rare and has never happened. However, lately the risk has increased and may happen more frequently in the future.
Do you notice improvements in the contract design?	Contracts today are correct concerning technical and legal issues but the level of

	available track possessions are low. A dialog exists and the contracts are revised by STA. For example, in maintenance contracts (includes functional requirements) there exists a provision stating a maximum allowance of disturbance from train operation that needs to be tolerated by the contractor. Previously, the contractor had to tolerate 20% interference with train operation while new contracts state "tolerate a certain disruption".
How can possession time be used more efficiently?	Possession continuity is one of the most important factors
What is the impact on productivity from unfavorable track possession categories (eg.overnight possessions)?	Sight worsens and the body feels tired. Resource usage increases, e.g. need for additional installations such as lights.
Does Infranord increase profit when overnight possessions are used?	Infranord earns more money because work is more expensive during nights and weekends, but in the long term workers health may be also affected. However, work daytime often involves short possession intervals with lower productive time.
Do financial incentives exist in the contract?	Yes, but not in projects. For example, in a maintenance contract, Infranord is rewarded in relation to amount of train disruption. If few trains are delayed, Infranord earns more money. However, cause and effect is not always obvious and delay can be difficult to measure and link to one contractor alone.
Are the soft parameters[1] a crucial factor in contract award processes?	STA is working on balancing soft and hard parameters (lowest cost) but further improvement is needed. Soft parameters are harder to set value on and thereby easier to question. May be a reason why STA is careful in applying soft parameters.
Have you suggestions on how possessions specification can be improved?	The contract must be clear regarding how new possessions should be assigned. Further, more clarity in provision about contractors tolerance of train disruption is needed.
Work smarter and develop equipments seems to be a way ahead to reduce possessions duration. How does Infranord look at that?	Infranord has relatively heavy and large machines, e.g. track lifter. Sweden should learn from US who are very forward in this area. For example, a good question is why contractors in Sweden drill instead of using less time consuming techniques to fasten sleepers.
How do you look on the possibility to detailed scheduling in the long-term plan for maintenance contracts?	Infranord is working on it. In the tender documents, the process should be described to let STA know how we manage track possessions.

[1] The award is not made on lowest cost alone. Selection is also based on quality criteria (soft parameters) such as tenders' construction method, technical and organizational ability.

4.3 Statistical Analysis

The current section presents results from the statistical analysis of collected data. It is presented as charts showing work hours grouped by possession interval. The data collection was based on the annual (APP) and periodic possession plan (PPP) documents. A comparative analysis is shown for a) the sum of all routes in West Sweden (see Table 1) and b) for a specific route Western Main Line (Västra stambanan).

4.3.1 Comparative analysis: All routes

Annual possession plan (APP) is constructed on the tactical activity level and includes major track engineering works. Periodic possession plan (PPP) is constructed on the operational activity level and includes a more exact plan of works. Unplanned work and routine work (called white possessions) are not considered in the analysis. Some changes may occur in the possession plan after publications of PPP (e.g. when a reserved possession are unoccupied of some reason) but we assume that the changes are small and will not affect the overall result to a greater extent.

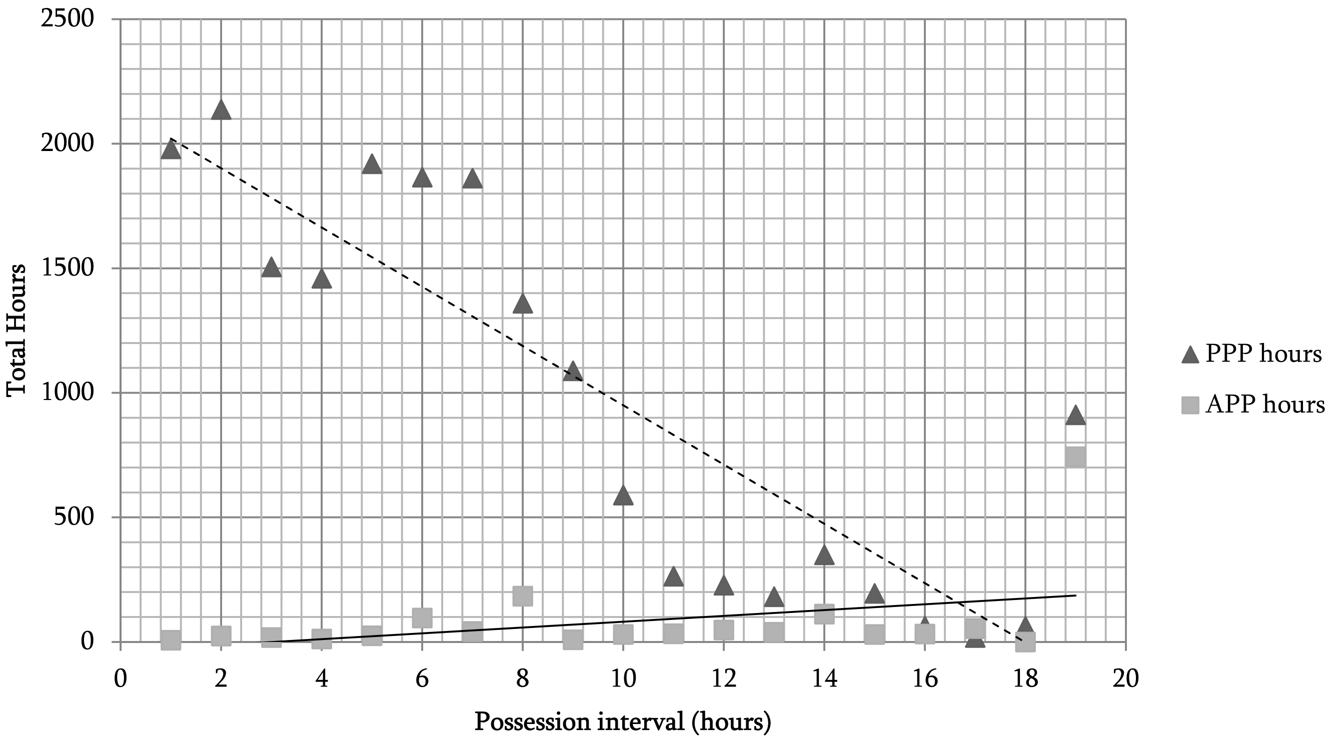


Figure 18. Result of possession hours for different possession interval for the sum of all routes in west Sweden in 2010.

As showed in Figure 18 there is a considerable gap between the amounts of possession hours planned in APP and PPP. For example, a very small portion of possessions with 5 hour interval existed in the APP (a total of 25 hours) while in Periodic possession plan (PPP), more than a total of 1900 hours were allocated in the 5 hours possession interval. In contrast, possession with a length of 18 hours had the same total hours in both plans.

4.3.2 **Comparative analysis: Main Western Line**

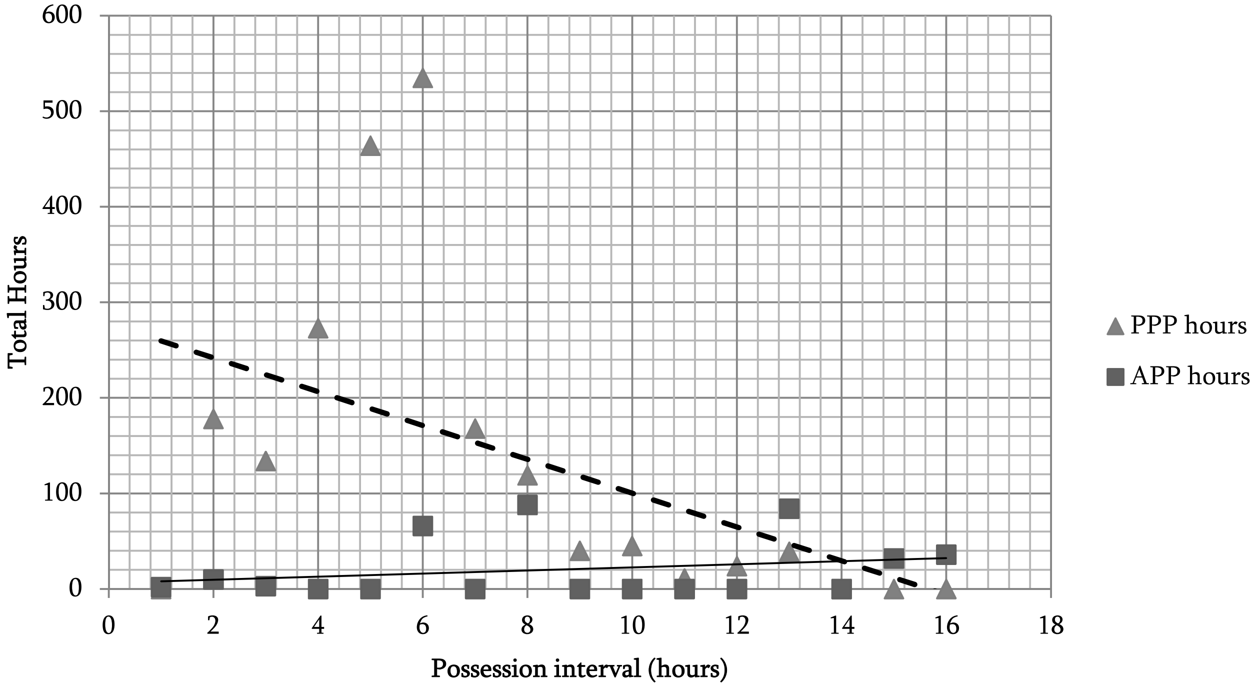


Figure 19. Result of possession hours for different possession interval for Western Main Line in 2010.

Western Main Line with its high traffic density is one of the most important routes in Sweden, connecting Sweden's two biggest cities Gothenburg and Stockholm. The gap between APP and PPP is also considerable as shown in Figure 19. Periodic possession plan is based on the actual need of track possessions to execute the ordered/needed work. The gap between APP and PPP shows the difference between planned work in Annual possession plan and needed possessions for engineering work in Periodic possession plan. See Appendix (II) for a comparison of work hours and numbers of interventions grouped by possession interval.

5 Discussion

It has been observed that the growth in the traffic volume has been positive while the punctuality has decreased (Åhren & Parida, 2009). The demands on quality and capacity have increased in the railway sector, leading to more trains and higher travelling speeds with higher axle loads. Heavier, wider, and longer trains running on the railway will result in higher degradation of railway asset and consequently higher maintenance need and cost. Long time functional life span is one of the important aspects of railway infrastructure which is highly dependent on the maintenance and renewal strategy used during its life cycle. In order to decrease maintenance cost and increase safety standards in a competitive environment with restricted budget, a cost effective track maintenance strategy is required, not only based on technical and safety limits but also on cost-effective maintenance (Arastehkhouy, 2011).

Putzalla & Rivier (2003) pointed out the conflict between capacity development, maintenance needs and engineering track possessions. An increase of wearing out resulting from traffic growth will increase demand for maintenance. Track possessions used for maintenance reduce capacity availability and therefore owners of infrastructure tend to prioritize availability instead of quality, and cut maintenance and renewal budgets (Putallaz & Rivier, 2003). Compared to other European countries, Sweden has an effective maintenance, but reinvestments level is very low in comparison and could result in higher rate of infrastructure degradation in a long-term aspect (Riksrevisionen, 2010).

Vickerman (2004) (2004) discusses the existence of incentives to ensure the optimal level of infrastructure asset maintenance. He concludes by referring to real evidence of privatization of infrastructure markets in U.K., that there is a need of improvement of the definition of quality indicators for infrastructure asset condition. Further, he states, that the quality of investment and maintenance is more important than the volume of these.

5.1 Resource Coordination Problems

Engineering track possession types have significant impact on production scheduling. Track possession duration has considerable influences on the productivity. Besides, knowing realistic possession information (types and duration) ex-ante (before entering into a contract), able contractors to allocate resources, construct a proper production plan and estimate the realistic project time and cost.

Outsourcing M&R in Sweden can be based on job specifications or functional requirements (see Ch. 2.3.5). In the first case, Swedish Transport Administration (STA) schedule maintenance and renewal tasks whereas the contractor schedules resources and executes the job. The job is carried out according to pre-described track access conditions that are agreed in a contract. When a contract is signed the contractor begins to coordinate and assign crews and equipments. A sudden change in work conditions during the project phase complicate scheduling and reduce the availability of resources. If the contractor fails to coordinate scheduled production with train paths, it results in considerable delay and disruptions in project. An example is the case with the late signed contract described in chapter 4.

5.1.1 Productive Time

The rail network is sparse and spread over a large area. Consequently transportation of technical crews, equipments, materials and machines is a time consuming process and incur high costs to the project. Productive time is the value adding time when technical crews directly increase the value of a technical system or a component. Figure 20 shows total work time consisting of a set of time blocks for a specific engineering work. The track possession time reserved for a work is not full productive work time. There is a need of preparation and setting time in the start and end of each event. Failures due to machinery problems or inability to fulfill the safety and quality requirements also reduce productive time.

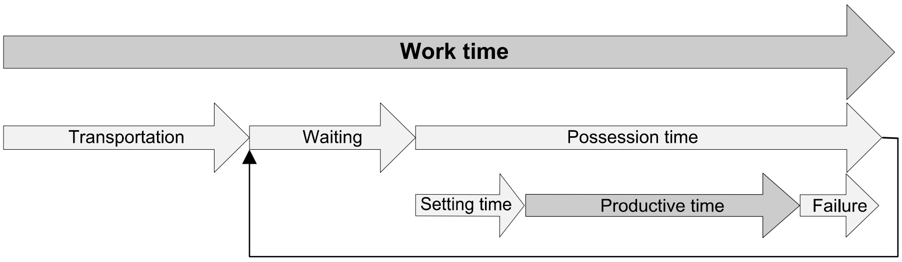


Figure 20. Different activities included in the work time.

Figure 20 indicates that productive time is a small part of the work time. Interruption of possessions results in new waiting and setting time because workers need to clear the work site in between. According to worksite safety regulations in Sweden, staffs are allowed to start the work one minute after train departure and forced to leave and clean the worksite ten minutes before the arrival of the next train.

For example if we assume two hours discontinuous track possessions without any transportation, about 22 minutes i.e. 18% of the total work time will be used for safety issues. In addition, depending on the work typology, setting time and failure probability cause further reduction of productive time in a specific possession interval.

5.2 **Productive Time vs. Possession Duration**

Figure 21 shows the process of single run ballast tamping on a double track line section over a train free period (Putallaz & Rivier, 2003). The track tamping machine has to stay idle at position A until the track possession time starts. Then it switches to position B and continues towards position C. When the work site (C-D) is reached, installation time starts. Execution of the work will begin between C and D. When point D is reached and re-installation time ends, the machine leaves the work site. Note that the machine have to leave the worksite before the possession time is about to end, even if the work is uncompleted.

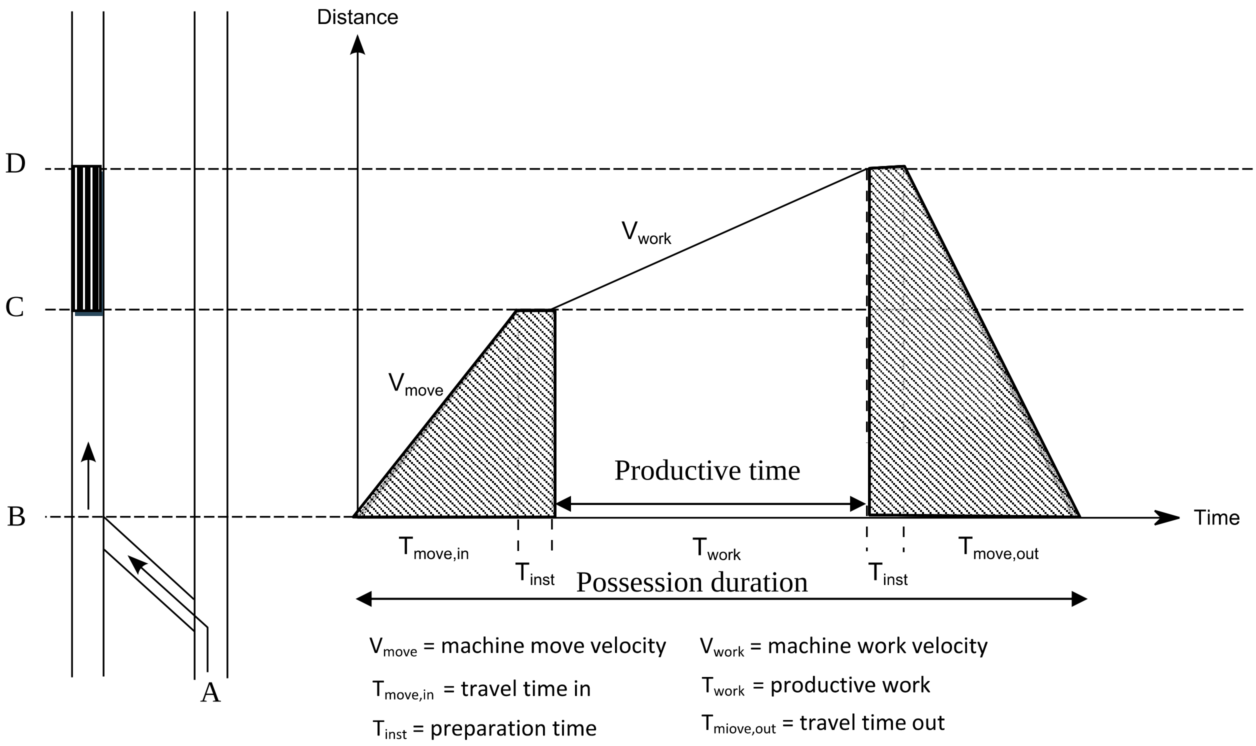


Figure 21. A distance-time diagram for a tamping task. Adapted from (Putallaz & Rivier, 2003).

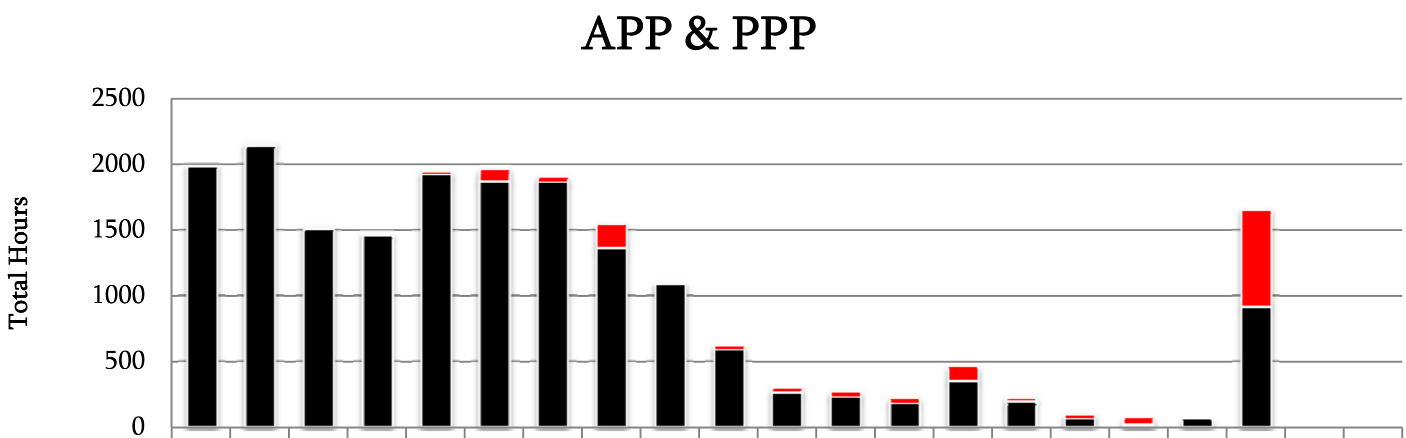
Figure 21 illustrates how the total productive time is linked to duration of the track possession. A step in possession duration increases productive time under the assumption of same equipment properties, machine and crews. It might be essential to understand the relations between track possession types, possession duration, productive time and cost-effectiveness of work.

5.3 **Cost-effective M&R**

Increasing demand on cost-effective maintenance and renewal leads to an increasing need for development of decision support systems for both infrastructure managers and service providers, to optimize the overall system performance. Development and alignment of such systems integrated in the long term planning strategy will not be achieved easily and in the near future.

Service providers must respond to unavailability of information during the tendering process, and in particular unknown track possessions. They should be informed before entering into a contract, about the allowable time a certain work can executed, to be able to plan an accurate work-schedule and estimate the best feasible bid-price. According to our interviews, it is very usual that the available time window for engineering work is not stated explicitly in the contract but refers to the long-term annual possession plan document (APP) stipulated by Swedish Transport Administration (STA).

In chapter 4.3.2, we estimated the frequency distribution of possession intervals on railway routes in West Sweden over a one year period. The table below shows a comparison between total hours scheduled in the long-term plan (APP) and short-term plan (PPP) for 2010. For example, possession of 8 hour durations reserved in Periodic possession plan constitutes a total of 1350 hours while in Annual possession plan it is just about a total of 184 hours.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	21	24
APP hours	7	24	18	12	25	96	42	184	9	30	33	48	39	112	30	32	54	0	744
PPP hours	1980	2138	1506	1460	1920	1866	1862	1360	1089	590	264	228	182	350	195	64	18	63	912

Figure 22. A quantitative comparison between APP & PPP 2010 in West Sweden.

As illustrated in Figure 22 the Periodic possession plan (PPP) is assumed to be the actual work execution and the real need of track possessions in order to execute the needed/ordered work on the railway network. APP is the annual possession plan and includes work planned 1 year in advance. The portion of works which is planned in the APP is very small compared to in the PPP. The gap between APP and PPP shows the different between long-term planned work/possession and actual needed work/possession in the railway network.

Different work conditions i.e. track possession types and duration, will affect the cost effectiveness of work as showed in Figure 23. As it showed in chapter 4, labour cost is a dominant factor in maintenance and renewals.

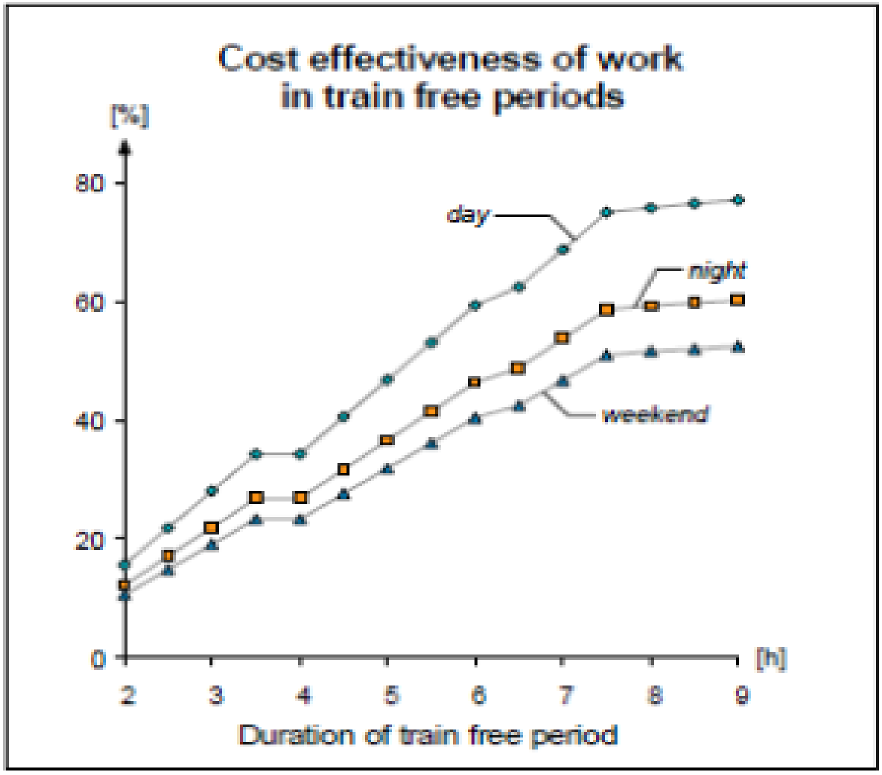


Figure 23. Cost effectiveness of work in train free periods (Bente & Lüking, 2001).

Depending on the work type, the shorter duration of train free period we have, the shorter productive work time we will get. Subsequently, shrinking the productive time increases activities duration and so, a larger number of track possessions are required to complete the work.

System unpredictability limits time windows for maintenance further. In case of disruption there are few re-routing options for trains and delayed trains will inevitably interfere with pre-planned maintenance activities (Higgins et. al., 1999). The cost sensitivity analysis (see Ch. 4.2.1) shows that 54 % of total project cost is related to labour cost. Overnight possessions accounted for 41 % of total track possessions in the project. However, the costs for overnight possessions constitute 52% of the total labour cost. The study reveals that variations in possession categories may affect the total project cost up to 21 % (see Table 4).

6 Conclusion

First, we present conclusions concerning the first research question (Ch 1.2) and afterwards recommendations for changes. Then, we present conclusions concerning the second research question (Ch 1.2) and associated recommendations.

6.1 Current Principles for Engineering Track Access Management

We have observed that possessions are scheduled and planned manually by the Swedish Transport Administration (STA). We find that possession conditions have a high impact on estimated bid-price and final project costs. Despite this, a dominant portion of possession information is provided 2 months before work execution.

In this study we have found the following criteria for the optimization of scheduling and planning engineering track access:

1. minimizing disruption of trains
2. minimizing total maintenance costs, including set-up and set-down time
3. minimizing crew travel time
4. minimizing number of nights with executed work
5. maximizing number of clustered and parallel work

Finding an optimal solution matching each criterion is not viable using manual methods. We have seen that a contractor naturally seeks to fulfill all criteria while the Infrastructure Manager (in this case the STA) seeks to fulfill criteria 1. According to our research only a small proportion of track possession is planned on an annual basis. Our research shows that 91 % of track possessions in West Sweden are planned in the operational level (PPP). Using criteria 2 is very difficult for planners in the Infrastructure Manager’s (IM) organization due to a seemingly missing knowledge about how possessions govern production costs. Criterion 3 is only viable when both contractor and IM plan and schedule M&R activities together.

A strong constraint on track access allocation is workers safety. Our research points out that workers safety may be affected by how well criterion 4 is fulfilled. The contractor opinion is that a high level of overnight possessions affects workers health and safety in form of increasing risk for mistakes arising from poor sight and tiredness. In addition, working nights instead of days could increase total project cost up to approximately 20% according to our analysis. Fulfilling criterion 4 increases worksite cost-effectiveness, productivity and safety. However, from case studies and interviews with the contractor we conclude that many possessions are planned in short perspective and executed at night and weekends. Besides, very high amount of possessions are scheduled on remaining capacity (actual capacity minus utilization).

Manual scheduling methods require rapid communications and we have observed various communication channels when a contractor is negotiating and requesting track access, e.g. telephone and email. Problem solving attitude, trust and cooperation is important, in particular in an uncertain environment as the railway sector. We have observed that, for the moment, management of engineering track access is dependent very much on the experience on few individuals inside IM’s and contractor organization. We have identified a need to catch and formalize relevant experiences and best practices for track access management to guard against eventual loss of knowledge, and accumulated distribution of knowledge.

With the background of abovementioned problems we recommend IM and contractor to focus on developing a long term understanding of each other’s businesses. To find the optimal possession interval, that minimizing both work site and capacity cost can be achieved only through collaboration and information sharing. We recommend the contractor to provide information to the client of what the client is buying before entering into a contract. See Putzalla and Rivier's (2003) estimation of optimal possession interval for a ballast screening activity (page 31). We also recommend the IM to develop optimization methods, such as a knowledge-based system, to be able to reach a more optimal maintenance schedule than the present method.

We suggest the IM to schedule track access fulfilling criterion 5 as much as possible, see Budai-Balke (2009). An option is to schedule a fixed track possession hours in APP every week reserved for preventive maintenance or corrective maintenance. That would increase possession continuity which has been recognized in our interviews and in earlier research as a key factor for increasing productivity. That would also increase possibilities for the IM to specify engineering track access.

6.2 Consequences of Incomplete Contracts

Lack of track access has shown to be associated with a cost premium for IM, due to the conflict between capacity development and M&R (see Ch 2.2.4). There is a risk that maintenance demands are neglected and postponed. Further, unfavorable track access conditions and short-term planning impose issues associated to specify track access in a contract.

From our study we see that lack of engineering track access results in an uncertain environment for a contractor in various ways. Uncertainty incurs transaction costs in form of re-negotiation, scheduling complexity and incomplete contracts that resulting in more administration. We have found that incomplete tender specifications increase the contractor's financial risk and may decrease the efficiency of the customer-relationship. We have seen that the contractor must respond to missing information by relying on standard contractual agreements which give them right to fair compensation for additional work and late changes. Missing data is compensated by assuming working conditions resulting in the lowest possible price and claims additional costs when they arises *ex-post*. To only rely on contractual agreements may however incur other risks for the contractor in form of a bad client-contractor relationship. As Kadefors (2004) argues, *"it is dangerous for contractors to rely on construction law for behavioral guidance if they wish to inspire trust"*.

We have observed in a case study (see Ch. 4.2.1) that uncertainty in track access circumstances could influence bid price up to 21 %. The aim of outsourcing includes reduction of service costs, reduction in personnel and increased flexibility of the business. It seems that a well functioning competitive environment is a fundamental condition to fulfill the aim of the outsourcing. The existence of a fair competitive environment seems to depend greatly on the level of completeness in the tender specifications. We recommend the IM to provide equal possibilities before tendering for all bidders to be able to handle lack of track possessions and estimate a feasible bid price.

Another indirect effect of incomplete contracts seems to be that it hides problems and prevent certain complex issues to be addressed. If the Infrastructure Manager is not able to plan and allocate M&R in an early phase, procedures for how to handle this gap should be expressed clearly in a formal language open for all parties before entering into a contract. Martin (1997) explains that due to complexity in maintenance contracts, the responsibilities between contractor and client should be explicitly separated. The study shows that, in terms of track access conditions, this is not done today in Sweden. We also recommend the contractor to improve administration and production processes, report unused possessions to the IM and cooperate with other contractors on the railway line to share possessions when possible.

In summary, we present actions that could help parties to gain better understanding of each other's efforts:

Before contract	**After contract**
Infrastructure Manager (IM)	
Express clearly procedures for handling lack of track access times	Adopt optimization methods for engineering track access
Finding a possession interval close to the optimal as possible	Provide collaborative communication and information systems (E-maintenance)
Contractor	
Provide information to the client of what the client is buying before entering into a contract	Cooperate with other contractors on the railway line and share possessions when possible
Develop production processes, i.e. use appropriate tools, work smarter and improve technology	Report unused possessions to the IM in order to free the capacity
	Optimize utilization of possessions and allocation of resources

It is worth to mention the "trade-off" between transaction cost incurred before and after entering into a contract. Winch (2001) points out that market competition can reduce production costs but also increase transactions cost due to the difficulty to write complete contracts. However it is obvious that an incomplete contract may instead increase transaction costs after the contract has been signed. For example, unknown track access increases the effort to schedule possession times, plan resources and negotiate track access with involved parties. An incomplete contract increases client's flexibility *ex-post* but also complexity for the contractor to plan production. In sum, advantages of a complete contract may weigh more than those arising from flexibility in a complex system such as the railway system.

References

Akerlof, G. A. (1970). The Market for Lemons: Qualitative Uncertainty and the Market Mechanism. *The Quarterly Journal of Economics, 84*, 488-500.

Albrecht, A. R., Panton, D., & Lee, D. (2010). Rescheduling rail networks with maintenance disruptions using Problem Space Search. *Computers & Operations Research*, DOI: 10.1016/j.cor.2010.09.001.

Al-Turki, M. U. (2009). Maintenance Planning and Scheduling. In Ben-Daya M. (ed) 2009, *Handbook of Maintenance Management and Engineering* (pp. 237-262). London: Springer.

Arastehkhouy, I. (2011). *Optimization of Track Geometry Maintenance: A Study of Track Geometry Degradation to Specify Optimal Inspection Intervals.* Luleå: Division of Operation and Maintenance Engineering, Luleå University of Technology.

Bajari, S., & Tadelis, P. (2001). Incentives versus transaction costs: a theory of procurement contracts. *RAND Journal of Economics, 32*, 287-307.

Bente, H., & Lüking, J. (2001). The Cost of Railway Infrastructure – Status quo and ways ahead. *Innovations for for a cost-effective Railway Track*, 3, 22-27.

British Standard. (1984). BS 3811: 1984 Glossary of Maintenance Management Terms in Terotechnology, HMSO, London.

Brusoni, V., Console, L., Lamma, E., Mello, P., Milano, M., & Terenziani, P. (1996). Resource based vs. Task-based Approaches for Scheduling Problems. In V. Brusoni, Z. Ras, & M. Michalewicz (Eds.), *Foundations of Intelligent Systems - Lecture Notes in Computer Science* (Vol. 1079, pp. 325-334). Berlin: Springer.

Budai-Balke, G. (2009). *Operations Research Models for Scheduling Railway Infrastructure Maintenance.* Phd. Thesis. Rotterdam: Erasmus University .

ECORYS Nederland. (2006). *Guidelines for Sustainable Partnerships in Railway Maintenance (Final Report).* Rotterdam 13 November: ECORYS.

Cheung, B. S., Chow, K. P., Hui, L. K., & Yong, A. M. (1999). Railway track possession assignment using constraint satisfaction. *Engineering Applications of Artificial Intelligence, 12*, 599-611.

Crocker, J. K., & Reynolds, J. K. (1993). The efficieny of incomplete contracts: an empirical analysis of air force engine procurement. *RAND Journal of Economics, 24* (1), 126-146.

Eisenhardt, K. (1989). Building Theories from Case Study Research. *The Academy of Management Review, 14* (4), 532-550.

Eisenhardt, K. M. (1989). Agency theory: An Assesment and Review. *The Academy of Management Review , 14* (1), 57-74.

Espling, U., & Kumar, U. (2008). Benchmarking of the Maintenance Process at Banverket (The Swedish National Rail Administration). In K. A. Kobbacy, & D. N. Murthy (eds.), *Complex System Maintenance Handbook - Springer Series in Reliability Engineering.* London. Springer London: Springer.

Eurostat. (2011). Retrieved May 1, 2011, from European Commission: http://epp.eurostat.ec.europa.eu/portal/page/portal/transport/data/main_tables

Hart, O., & Moore, J. (1988). Incomplete Contracts and Renegotiation. *Econometrica, 56* (4), 755-785.

Higgins, A. (1998). Scheduling of Railway Track Maintenance Activities and Crews. *The Journal of the Operational Research Society, 49* (10), 1026-1033.

Higgins, A., Ferreira, L., & Lake, M. (1999). Scheduling rail track maintenance to minimise overall delays. *The 14th International Symposium on Transportation and Traffic Theory, July, 1999.*

Jick, T. (1979). Mixing Qualitative and Quantitative Methods:Triangulation in Action. *Administrative Science Quarterly, 24* (4), 602-611.

Kadefors, A. (2004). Trust in project relationships - inside the black box. *International Journal of Project Management, 22* (3), 175-182.

Kumar, U. (2008). System Maintenance: Trends in Management and Technology. In K. B. Misra (Ed.), *Handbook of Performability Engineering*. London: Springer.

Márquez, A. (2007). *The Maintenance Management Framework*. London: Springer.

Martin, H. (1997). Contracting out maintenance and a plan for future research. *Journal of Quality in Maintenance Engineering, 3* (2), 81-90.

Mattsson, L. (2007). Railway Capacity and Train Delay Relationships. In L. Mattsson, A. Murray, & T. Grubesic (Eds.), *Critical Infrastructure - Advances in Spatial Science* (pp. 129-150). Berlin: Springer Heidelberg.

Mercer Management Consulting. (2002). *The GB Rail Industry: In its own words - Problems and Solutions.* London: DTLR.

Misra, K. (2008). Maintenance Engineering and Maintainability: An Introduction. In K. Misra (Ed.), *Handbook of Performability Engineering*. London: Springer.

Murthy, D., & Jack, N. (2008). Maintenance Outsourcing. In K. A. Kobbacy, & D. N. Murthy (eds.), *Complex System Maintenance Handbook - Springer Series in Reliability Engineering.* London: Springer.

Onwuegbuzie, J., & Johnson, B. (2004). Mixed Methods Research: A Research Paradigm Whose Time Has Come. *American Eduactional Research, 33* (7), 14–26.

Potts, K. (2008). *Construction Cost Management: learning from case studies.* London: Taylor and Francis.

Putallaz, Y., & Rivier, R. (2003). Strategic maintenance and renewal policy of a railway corridor, taking into account the value of capacity. *World Conference on Rail Research (WCRR 03),* September 2003. Edinburgh.

RailNetEurope. (2001). *Network Statement Glossary*. Retrieved May 30, 2011, from RailNetEurope: www.railneteurope.com/.../Glossary/Glossary_of_Nst_related_Terms_OnlineVersion.xls

Riksrevisionen. (2010). *Underhåll av järnväg (Railway Maintenance).* Stockholm: Riksdagstryckeriet.

Silverman, D. (2005). *Doing Qualitative Resarch: a practical handbook*, 2nd ed. London: SAGE Publications.

Swedish Transport Administration. (2011). *Trafikveket.* Retrieved May 30, 2011, from http://www.trafikverket.se/Om-Trafikverket/Andra-sprak/English-Engelska/Railway-and-Road/Network-Statement1/Network-Statement-2012/

Transportstyrelsen. (n.d.). Retrieved from http://www.transportstyrelsen.se/en/About-us/

Vatn, J., Steiro, T., & Nordskag, A. (2003). An overview to outsourcing - trends and different options. *Innovations for a cost effective Rail Track. 6-13.*

Vickerman, R. (2004). Maintenance incentives under different infrastructure regimes. *Utilities Policy, 12* (4), 315–322.

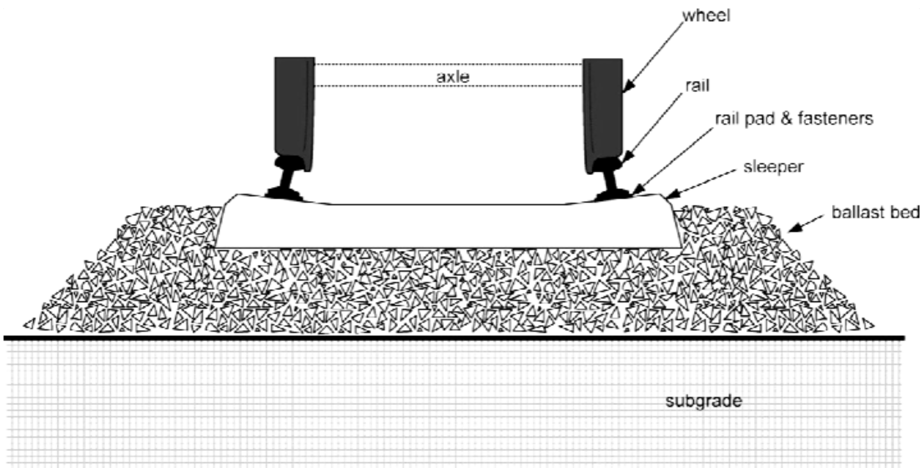
Williamson, E. O. (1985). *The economic institutions of capitalism.* London: Collier Macmillan.

Åhren, T., & Parida, A. (2009). Overall railway infrastructure effectiveness (ORIE) - A case study on the Swedish rail network. *Jornal of Quality in Maintenance Engineering, 56* (1), 17-30.

Glossary

BALLAST[1]

The purpose of ballast is to support the rail/sleeper combination, to distribute the load applied to it, to facilitate drainage to the track and thereby keep water away from rails and sleepers. The ballast is made up of stones of granite or a similar material and should be rough in shape to improve the ability of locking of stones (in this way they will resist better to the movements).



BALLAST CLEANING[2]

The process for renewing the roadbed involves removing the ballast, cleaning it, and replacing it. The shaker screen separates the good ballast from the bad ballast. Clean ballast is then returned to the track for tamping along with more ballast to make a good roadbed.

BALLAST TAMPING[3]

Ballast tamping is the process by which ballast is packed around the sleepers of a track to ensure the correct position for the location, speed and curvature. Can be done manually or mechanically by special tamping machines.

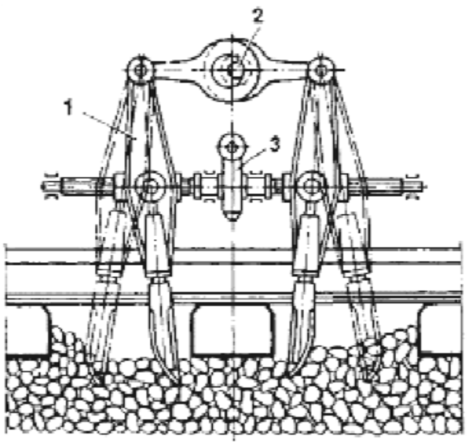


Figure 14 Diagram of the working element of a tamping machine: (1) tamping arm, (2) eccentric shaft, (3) squeezing mechanism

CATENARY SYSTEMS[7]

The catenary system consists of the overhead power

	cables for electric trains. While age and corrosion are important in the speed of degradation of catenary system, heavily used systems are more likely to require higher levels of maintenance and renewal.
ENGINEERING WORKS[5]	Technical works on the rail track, including construction and alteration.
LINE[7]	A line consists of one or more adjacent running tracks forming a route between two points.
LINE CAPACITY[3]	Line capacity is the maximum possible number of trains capable of being operated over a line in one direction. It is usually expressed in trains per hour.
PATH-ALLOCATION PROCESS [5]	Process that involves assigning specific train paths to railway operators.
POSSESSION[7]	Non-availability of part of the rail network for full use by trains during a period of time reserved for the carrying out of works is called "possession". Possession is an operational arrangement that prohibits scheduled train movements, marshalling or shunting activities on the track (RailNetEurope, 2001).
RAIL[1]	Rail is a rolled steel shape designed to be laid end-to-end in two parallel lines on sleepers to form a track for railroad rolling stock. Rails deteriorate through natural processes, such as corrosion. In certain environmental conditions (such as heavy pollution, wet tunnels and salt-laden atmospheres) this process can be accelerated in such of way that it becomes the primary factor of maintenance and renewal. The life of the rail is also determined by fatigue. It is considered to be partly "consumed" each time it is subjected to the wheel loads of passing trains. As the cumulative traffic carried by a piece of rail increases with its age in service, there will be an increasing likelihood that the rail metal will develop internal defects. Monitoring of rail defects, and the actions necessary to respond to them when they are detected, are both important elements of rail maintenance.
RAIL GRINDING[2]	Rail grinding is the process to maintain a predetermined profile on the head of the rail in order to maximize rail life and minimize rolling resistance reducing wheel wear and improving fuel economy.
RAILWAY[7]	A railway is a transport system in which trains run on steel rails. On most railways, the tracks consist of two rails, which are placed exactly 143.5 cm apart.
RAILWAY NETWORK[7]	Railway network means all railways in a given area
ROLLING STOCK[7]	Rolling stock consists of locomotives, passenger and freight vehicles owned or operated by a company.

SHUNTING[5] To switch a rail vehicle from one track to another.

SIDING[6] An auxiliary track to a main or secondary track for the meeting or passing of trains is called a siding.

SIGNALS[3] Signals are the visual indications passed to a train driver to advise the speed, direction or route of the train.

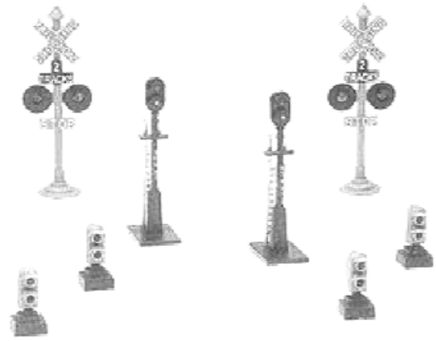


Figure 15 Different types of signals

SLEEPERS (or TIES)[3] The sleepers are the transverse members of the track, made of wood, concrete or sometimes steel, which are used to secure the rails at the correct gauge. Steel chairs, fixed to the sleepers, hold the rails in place by means of clips or keys. Sleepers degrade in various ways, but under good conditions the wooden sleepers may last up to 25 years. Besides the environmental factors, such as corrosion, the effects of use also drive the costs of sleeper maintenance and renewal. The repeated impact by passing trains may cause fatigue, which leads, for example, to cracking or splitting and the failure of the rail fastening. The load imposed upon sleepers will vary with the track design, the quality of its maintenance, the quality of vehicle maintenance and the nature of the underlying track foundation.

SWITCHES (or POINTS)[3] Switch is a track section, which allows the train to move from one track to another.

USAGE COST[1] Usage cost is defined as that element of the total cost of maintenance and renewal, which varies with the amount and nature of traffic carried. Not all maintenance and renewal costs depend on usage. The costs of certain types of asset are considered not to vary at all and even where assets are considered to have usage related costs, the degree and significance of these costs varies by asset type.

TRAIN PATH[5] The infrastructure capacity needed to run a train between two places over a given time period.

TRACK[1] The track is a fundamental part of the railway infrastructure. The usual track consists of the two steel rails, secured on sleepers to keep the rails at the correct distance apart and capable of supporting the weight of the trains. The third major component of the track is the ballast. The costs of maintaining and renewing track assets are considered to be the most significant usage-related costs. These costs are also heavily influenced by the interaction between track and train. Poorly maintained vehicles impose greater track forces and hence cause greater track damage and more rapid degradation of the track assets; similarly, poorly maintained track imposes greater wear and thus higher rolling stock maintenance costs.

TRACK GEOMETRY[1]	Track geometry measurement means to measure the curve, grade and cross level condition of the track. To maintain the geometry of the track means to maintain its designed horizontal and vertical alignment and the dimension relationship between the two running rails. Track geometry maintenance can involve several processes, including manual attention. However, the most common form is mechanical tamping, in which special machines consolidate the ballast to support the corrected track geometry.
TRACK INFRASTRUCTURE[7]	The track infrastructure consists of rails, sleepers, ballast, fastenings, switches, crossings and signals.
TRAFFIC DENSITY[7]	Traffic density means the number of trains, which are running at the same time on a certain portion of a line.

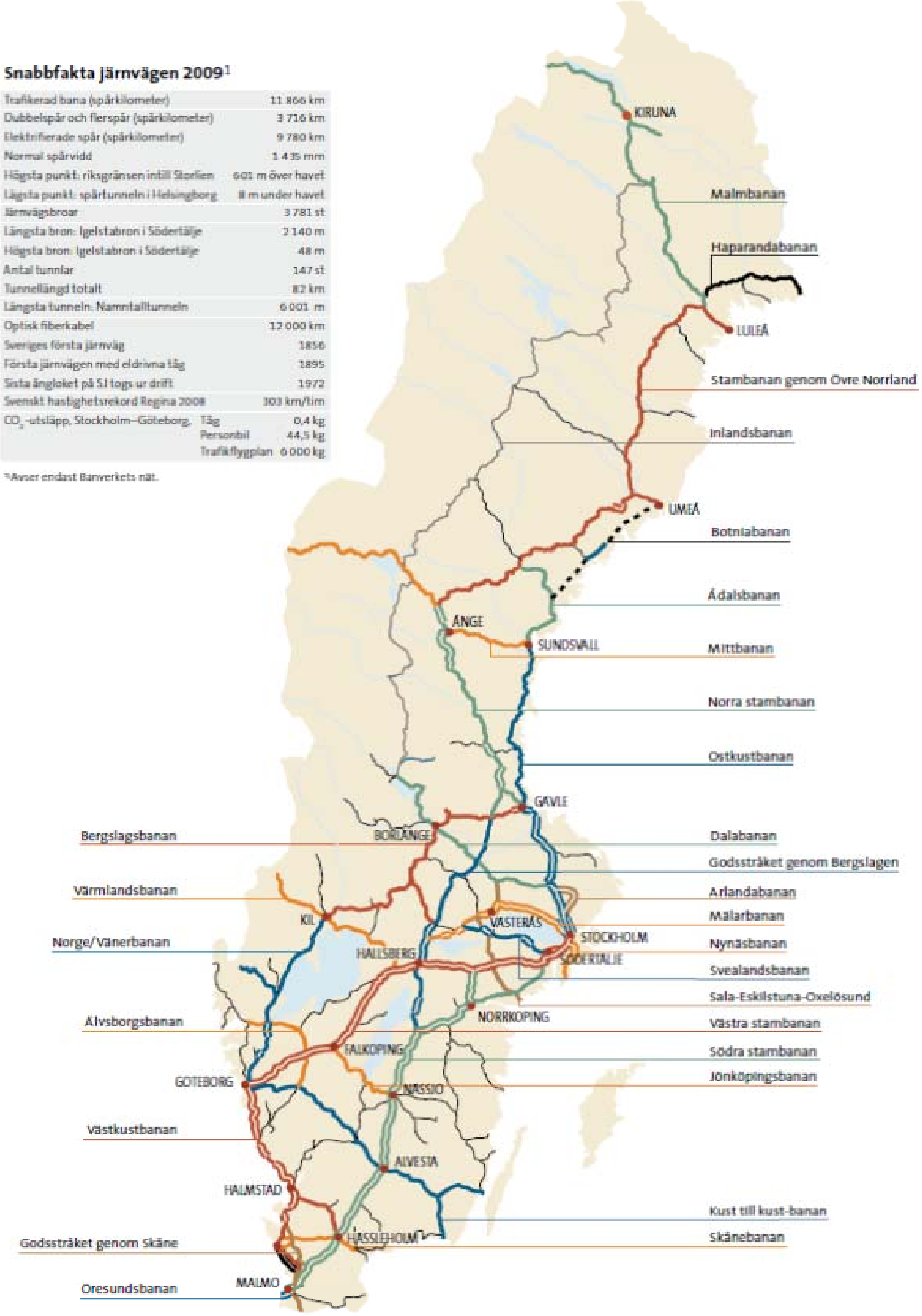
Appendix (I) – Map of Railway Routes in Sweden

Svenska järnvägsnätet

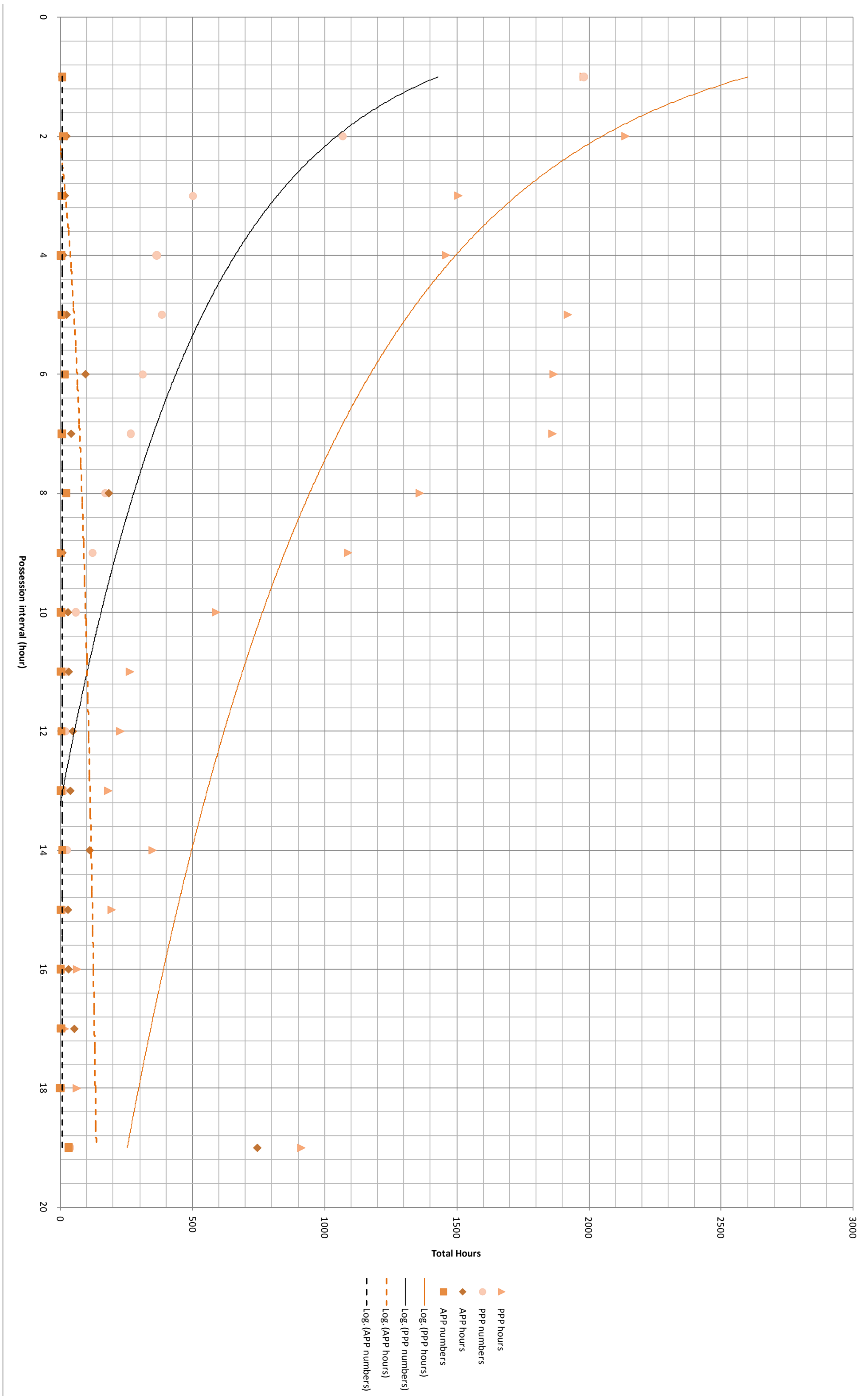
Snabbfakta järnvägen 2009[1]

Trafikerad bana (spårkilometer)		11 866 km
Dubbelspår och flerspår (spårkilometer)		3 716 km
Elektrifierade spår (spårkilometer)		9 780 km
Normal spårvidd		1 435 mm
Högsta punkt: riksgränsen intill Storlien		601 m över havet
Lägsta punkt: spårtunneln i Helsingborg		8 m under havet
Järnvägsbroar		3 781 st
Längsta bron: Igelstabron i Södertälje		2 140 m
Högsta bron: Igelstabron i Södertälje		48 m
Antal tunnlar		147 st
Tunnellängd totalt		82 km
Längsta tunneln: Namntalltunneln		6 001 m
Optisk fiberkabel		12 000 km
Sveriges första järnväg		1856
Första järnvägen med eldrivna tåg		1895
Sistaångloket på SJ togs ur drift		1972
Svenskt hastighetsrekord Regina 2008		303 km/tim
CO_2-utsläpp, Stockholm–Göteborg	Tåg	0,4 kg
	Personbil	44,5 kg
	Trafikflygplan	6 000 kg

[1]Avser endast Banverkets nät.



Appendix (II) – Chart of Total Work Hours and Numbers of Interventions



This chart is based on data collected from Periodical and Annual Possession Plans for 2010 for Western Main Line. It presents total work hours and numbers of interventions grouped by possession interval from tactical and strategic level of scheduling.