

# Maintenance Related Losses

**A study at the Swedish National Rail Administration**

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Department of Business Administration and Social Sciences  
Division of Quality Technology & Environmental Management



**Licentiate Thesis No. 23**

**Division of Quality and Environmental Management**

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*"The edge... there is no honest way to explain it because the only people who know where it is are those that have gone over"* Hunter S. Thompson



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# ABSTRACT

The global competition among companies has lead to higher demands on the production system. Quality has become an important factor for competition. Customer satisfaction depends upon the fulfillment of a number of quality parameters. Two important quality parameters are dependability and safety. Maintenance is performed to ensure dependability and safety of the systems. Normal operation will gradually impair the performance, due to the normal degradation caused by wear, dirt, corrosion and overloading. Maintenance is therefore important for the prevention of hazardous states of the systems, i.e. for incident and accident prevention. However, although maintenance is performed in order to increase the safety, incorrectly performed maintenance can reduce the safety of the systems and create losses.

The purpose of this thesis is to explore and describe different deviations from the intended maintenance activities that result in losses, manifested in incidents and accidents. The main aim of this is to control the contracted maintenance work better, and thereby ensure safety for passengers and personnel at the Swedish National Rail Administration. The results are intended to be a part of the continuous improvement work at the Swedish National Rail Administration. To fulfil the stated purpose an archival study supported by a literature study has been performed. The archival study focused on incidents and accidents related to the Swedish railway. The main objective of this study is to identify, classify and analyze maintenance related incidents and accidents.

The result of the study may be described in two parts. The first part is an analytical model for the investigation of maintenance related incidents and accidents. The model is founded on theoretical findings. The model describes the chain of events starting with lack of control and ending in the losses, manifested in incidents and accidents. The second part, which is based on empirical findings, is a taxonomy of incidents and accidents related to the Swedish railway. The maintenance related incidents and accidents are analysed and classified. The primary causes of these incidents and accidents are determined and discussed. About 30% of the track related incidents and accidents were caused by improper maintenance. Some contributory causes of these were lack of communication and rule violations.



# SAMMANFATTNING

Den globala konkurrensen bland företagen ställer högre krav på produktionssystemen. Kvalitet har blivit en viktig faktor för konkurrenskraften. Kundtillfredsställelse beror på uppfyllandet av ett antal kvalitetsparametrar. Två viktiga kvalitetsparametrar är driftsäkerhet och säkerhet. Underhåll utförs för att säkerställa systemets driftsäkerhet och säkerhet. Den normala driften av systemet leder till en gradvis försämring av dess status p.g.a. slitage, smuts, korrosion och överbelastning. Underhåll är därför viktigt för att förebygga farliga tillstånd i systemet. Fast underhåll genomförs för att öka säkerheten kan felaktigt utfört underhåll reducera systemets säkerhet och skapa förluster.

Syftet med denna avhandling är att utforska och beskriva olika avvikelser från de tänkta underhållsaktiviteterna, vilka skapar förluster och orsakar incidenter och olyckor. Det huvudsakliga målet är att bättre kunna styra underhållsentreprenader och därigenom säkerställa säkerheten för passagerare och personal vid Banverket. Resultaten syftar till att vara en del av det ständiga förbättringsarbetet vid Banverket. För att uppfylla syftet har en databas- och litteraturstudie genomförts. Databasstudien fokuserades på incidenter och olyckor vid den Svenska järnvägen. Syftet med denna studie är att identifiera, klassificera och analysera underhållsrelaterade incidenter och olyckor.

Studiens resultat kan delas upp i två delar. Den första delen är en dataanalysmodell som används för databasstudien. Denna modell baseras på identifierad teori. Denna dataanalysmodell beskriver orsakskedjan från bristande styrning till förluster, vilka manifesteras i incidenter och olyckor. Den andra delen, vilken baseras på empiri, är en klassificering av incidenter och olyckor vid den Svenska järnvägen. Underhållsrelaterade incidenter och olyckor klassificeras och analyseras. De primära orsakerna till dessa incidenter och olyckor bestäms och diskuteras. Ungefär 30% av de spårrelaterade incidenterna och olyckorna orsakas av bristfälligt utfört underhåll. Andra bidragande orsaker är bristande kommunikation och regelbrott.



# LIST OF APPENDED PAPERS

This thesis includes an extended summary and the following three papers, appended in full.

- PAPER I** Holmgren, M. & Akersten, P.A. (2002a). Maintenance related risks – Do they need any further investigation? *Proceedings of the 3<sup>rd</sup> Edinburgh Conference on RISK: Analysis, Assessment and Management*, Edinburgh, Scotland, April 8-10, 2002.
- PAPER II** Holmgren, M. & Akersten, P.A. (2002b). The maintenance process: looked upon through risk glasses. *Proceedings of the 16<sup>th</sup> International Maintenance Congress Euromaintenance 2002*, Helsinki, Finland, June 3-5, 2002, 267-273.
- PAPER III** Holmgren, M. (2003). Maintenance related losses – A study of Swedish rail and track related accidents and incidents. *Submitted for publication*.



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# 1 INTRODUCTION

*A brief introduction will be given in this chapter in order to introduce the reader to the problem and explain why the author found the research area interesting.*

## 1.1 Background and Problem Discussion

The global competition among companies has lead to higher demands on the production system<sup>1</sup> (Miyake & Enkawa, 1999). Quality has become an important factor for competition. (Bergman & Klefsjö, 1997)

One approach to quality is Total Quality Management, TQM (Ollila & Malmipuro, 1999). TQM may be regarded as a management system consisting of values, methodologies<sup>2</sup> and tools<sup>3</sup> (Hellsten & Klefsjö, 2000). The aim of Total Quality Management is increased internal and external customer satisfaction with a reduced amount of resources (Bergman & Klefsjö, 2003).

Customer satisfaction depends upon the fulfillment of a number of quality parameters. Two important quality parameters are dependability<sup>4</sup> and safety. Different kinds of activities are performed to ensure dependability and safety. One of them is maintenance<sup>5</sup>. (Bergman & Klefsjö, 1997)

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<sup>1</sup> A system is a network of interdependent components that work together to try to accomplish the aim of the system (Deming, 1994).

<sup>2</sup> A Methodology is a way to work within an organisation to reach the values and consists of a number of activities performed in a certain way (Hellsten & Klefsjö, 2000).

<sup>3</sup> A tool is here defined as “rather concrete and well-defined tools, which sometimes have a statistical basis, to support decision-making facilitate analysis of data”. (Hellsten & Klefsjö, 2000)

<sup>4</sup> Dependability is here defined as a collective term used to describe the availability and its influencing factors: Reliability, Maintainability and Maintenance Supportability. Reliability is the ability of an item to perform a required function under given conditions for a given time interval. Maintainability is the ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources. Maintenance Supportability is the ability of a maintenance organization to have the right maintenance support at the necessary place for performing the required maintenance activity at a given instant of time or during a given time interval. (SS-EN 13306)

<sup>5</sup> Maintenance is defined as the combination of technical and administrative actions such as supervision actions intended to retain an item in or restore it to a state in which it can perform a required function (IEV191-07-01, 2002).

However, maintenance is not something new. Maintenance could be found already in the Industrial Revolution, generally held to have begun in England in about 1750. Maintenance then consisted of industrial craftsmen such as smiths, coopers, and carpenters repairing the buildings, primitive machines and vehicles for the day. There were no standardization and interchangeable parts, so maintenance and construction had to be integrated. Thomas Jefferson developed the first interchangeable parts in 1785. He noted that if musket parts were made accurately enough they could be interchangeable. It was easier to maintain the system when the maintenance personnel did not have to adjust the spare parts when they were replaced. Maintenance based on interchangeable parts was then born. (Sherwin, 2000)

Normal operation of the systems will gradually impair the performance of the systems. Wear, dirt, corrosion and overloading are some contributory causes of the degradation<sup>6</sup> of the systems (Clifton, 1974). Therefore, the management must determine a proper maintenance methodology to ensure the functioning of the systems (Coetzee, 1998). There are numerous different maintenance methodologies applied within different industries. A methodology, or way of working in the organization to reach the goals, consists of a number of activities performed in a certain order (Akersten & Klefsjö, 2003). Some examples of maintenance methodologies that are frequently used are: Total Productive Maintenance, TPM (Nakajima, 1988); Reliability Centred Maintenance, RCM (Nowland & Heap, 1978); Condition Based Maintenance, CBM (Hywel, 1994).

Maintenance is also important for the system's impact on safety and for incident<sup>7</sup> and accident<sup>8</sup> prevention (Uth, 1999). However, although maintenance is performed in order to increase the safety, incorrectly performed maintenance may reduce the safety of the system and thereby enable the possibility

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<sup>6</sup> Degradation is here defined as an irreversible process in one or more characteristic of an item due to either time, use or external cause. Degradation may lead to a Failure. Failure is the termination of the ability of an item to perform a required function. (SS-EN 13306)

<sup>7</sup> An incident is here defined as an undesired event that can, or does, result in losses (Bird & Loftus, 1976).

<sup>8</sup> An accident is here defined as an unplanned and uncontrolled event in which the action or reaction of an object, substance, person, or radiation results in personal injury or the probability thereof (Heinrich et al., 1980). It is usually the result of a contact with a source of energy above the threshold limit of the body or structure (Bird & Germain, 1996).

for extensive losses<sup>9</sup> (Kletz, 1988). Furthermore, improper maintenance activities due to or resulting from the execution were a contributory cause of some major accidents in the chemical industry in Germany (Uth, 1999). Another example is the Piper Alpha accident in 1988, which was caused by maintenance work that unintentionally created latent faults<sup>10</sup> at the platform, causing it to fail dangerously at start-up (Hale et al., 1998). Besides safety aspects, improper maintenance may cause the system to deteriorate, thereby creating quality deficiencies, such as delays and non-conforming products (Ollila & Malmipuro, 1999).

The use of contractors to undertake important work, such as maintenance, is not a new issue. It is common nowadays that companies worldwide focus on their core business and contract out different functions, such as maintenance, in order to achieve cost reduction (van der Meer-Kooistra & Vosselman, 2000).

Although involvement of maintenance contractors will in some cases reduce the direct cost for the company, there is also an increased need for better control, which requires the establishment of suitable management control systems (van der Meer-Kooistra & Vosselman, 2000). Administrator control may be affected by contracted maintenance, especially if proper information about system changes and repair is missing (Kletz, 2001). In the United Kingdom, several accidents have occurred at the British Rail due to inadequate control of the maintenance contractors. Some recent examples are the derailment and collision at Ladbroke Grove in 1999, which caused severe losses, and the derailment near Hatfield in 1999 (HSE, 2002).

In Sweden the Swedish National Rail Administration ("Banverket") decided to open up their maintenance to the free market in July 2001. Instead of conducting maintenance within their own organisation, contractors were invited to attend in the bidding for maintenance contracts regarding some Sections of the track in 2002. (Banverket, 2003)

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<sup>9</sup> The term loss is here defined as an undesired event that affects people or property creating physical or economic harm (Bird & Germain, 1996).

<sup>10</sup> Latent fault is here defined as an existing fault that has not yet been detected. A fault is a state of an item characterised by inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources. (SS-EN 13306)

The Swedish National Rail Administration must ensure that passenger safety is high and has therefore adopted a zero vision, meaning that nobody is to be killed or seriously injured as a consequence of a traffic accident (Banverket, 2003). Experiences obtained from the United Kingdom and other countries show that contracting out maintenance may cause losses if not managed properly.

Therefore it is important to identify, understand, and control different deviations that may occur due to insufficiently controlled maintenance, in order to create possibilities of improving the safety for the passengers and any third party when maintenance is contracted out.

## 1.2 Purpose of the Study

The purpose of this thesis is to explore and describe different deviations from the intended maintenance activities that result in losses, manifested in incidents and accidents. The main aim of this is to control the contracted maintenance work better, and thereby ensure safety for passengers and personnel at the Swedish National Rail Administration. The results are intended to be a part of the continuous improvement work at the Swedish National Rail Administration.

## 1.3 Research Questions

The purpose of the study has been transferred to the following research questions:

1. How can maintenance related losses, manifested in incidents and accidents, be analysed?
2. What are the primary causes of the maintenance related losses at the Swedish National Rail Administration?
3. How can the maintenance related losses be illustrated in relation to the maintenance processes?

## 1.4 Limitations

This thesis focuses on railway track related maintenance, and not maintenance connected to the rolling stock, i.e. different types of vehicles on the railway track. The reason for this limitation is that maintenance of the railway track is going to be contracted, and therefore the need for administrative control increases.

## 1.5 Structure of the Thesis

The structure of the thesis is presented in Figure 1.1.

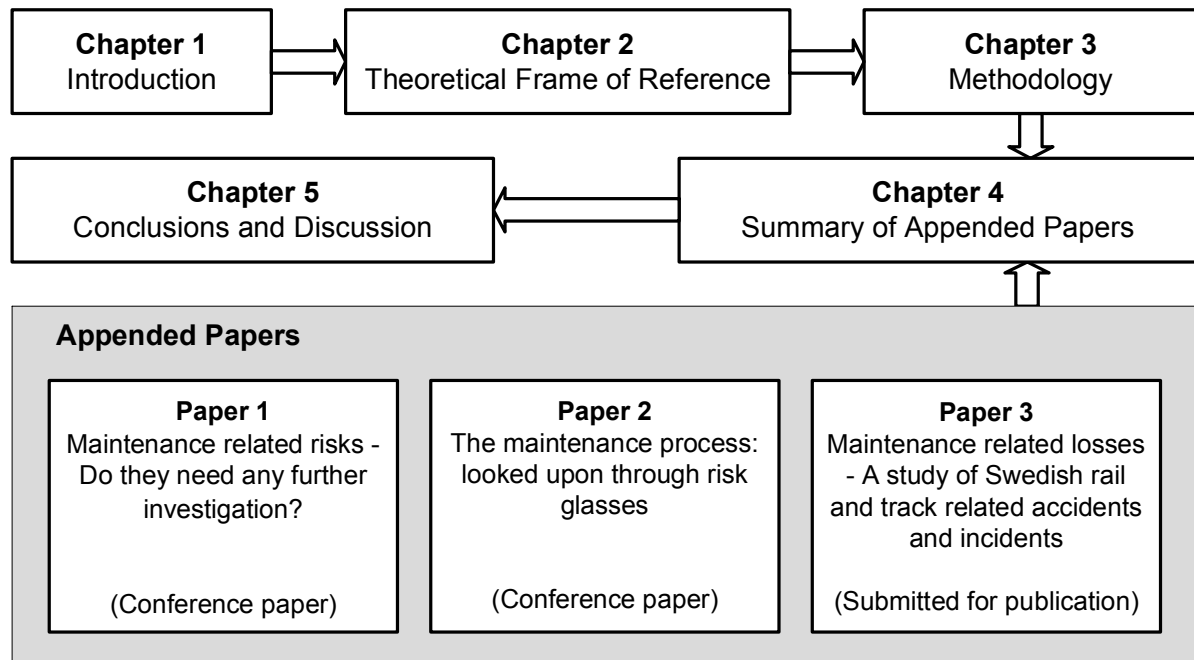
The first chapter (Introduction) starts with a description of the background and research problem. Thereafter, the purpose, research questions, limitations and thesis structure are outlined.

In the second chapter (Theoretical Frame of Reference) the theoretical framework will be presented, including aspects of Maintenance Management and Safety Management.

In the third chapter (Methodology) the chosen research design and different aspects of data collection and data analysis will be presented. Validity and reliability issues of the study will also be discussed.

In the fourth chapter (Summary of Appended Papers) the background and purpose of the different papers will be presented. Moreover, the methodology applied in the different studies, which are presented in the papers, and the conclusions drawn from the studies will be presented.

In the fifth chapter (Conclusions and Discussion) the general conclusions drawn from the research work will be presented and a discussion will be held. Finally, further research work will be presented.



*Figure 1.1. The figure illustrates the structure of this thesis, including five chapters and three appended papers.*

## 2 THEORETICAL FRAME OF REFERENCE

*This chapter consists of the theoretical frame of reference. Areas important for this thesis are described.*

### 2.1 Quality

Crosby (1979) defines product quality as “conformance to requirements”, Deming (1986) says that “quality should be aimed at the needs of the customers, present and future”, and Taguchi & Wu (1979) states that “the lack of quality is the losses a product impacts to society from the time the product is shipped”, and gives by that a definition, which is closely related to today’s concept of ‘sustainable society’. According to the international standard ISO 9000:2000 “quality is the degree to which a set of inherent characteristics fulfils the requirements i.e. the needs and expectations that are stated, generally implied or obligatory”. In summary this means that today’s view of quality is closely related to customer satisfaction, a view that is also expressed in the definition by Bergman & Klefsjö (2003) when they claim that “the quality of a product is its ability to satisfy, or preferably exceed, the needs and expectations of the customers”.

The concept of product quality has many dimensions. For goods, some of them are (Bergman & Klefsjö, 2003):

- Reliability, which is a measure of how often problems occur and how serious these are.
- Maintainability, which summarizes how easy or difficult it is to detect, locate and take care of problems.
- Environmental impact, which is a measure of how the product affects the environment, e.g. in the form of emissions of recyclability, and how environmental aspects are treated in the production.
- Safety, meaning that the article does not cause damage to people or property, or, in some cases, provides adequate protection against damage.

Quality activities and improvements are today often covered in the concept of Total Quality Management (TQM). This concept may be described in several ways, but during the last few years a couple of papers have been presented in which a perspective of management system has been used to define TQM. One of these papers is Hellsten & Klefsjö (2000), who define Total Quality Management as “a continuously evolving management system consisting of values, methodologies and tools, the aim of which is to create external and internal customer satisfaction with a reduced amount of resources”.

The values, which should be the basis for the quality culture, are, according to Bergman & Klefsjö (2003):

- Focus on customers
- Focus on processes
- Base decisions on facts
- Let everybody be committed
- Improve continuously
- Committed leadership

In today's society we are becoming increasingly dependent on the technological systems. The consequences of interruption or accidents caused by these systems are often serious, sometimes disastrous. Consequently, reliability and safety are extremely important quality dimensions and reliability engineering, comprising methodologies and tools for increased reliability and safety is a vital part of Total Quality Management. According to Bergman & Klefsjö (2003), the main aim of reliability engineering is to:

- Find causes of failures and try to eliminate these, i.e. increasing the failure resistance of the product.
- Find the consequences of failures and, if possible, reduce and eliminate their effects, i.e. increasing the tolerance of the product to failure. This is sometimes called increased fault tolerance.

In reliability engineering and reliability management the importance of progressive, systematic improvement work cannot be overemphasized. Here the decisions have to be based on facts. The causes of failure, or the possible events that might cause failure, have to be systematically analysed and it is, as in most other improvement work, important to look systematically at the relevant processes and improve their ability to produce and maintain a system's reliability and safety in an efficient way. The more complex the prod-

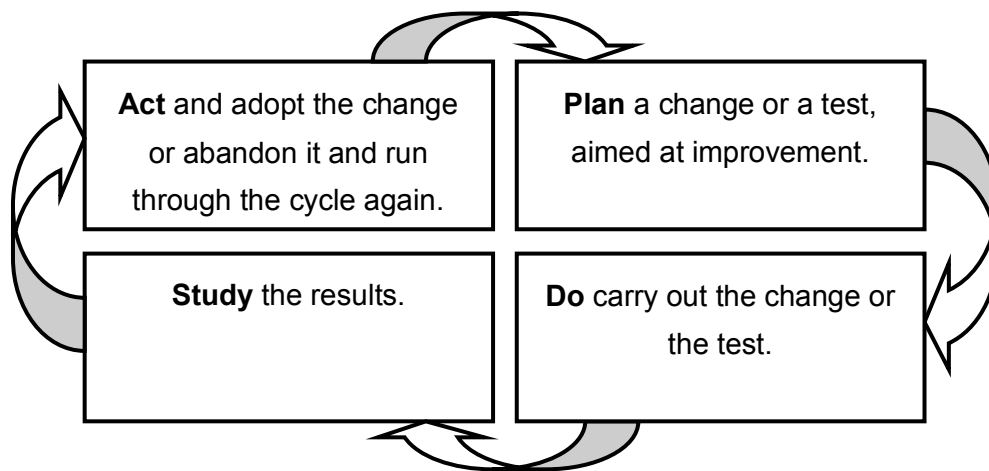


ucts are that we study, the more important it is to establish a system view taking the interaction between the elements into consideration in order to ensure that the system is something more than the sum of the individual elements. (Bergman & Klefsjö, 2003)

A system is here defined as a network of interdependent components that work together to try to accomplish the aim of the system (Deming, 1994).

### 2.1.1 The Deming Cycle

The Deming Cycle is often used in order to establish a mental model of continuous improvement work. The different phases of the Deming Cycle are illustrated in Figure 2.1.



*Figure 2.1. The Deming cycle illustrates different phases in the continuous improvement work. The first step starts with an identified problem and a suggestion for improvement is planned (plan). In the second phase (do) the change for improvement is applied. Then, the result of the change is studied (study). Finally, if the change was successful, the results are adopted and new routines and methodologies are established. (Source: Deming, 1994)*

**Plan:** The first step starts with an idea of improvement of a product or a process. It leads to a plan for the test, comparison or experiment. It is very important to plan the improvement carefully; a too quick start may be ineffective (Deming, 1994). The decisions taken must be based on facts (Bergman & Klefsjö, 2003).

**Do:** Carry out the change or test (Deming, 1994). It is then important to make everybody involved fully aware of the problem and the agreed improvement steps (Bergman & Klefsjö, 2003).

**Study:** When appropriate steps have been taken to solve the problem during the Do-phase, we need to study suitably chosen parameters and carefully analyse the data (Bergman & Klefsjö, 2003). This means that we study the results (Deming, 1994).

**Act:** Adopt the change or abandon it and run through the cycle again with different conditions (Deming, 1994). If we got an improvement we have to adopt the change and establish new routines and methodologies. If the actions taken did not give the expected results we need to abandon the change and run through the cycle once again. However, it is important also to learn from the way we perform improvements in order to improve our improvement work (Bergman & Klefsjö, 2003).

## 2.2 Maintenance Management

All equipment is prone to break down sooner or later. Therefore, there must exist some support to repair, restore, or replace defective units. This support is called maintenance (Coetzee, 1998). Maintenance may be defined as the combination of technical and administrative actions, such as supervision actions, intended to retain an item in or restore it to a state in which it can perform a required function (IEV 191-07-01, 2002). Maintenance has developed into a complex investment activity, rather than a cost producing activity, due to the insight that efficient maintenance increases the profit of the company (Groote, 1994). According to Tsang (2002), maintenance is complex, due to high demands of asset availability and reliability in capital-intensive operations.

Maintenance Management may be described as the activities of the management that determine Maintenance Objectives<sup>11</sup>, Maintenance Strategies<sup>12</sup>, and

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<sup>11</sup> Maintenance Objectives is here defined as targets assigned, and accepted for the maintenance activities (SS-EN 13306).

<sup>12</sup> Maintenance Strategy is here defined as a management method, used in order to achieve the Maintenance Objectives (SS-EN 13306). Note that the word methodology is preferred in this thesis instead of method.

responsibilities (SS-EN 13306). Thereafter Maintenance Plans<sup>13</sup> and control, including supervision, must be implemented in the organisation. Finally, the adopted methodologies in the organisation, including economic aspects, must be evaluated (SS-EN 13306).

According to Coetzee (1998), the complexity of maintenance has made it necessary for both the maintenance personnel and the management to have a maintenance model as fundamental reference in all decision-making regarding maintenance aspects. Therefore, an attempt was made by Coetzee (1998) to illustrate Maintenance Management, see Figure 2.2. Maintenance Management must meet different maintenance demands, which arise from the system design and are defined in the maintenance plan development. Maintenance Management must also control the different external resources supporting the maintenance work, such as maintenance consultants and different original equipment manufacturers (OEM). It is also important to control the internal resources, such as maintenance operators and the capacity of the system. Control of spare parts and rotables (e.g. items that are exchanged from the system and then renewed) are another important aspect of Maintenance Management. The results of Maintenance Management are evaluated and feedback should be given to the maintenance demands and the design phase of new similar systems as a part of the continuous quality improvement work (Coetzee, 1998).

However, Coetzee's (1998) approach to Maintenance Management, illustrated in Figure 2.2, does not describe the activities conducted inside the maintenance organisation on a sufficiently detailed level. Therefore, it is necessary to find a way of illustrating these activities. The EFNMS (2000) has made an attempt to illustrate these activities and therefore developed two maintenance processes, for the corrective maintenance, and the preventive maintenance respectively, see Figure 2.4 and 2.5 for an illustration. These processes will be presented in Section 2.2.2 and 2.2.3.

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<sup>13</sup> Maintenance Plan is here defined as a structured set of tasks that includes the activities, procedures, resources and the time scale required to carry out maintenance (SS-EN 13306).

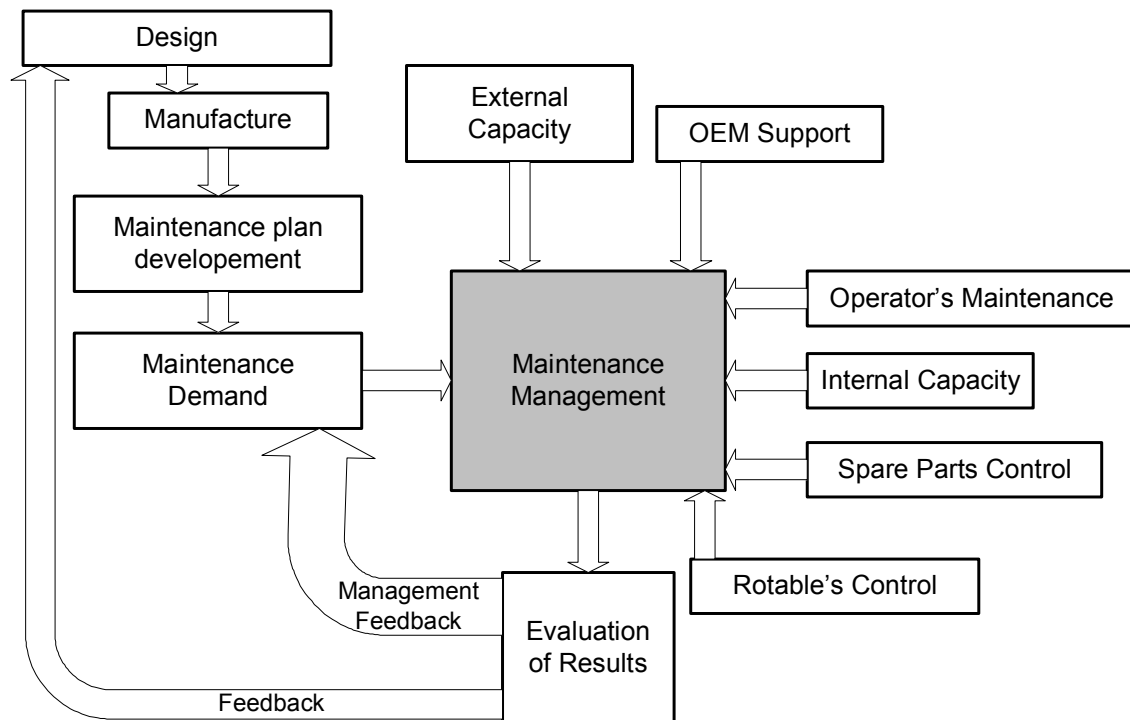


Figure 2.2. An illustration of Maintenance Management, which is supported by different external and internal resources. This illustration emphasises that the maintenance demands of the technical system, which originate from the system design, must be met with certain internal and external resources. (Source: Coetzee, 1998)

### 2.2.1 Maintenance Strategy

Maintenance activities must be guided by a Maintenance Strategy, which may be divided into Design-out Maintenance; Preventive Maintenance and Corrective Maintenance, see Figure 2.3 for an illustration of the different Maintenance Strategies. (Coetzee, 1998)

Design-out Maintenance aims at changing the design of the product or system, in order to eliminate, or reduce, the need for maintenance during the life cycle (Kelly, 1999). However, Design-out Maintenance is not an appropriate strategy for the railway with its large infrastructural assets. Therefore, this Maintenance Strategy will not be further discussed in this thesis.

Preventive Maintenance may be seen as the maintenance carried out at predetermined intervals or according to prescribed criteria, intended to reduce the

probability of failure<sup>14</sup> or the degradation of the functioning of an item (IEV 191-07-07, 2002). This means that maintenance is performed before a failure is developed. The Preventive Maintenance can be done at predetermined intervals, e.g. after a certain time or when the state of an item has reached predetermined limits.

Corrective Maintenance is the maintenance carried out after fault recognition, intended to bring back an item into a state in which it can perform a required function (IEV 191-07-07, 2002). This means that maintenance is performed after the fault of an item has been detected, in order to restore the item.

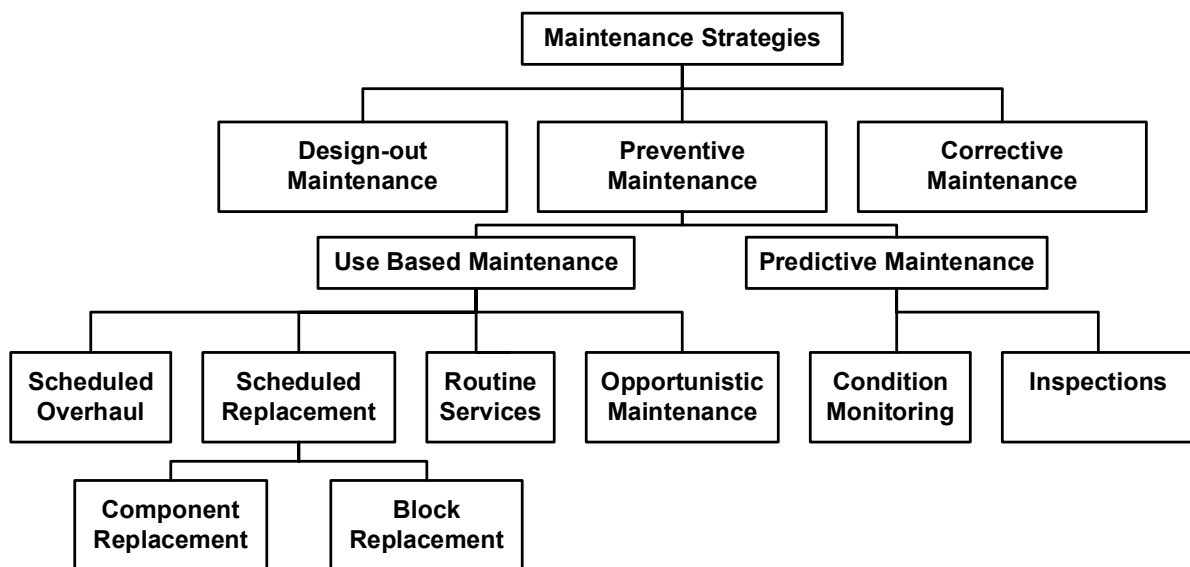


Figure 2.3. An illustration of different Maintenance Strategies. The top structure is broken down into the design-out of failure modes, the prevention of them or the correction of faults that are recognised. (Source: Coetzee, 1998)

### 2.2.2 Preventive Maintenance Process

One Preventive Maintenance Process, developed by EFNMS (2000) is illustrated in Figure 2.4. The Preventive Maintenance Process consists here of four process activities, supported by documents, data and resources. The process starts with a failure statistics report and the configuration of Preventive Maintenance starts. The configuration of Preventive Maintenance is supported by a maintenance policy for the equipment, and asset data, such as

<sup>14</sup> Failure is here defined as the termination of the ability of an item to perform a required function (SS-EN 13306).

drawings, technical specifications and location of the equipment. The second process activity is preventive maintenance planning, which is supported by maintenance measurement of previously conducted maintenance work. The output of the second process activity is a work order used for the preventive maintenance performance. The third activity is the preventive maintenance performance. This activity is supported by maintenance manuals, staff or contractors and spare parts. The output is a functioning system, but consumed materials, such as worn-out parts, must be disposed of. Feedback is given when the preventive maintenance work has been done. The last process activity is control of the function. In this activity feedback is given back to different activities in the Preventive Maintenance Process and the account register is updated. (EFNMS, 2000)

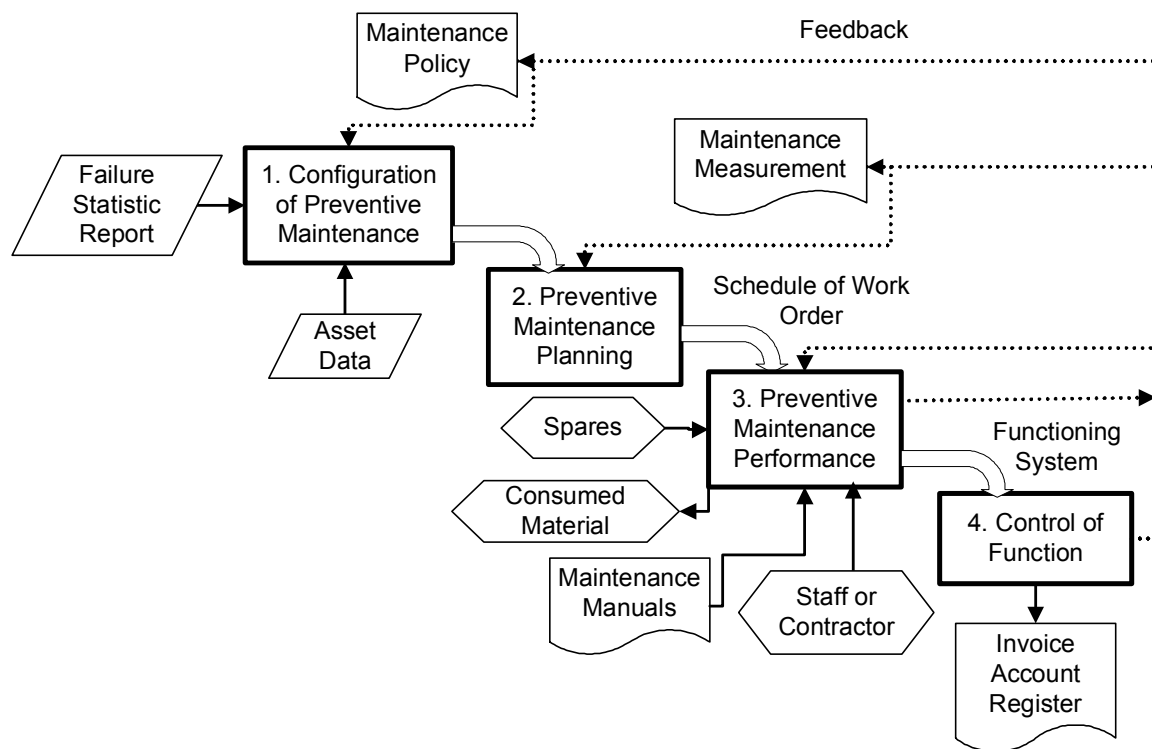


Figure 2.4. A Preventive Maintenance Process illustrating the workflow, consisting of four different activities, and the supported resources. (Source: EFNMS, 2000)

### 2.2.3 Corrective Maintenance Process

One Corrective Maintenance Process, developed by EFNMS (2000) is illustrated in Figure 2.5. The Corrective Maintenance Process consists here of four process activities, supported by documents, data, and resources. The Correc-

Corrective Maintenance Process starts with a failure report at the first process activity, failure registration. The failure registration is supported by a service policy for the equipment and asset data, such as drawings, technical specifications and location of the equipment. The second process activity is corrective maintenance planning, which is supported by the maintenance policy. The output of the second process activity is a work order, used for the performance of the Corrective Maintenance. The third activity is the repair performance. This activity is supported by maintenance manuals, staff or contractors and spare parts. The output is a functioning system, but consumed materials, such as worn out parts, must be disposed of. Feedback is given when the corrective maintenance work has been done. The last process activity is control of the function. In this activity feedback is given back to different activities of the Corrective Maintenance Process and the account register is updated. (EFNMS, 2000)

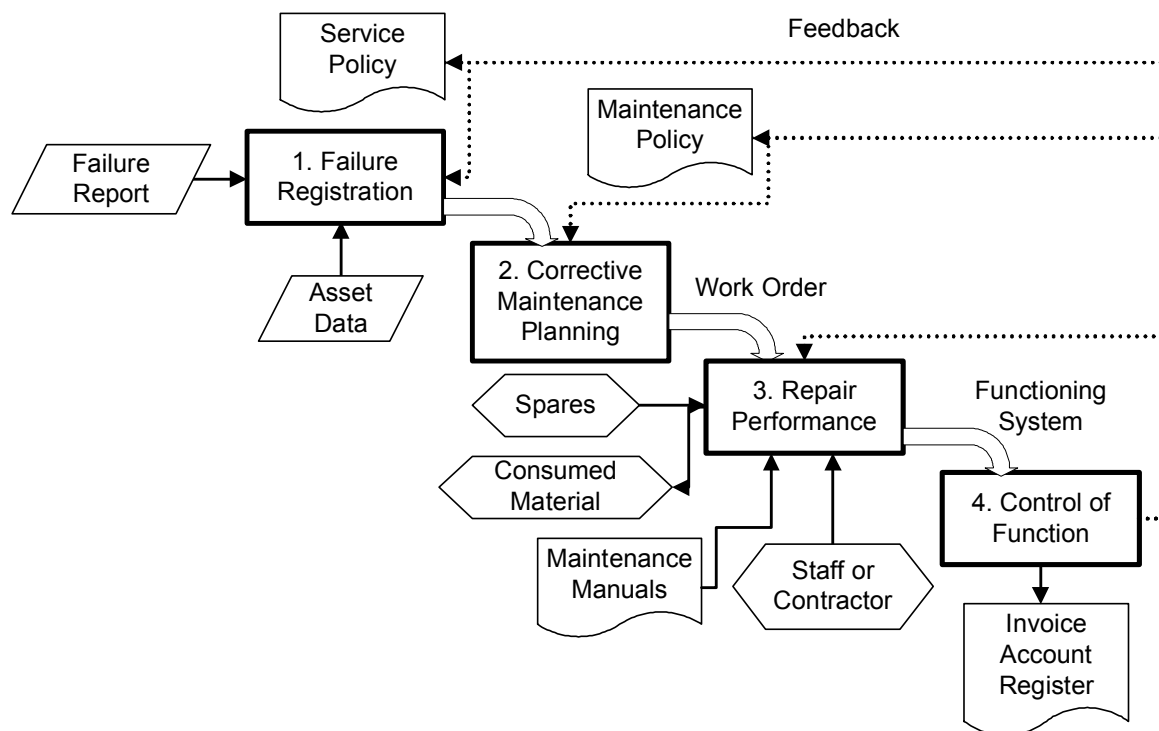


Figure 2.5. A Corrective Maintenance Process, illustrating the workflow, consisting of four different activities, and the supported resources. (Source: EFNMS, 2000)

## 2.3 Risk Management

It is necessary for the management to understand the level of risks the organisation is facing, and how these risks change as a result of the operating conditions (Hunt & Wierman, 1990). Undesirable events may occur as a result of component and subsystem failures and might lead to loss of human life, personal injury, damage to the environment or loss of economic values (Aven, 1992).

Risk Management aims at predicting where hazardous events<sup>15</sup> may happen and thereby making it possible to prevent the accidents that have not yet occurred (McKinnon, 2000). Shortcomings when analysing, evaluating and controlling risks are the key events that produce losses in the organisation (Bird & Loftus, 1976).

The aim of Risk Management is to consider the impact of certain risky events on the performance of the organisation. Alternative methodologies<sup>16</sup> for controlling these risks and their impact on the organisation must be devised. These methodologies must be related to the general decision framework used in the organisation. (Ridley & Channing, 1999)

Risk Management may, more exactly, be defined as a systematic application of management policies, procedures and practices to the tasks of analysing, evaluating and controlling risks<sup>17</sup> (IEC60300-3-9, 1995). Therefore, Risk Management is often structured in the three parts Risk Analysis, Risk Evaluation, and Risk Control, see Figure 2.6.

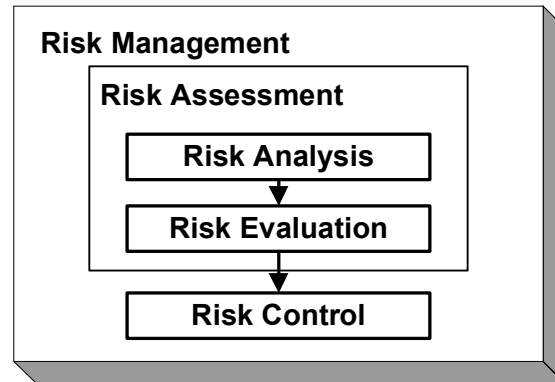
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<sup>15</sup> Hazardous event is here defined as an event which may cause harm. Harm is defined as a physical injury or damage to health, property, or the environment. (SS-EN 13306)

<sup>16</sup> Ridley & Channing (1999) use the term strategy when describing Risk Management. The present writer prefers to use the term methodology, which is defined as a way to work within an organisation to reach the values, and consists of a number of activities performed in a certain way (Hellsten & Klefsjö, 2000).

<sup>17</sup> A risk is here defined as a combination of the frequency, or probability, of occurrence and the consequence of a specified hazardous event (IEC60300-3-9, 1995).





*Figure 2.6. Risk Management consists of Risk Analysis, Risk Evaluation and Risk Control. Risk Analysis aims at identifying hazards, and at estimating the risk to individuals, populations, property, or environment. Risk Evaluation includes judgements of the tolerability of the risk on the basis of the Risk Analysis. Risk Control aims at managing and reducing the risk, and at implementing control activities in the organisation. (Source: IEC60300-3-9, 1995)*

Backlund (1999) states that Risk Management requires an integrated approach, including both organisational and technical aspects. This is, for example, supported by the Presidential Commission that investigated the loss of the space shuttle Challenger in 1986 (Baron & Paté-Cornell, 1999). The Commission concluded that organisational factors were at the root of the technical failure that led to the disaster. Some organisational factors could be traced to weak communication, misguided incentives and resource constraints, which in turn could be linked to the rules, structures, and culture of the organisation (Paté-Cornell & Fischbeck, 1993).

Risk Assessment, as a part of Risk Management, may be defined as an overall process consisting of Risk Analysis and Risk Control (IEC60300-3-9, 1995). However, as in many other cases, the interpretation of the concept differs among authors. For some authors, Risk Assessment means the entire process from identifying hazards and risks, estimating the risks and eliminating or reducing them. See, for example, Schlechter (1995) and Kumar & Svanberg (1999), who describe such risk assessment processes.

Some of the benefits of Risk Assessment are that it indicates where the greatest gains may be obtained with the least amount of resources, and which activities should be given priority (McKinnon, 2000).

### 2.3.1 Risk Analysis

Risk Analysis is a methodology with the aim of systematically measuring the degree of danger in an operation (McKinnon, 2000). Risk Analysis may be defined as a systematic use of information to identify hazards<sup>18</sup> and to estimate the risk of individuals or populations, property or the environment (IEC60300-3-9, 1995).

The purpose of Risk Analysis is to reduce the uncertainty of a potential accident situation and to provide a framework for systematically investigating all eventualities that may occur (IEC60300-3-9, 1995). Risk Analysis is a methodology that looks not only at what happened in the past, but also at what could happen in the future (McKinnon, 2000).

Simply stated, Risk Assessment is a methodology for identifying accidents that have not yet occurred (McKinnon, 2000). This methodology is useful for identifying different risks and approaches to their solution, but also for providing objective information, useful for fact-based decisions (IEC60300-3-9, 1995).

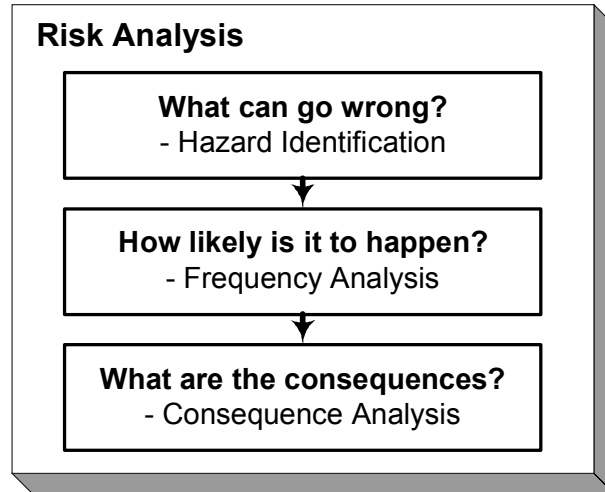
Some of the benefits of Risk Analysis are (IEC60330-3-9, 1995):

- Systematic identification of potential hazards is established.
- Systematic identification of potential failure modes is established.
- Quantitative risk statements or ranking are obtained.
- Important contributors to risks and weak links in the system are identified.
- Better understanding of the system and its installation is obtained.
- A basis for preventive maintenance and inspection is obtained.

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<sup>18</sup> A hazard is here defined as a source of potential harm or a situation with a potential for harm (IEC60300-3-9, 1995).

In summary, Risk Analysis aims at answering three fundamental questions, see Figure 2.7. In order to answer these questions Hazard Identification, Frequency Analysis, and Consequence Analysis are used as support.



*Figure 2.7. A Risk Analysis aims at answering three fundamental questions. To answer these questions different tools are used as a support. (Source: IEC60300-3-9, 1995)*

Hazard Identification<sup>19</sup> of all possible hazards is the first step of the Risk Analysis. Correct Hazard Identification ensures effective and beneficial Risk Management. But, if risk managers do not succeed in identifying all possible risks that challenge the organisation, then these non-identified risks will become non-manageable. (Tchankova, 2002)

There are numerous ways of performing hazard identification, such as Hazard and Operability Studies, HAZOP (Harms-Ringdahl, 2001); Failure Mode and Effect Analysis, FMEA (Stamatis, 1994) and other tools such as accident and incident investigation (Ferry, 1988) or Near-miss investigation (Jones, et al., 1999).

Studying past accident and incident reports is a useful way of predicting future hazards. By studying past loss-producing events, a pattern can be derived that would indicate certain recurring and inherent hazards in the business. (Jones et al., 1999)

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<sup>19</sup> Hazard Identification is a process of recognizing that a hazard exists and defining its characteristics (IEC60300-3-9, 1995).

Near-misses are also vital for Hazard Identification (Jones et al., 1999). Near misses, or events, which under slightly different circumstances could have resulted in losses, are good indicators of the presence of hazards challenging the organisation (McKinnon, 2000).

Frequency Analysis is used for the estimation of the likelihood of each undesired event, which is identified in the hazard identification step (McKinnon, 2000). Here for example historical records and Failure Mode and Effects Analyses FMEA (Stamatis, 1994) are useful.

Consequence Analysis is used for the estimation of the impact, if an undesired event should occur (IEC60300-3-9, 1995). Here, for instance, Fault-Tree Analysis and FTA (Harms-Ringdahl, 2001) are useful.

Neither Frequency Analysis nor Consequence Analysis is used in this thesis. Therefore these concepts will not be further discussed.

### 2.3.2 Risk Evaluation

The second step in the Risk Assessment is Risk Evaluation<sup>20</sup>. The main objective of Risk Evaluation is to ensure that the cost of risk reduction justifies the degree of risk reduction. The main aim of Risk Evaluation is to enable the management to make decisions on risk reduction priorities in the business. (McKinnon, 2000)

However, Risk Evaluation is not used in this thesis, and therefore it will not be further discussed.

### 2.3.3 Risk Control

The final step in the Risk Management is Risk Control<sup>21</sup>. The objective of Risk Control is to minimize, or when possible, transfer the risks that have been assessed (McKinnon, 2000). The goal of Risk Control is to reduce the severity

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<sup>20</sup> Risk Evaluation is here defined as a process in which judgements are made on the tolerability of the risk on the basis of Risk Analysis, and taking into account such as socio-economic and environmental aspects (IEC60300-3-9, 1995).

<sup>21</sup> Risk Control is here defined as a process of decision-making for managing and/or reducing risk, its implementation, enforcement, and re-evaluation from time to time, using the results of risk assessment as one input (IEC60300-3-9, 1995).

and frequency of the likelihood of undesired events occurring to a level As Low As Reasonably Practicable, ALARP (Melchers, 2001).

There are basically four ways of controlling the risks (McKinnon, 2000):

- **Terminate the risk.** This is the ideal way, to terminate the risk entirely by stopping a hazardous procedure or processes.
- **Tolerate the risk.** If the risk is tolerated, the benefits deriving from the risk outweigh the consequences of the risk. The potential impact of the risk is also lower than the cost of eliminating it.
- **Transfer the risk.** The risk is transferred somewhere else, by ensuring the risk, or placing it somewhere outside the business. The risk is not eliminated, but just transferred to someone else outside the company's own organization.
- **Treat the risk.** Treating the risk involves setting up a control for reducing the risk and thereby reducing the probability of an undesired event.

Risk Control is not used in this thesis. Therefore it will not be further discussed here.

## 2.4 Accident Causation Models

There are different models that describe the accident causation sequence (Ridley & Channing, 1998). According to Groeneweg (1998), the simplest representation of an accident is the result of a single unsafe<sup>22</sup> or substandard<sup>23</sup> act, see Figure 2.8. The substandard act is also referred to as an unsafe act. However, it is not always clear that the act really is unsafe (Groeneweg, 1998).

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<sup>22</sup> The term unsafe act is here defined as an act that initiates the accident causation scheme. Note that an unsafe act is only "unsafe" in a certain context. (Groeneweg, 1998)

<sup>23</sup> Substandard act is here defined as an act that deviates from the established standard, regulations or guidelines of the organization (Groeneweg, 1998).

Whether an act is substandard or not is related to the standards and guidelines of the organization. Therefore, the term substandard act is used in this thesis.

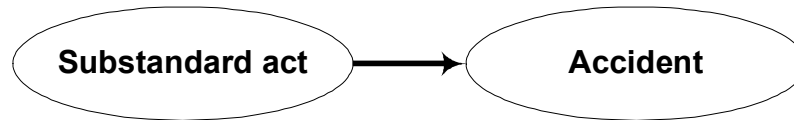


Figure 2.8. A simple model that describes an accident causation scheme, starting with one single substandard act, which results in an accident. (Source: Groeneweg, 1998)

#### 2.4.1 Reason's Accident Causation model

Reason (1990) illustrates the cause of the accident causation with substandard acts and safety barriers<sup>24</sup>; see Figure 2.9.

Accident prevention may be accomplished by adding some safety barriers. Only when all safety barriers have been broken is the accident causation a fact. If one safety barrier has been able to prevent the accident from occurring, an incident is caused. However, as defined earlier, an incident may also cause losses. The difference is that an accident causes injuries to a person.

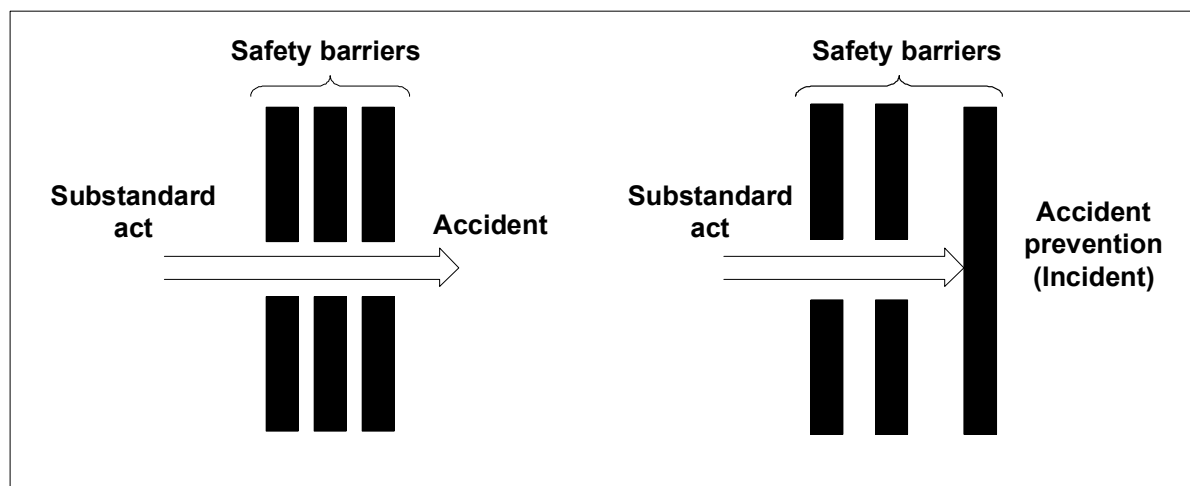
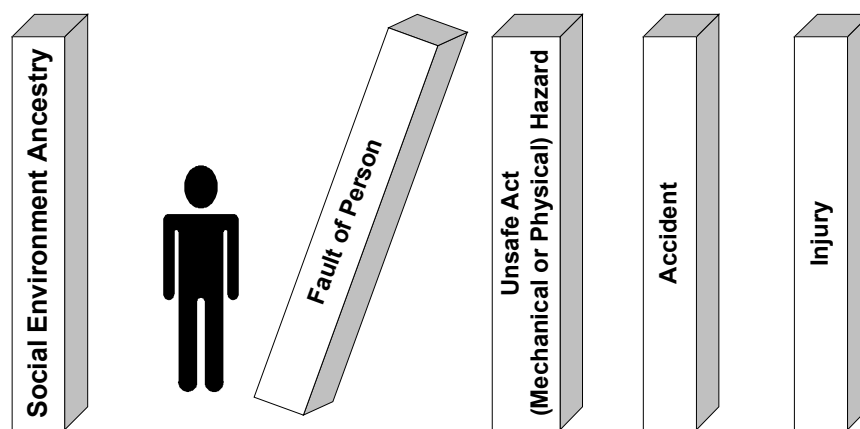


Figure 2.9. Reason's accident causation model. The accident causation starts with a substandard act, but safety barriers can prevent an accident from occurring. (Source: Groeneweg, 1998)

<sup>24</sup> A safety barrier here defined as defensive barrier that prevents the accident to occur. Some examples of safety barriers are "child-proof" lids, air-bags and safety belts. (Groeneweg, 1998)

## 2.4.2 Heinrich's Loss Causation Model

In 1931, Heinrich formulated a foundation, based on ten axioms, which is the origin of many accident causation models (Groeneweg, 1998). Heinrich developed the first approach to loss causation models in 1931, see Figure 2.10. Heinrich distinguished five steps one after the other, in which the third step stands for the single, critical unsafe act, instead of a possible combination of unsafe acts and specific situations (Groeneweg, 1998). Petersen (1988) states that Heinrich's approach is quite clear and practical as an approach to loss control. Simply stated, if you are to prevent losses from occurring, remove the unsafe acts.



*Figure 2.10. Heinrich's five-step domino model, first presented in 1931. The person is burdened by the social environment; an unsafe act initiates the domino effect causing accidents. (Source: Heinrich et al., 1980)*

However, Petersen (1988) states that the interpretation of Heinrich's theory has been too narrow. For instance, when a single act or a single condition that caused the accident is identified, it is possible that many other causes are left unmentioned. When the unsafe condition that is identified at the inspection is removed, it is possible that the root cause<sup>25</sup> of the potential accident is not found.

Today, we know that there may be many contributory factors, causes, and subcauses behind every accident (Petersen, 1988). There are other theories that consider multiple causes, factors combined together in random fashion

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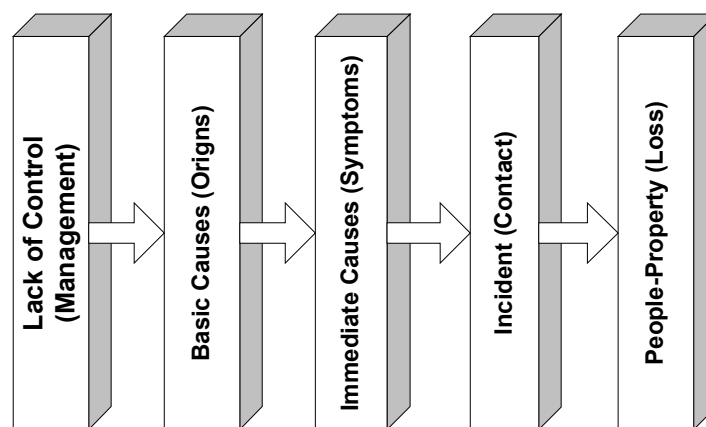
<sup>25</sup> Root cause is here defined as the underlying cause to the accident causation scheme.

causing accidents, but these are too complicated to use for the fulfilment of the purpose of this thesis. See, for instance, Ferry (1988) for a description of multiple accident causations and descriptions thereof.

### 2.4.3 Bird and Loftus Loss Causation Model

Another Loss Causation Model, LCM, was developed by Bird & Loftus (1976). This model is an updated version of Heinrich's early domino model, presented in 1931. The LCM model, see Figure 2.11, was updated to reflect the direct management relationship involved in the causes and effects of all incidents that could downgrade a business operation (Bird & Germain, 1976). Bird and Germain added a factor of influence to the domino chain by putting lack of control by management at the beginning of each accident causation scheme in their Loss Causation Model (Groeneweg, 1998). Since fundamentally uncontrollable factors were not considered, this model suggests that all accidents are avoidable if the management exerts enough control.

Lack of control is manifested in immediate causes, which are merely the symptoms of the problem. These immediate causes result in incidents at contact, with the possibility of loss of people or property (Groeneweg, 1998). The different steps in the model are briefly presented below.



*Figure 2.11. The Loss Causation Model, an updated Heinrich model, reflecting the direct management relationship involved in the causes and effects of all incidents. (Source: Bird & Loftus, 1976)*



**Lack of Control:** By control, Bird & Loftus (1976) refer to four aspects of management: planning, organizing, leading, and controlling. Some of the causes that make the first domino fall are (Bird & Loftus, 1976):

- An inadequate program and inadequate program knowledge.
- Inadequate program standards and knowledge of program standards.
- Failure to perform to standards, or to manage employee compliance to standard.

**Basic Causes:** Lack of management control causes certain basic causes<sup>26</sup> of incidents that downgrade the business operation. There are other names for the basic causes, such as root causes, indirect causes, underlying causes or real causes (Groneweg, 1998).

Basic causes contain both personal factors and job factors. Personal factors include: lack of knowledge or skill, improper motivation and physical or mental problems. Job factors include inadequate work standards, inadequate design or maintenance, inadequate purchasing standards, normal wear and tear and abnormal usage. (Bird & Germain, 1996)

The basic causes aim at explaining why people engage in substandard practices. Likewise, the basic causes referred to as job factors explain why substandard conditions are created or exist. Basic causes then are clearly the origin of substandard acts and conditions, and failure to identify these origins of loss in this step in the sequence permits this domino to fall, initiating the possibility of a further chain reaction. (Bird & Loftus, 1976)

**Immediate causes:** The immediate causes<sup>27</sup>, or substandard practices<sup>28</sup> and substandard conditions<sup>29</sup>, are associated with the incident that originates di-

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<sup>26</sup> Basic causes are also referred to as indirect causes in this thesis.

<sup>27</sup> Immediate causes are also referred to as primary causes in this thesis.

<sup>28</sup> The substandard practice could involve both acts of people and conditions related to physical things (Bird & Loftus, 1976).

<sup>29</sup> A substandard condition is described as a condition that could directly permit the occurrence of an accident (Bird & Loftus, 1976).

rectly from the basic causes. The immediate cause is a substandard act, which is a violation of an accepted safe procedure. This violation could permit the occurrence of an accident.

Whether we refer to these deviations as substandard practices or substandard conditions, there is one important thing common to all. Basically, these are only a symptom of the basic cause that permitted the practices or conditions to exist. If, and when, we fail to determine what the basic causes behind the symptoms really are, we fail to prevent this domino from falling, and the direct potential for loss still exists. (Bird & Loftus, 1996)

**Incident:** The definition of incident is, according to Bird & Loftus (1976), an undesired event that may, or does, result in losses. Whenever substandard practices and substandard conditions are permitted to exist, the door is always open for the occurrence of an incident that may or may not result in a loss. The incident is undesired, since the final results of its occurrence are difficult to predict and are most frequently a matter of chance<sup>30</sup>. (Bird & Loftus, 1976)

**Loss:** Once the entire sequence has taken place and there is a loss, with people or property involved, the results are usually chance events. The element of chance is involved in quality and production losses as well as those involved in safety, health and security. Losses involved in all areas may be considered as minor, serious, major or catastrophic depending on the outcome. (Bird & Germain, 1996)

#### 2.4.4 McKinnon's Loss Causation Model

McKinnon (2000) has further developed the Loss Causation Model, LCM, developed by Bird & Loftus (1976). The model is called Cause, Effect, and Control of Accidental Loss Domino Sequence, CECAL, see Figure 2.12. This model describes the chain of events from poor control due to the failure to the assessment of all risks (McKinnon, 2000).

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<sup>30</sup> Chance is here defined as the result, or manifestation of circumstances that could not be predicted or controlled.

Still, the causation scheme follows the basic and immediate causes, as presented by Bird & Loftus (1976), but different forms of chance, called “Luck Factors”, are introduced. Depending on chance, the magnitude of the losses varies. These losses are manifested in incidents and accidents, while some losses still remain hidden. (McKinnon, 2000)

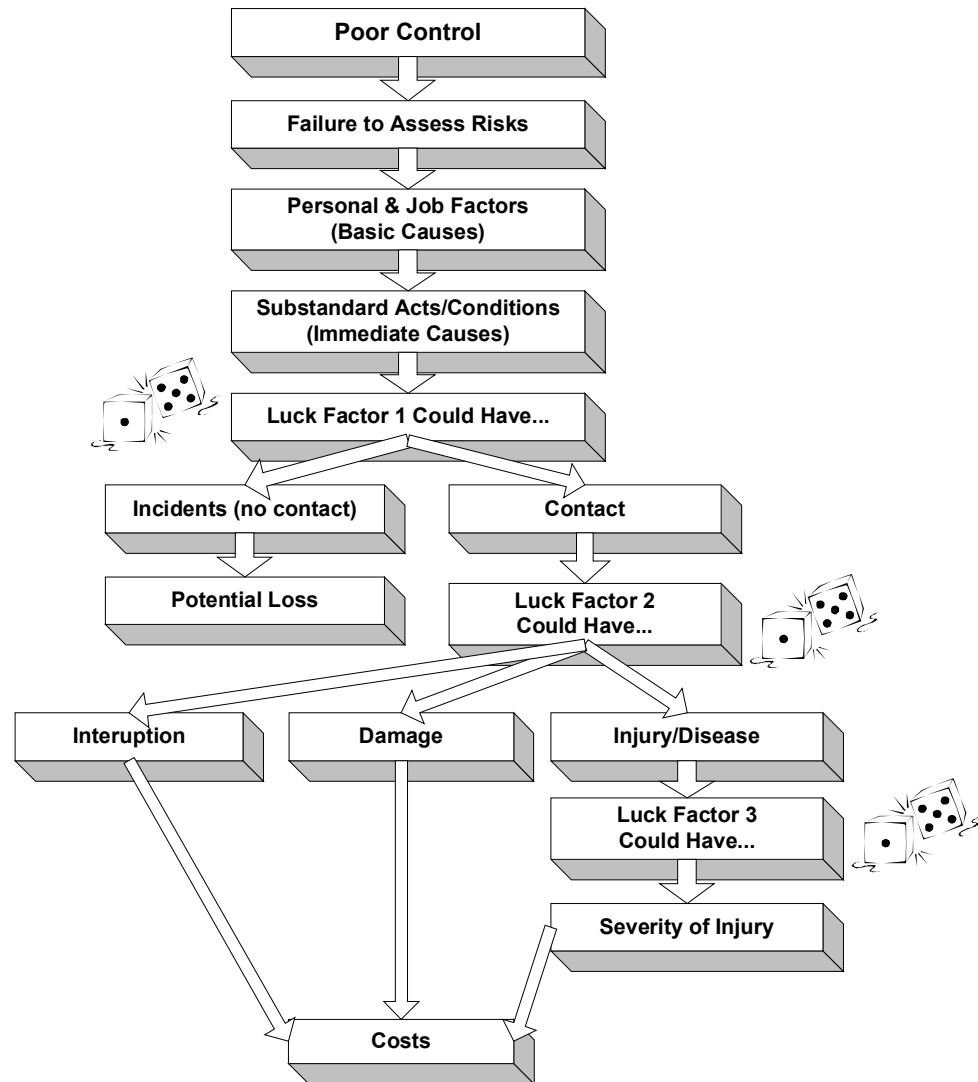


Figure 2.12. The Cause, Effect, and Control of Accidental Loss domino sequence, CECAL. The model shows how the failure to assess the risk triggers poor control and leads to losses and subsequent costs. Chance is introduced in some different steps, impacting the outcome and introducing the impact of randomised events. (Source: McKinnon, 2000)

## 2.5 Accident Investigation

The main reasons for performing accident investigations are to find the root cause of the problem, and to prevent the recurrence of a similar accident (McKinnon, 2000; Ferry, 1988; Groeneweg, 1998). The root causes of the problem should be eliminated, as a part of the continuous improvement work, in order to strive for higher quality (Bergman & Klefsjö, 2003).

Accident investigation is, according to Kletz (1988) “like peeling an onion. Beneath one layer of causes and recommendations, there are others, less superficial, layers. The outer layers deal with the immediate technical causes while the inner layers are concerned with ways of avoiding the hazards and finding underlying causes, such as weaknesses in the management system.” Very often only the outer layer, the immediate technical causes are investigated. Although it is possible to prevent the latest accident from happening again, considering the indirect causes and immediate causes together may prevent similar accidents from happening again (Kletz, 1988).

The accident investigation process may be described according to the steps presented below (Kletz, 1988):

1. **Describe what happened.** It is important to document and describe the accident as clearly as possible.
2. **Determine real causes.** If real causes are not identified, there is little or no return of the investment of the time spent looking for them.
3. **Describe the risks.** Good investigations provide the basis for deciding the likelihood of recurrence and the potential for major losses. These two factors are critical for determining the time and money to be spent on corrective actions.
4. **Develop control.** Adequate control aimed at minimizing, or eliminating a problem can only come from an investigation that has truly solved the problem. If not, the problem will appear again and again but with different symptoms.

5. **Define trends.** Few incidents and accidents are isolated events. However, when a significant number of good reports are analyzed, emerging trends can be identified, and dealt with.
6. **Demonstrate concern.** Accidents give people pictures of threats to their wellbeing. Sometimes it is reassuring to see an objective investigation in process, because it bolsters employee confidence and improves public relations.

It is important to emphasize that accident investigations should not be concerned with finding scapegoats instead of the root causes. If the focus is on finding scapegoats then people will not report all the facts and we will never find out what really happened. In that case we are not able to prevent similar accidents from happening again (Kletz, 1988).



## 3 RESEARCH METHODOLOGY

*There are many different approaches to doing scientific research. In this chapter a brief introduction to some of these approaches is presented and the chosen research approach is discussed.*

### 3.1 Introduction

In general the reason for doing research is to find out why things happen as they do (Carey, 1994). To do research we must choose a methodology. Denzin & Lincoln (1994) state that the term methodology focuses on “best means for gaining knowledge about the world”. The term methodology refers to the way in which we approach the problem and seek answer to it (Taylor & Bogdan, 1984).

### 3.2 Research Purpose

There are different ways of classifying a research study, for example as: exploratory, descriptive and explanatory. The exploratory study aims at generating basic knowledge and demonstrates the character of a problem by collecting information through exploration. Exploratory studies are conducted in order to create an understanding of different conditions and events. An explorative study may be used for unstructured research problems, which are difficult to delimit. A descriptive study is appropriate to use when the research problem is structured for identifying relations between certain causes. The aim of a descriptive investigation is to perform empirical generalizations. The explanatory study may be used for analyzing causes and relationships, which together cause a certain phenomenon. (Eriksson & Wiedersheim-Paul, 1997)

The purpose of this thesis is to “explore and describe different deviations from the intended maintenance activities that result in losses, manifested in incidents and accidents.” To fulfil this purpose an exploratory and descriptive approach has been chosen. A motive for approaching the research as exploratory is to generate knowledge and understanding about maintenance related losses in the railway context. The knowledge gained from the explorative approach is intended to be used in order to control the maintenance work better. The improved control of maintenance may be seen as a part of

the continuous improvement work at the Swedish National Rail Administration. The reason for also choosing a descriptive approach is the need to describe how maintenance related incidents and accidents can be analysed in order to structure the search for the primary causes, which result in improper maintenance.

### 3.3 Research Approach

According to Alvesson & Sköldberg (1994), the research approach may be divided into: deduction, induction or abduction, see Table 3.1.

**Deduction:** The deductive approach strives to generate hypotheses, which are testable statements, based on existing theory. The results are derived by logical conclusions. (Eriksson & Widarsheim-Paul, 1997)

**Induction:** The inductive approach is based on empirical data and conclusions are drawn from the experience gained from the study (Patel & Davidson, 1994).

**Abduction:** Abduction may be considered as a combination of deduction and induction. The researcher can start with a deductive approach and make an empirical collection based on a theoretical framework, and then continue with the inductive approach to develop theories based on the previously collected empirical data. During the research process an understanding of the phenomenon is developed and the theory is adjusted with respect to the new empirical findings. (Alvesson & Sköldberg, 1994)









	Deduction	Induction	Abduction	Approach used in this thesis
Theoretical				
Empirical				

Table 3.1. Illustration of the different research approaches: Deduction, Induction and Abduction (Source: Alvesson & Sköldberg, 1994). To the right the approach chosen in this thesis is illustrated.



The research process in this thesis started with a plan for the research design. Therefore a deductive approach was used when a literature study was made in order to identify the need for further investigation of maintenance related losses, manifested in different incidents and accidents. Thereafter, a data analysis model was adapted, which can be used for the analysis of maintenance related losses at the Swedish National Rail Administration. This model is based on identified theoretical foundations. The analysis model was then applied, in an inductive approach, when studying empirical data from a database, BOR (see Section 3.5.2). Conclusions could be drawn due to experience gained from the empirical study. The inductive approach was then used once more for the identification of suitable ways of illustrating the identified maintenance related losses. The research approach is therefore similar to the abductive approach, see Table 3.1.

Research may also be divided into a qualitative or a quantitative approach. Quantitative information is conveyed by numbers and qualitative information is generally conveyed by words (Eriksson & Widarsheim-Paul, 1997). The quantitative approach emphasises the measurement and analysis of causal relationships between different variables (Denzin & Lincoln, 1994). The qualitative approach aims at giving an explanation of causal relationships between different events and consequences (Miles & Huberman, 1994).

The chosen research approach in this thesis is qualitative. This approach aims at exploring maintenance related losses in a railway context. Furthermore, the approach also aims at describing different deviations from the desired maintenance process, resulting in losses, which are manifested in different incidents and accidents.

### 3.4 Research Strategy

The choice of research strategy depends on what kind of information the researcher is looking for due to the purpose of the study and the research questions (Merriam, 1998; Yin, 1994). Each research strategy has strengths and weaknesses depending on three conditions: the type of research question, the extent of control the researcher has of behavioural events and the degree of focus on contemporary events, as opposed to historical events (Yin, 1994). The selection of an appropriate research strategy is illustrated in Table 3.2.

Strategy	Form of research question	Requires control of behavioral events?	Focuses on con-temporary events?
Experiment	How, why	Yes	Yes
Survey	Who, what, where, how many, how much	No	Yes
Archival analysis	Who, what, where, how many, how much	No	Yes/No
History	How, why	No	No
Case Study	How, why	No	Yes

*Table 3.2. The selection of appropriate research strategies for different research situations (Source: Yin, 1994).*

The stated purpose of this thesis has been transferred to the following research questions:

1. How can maintenance related losses, manifested in incidents and accidents, be analysed?
2. What are the primary causes of the maintenance related losses at the Swedish National Rail Administration?
3. How can the maintenance related losses be illustrated in relation to the maintenance processes?

These research questions focus mainly on “how” and “what”. Therefore, an archival analysis strategy has been chosen. The main motive for choosing this approach was that data was already collected, and therefore available in a database called BOR. The archival analysis strategy was supported by a literature study, in order to gain knowledge about the research area. The literature study was also conducted in order to identify and to adapt a suitable data analysis tool, which can be used in the database study.

### 3.5 Data Collection

There are different ways of collecting data. Yin (1994) presents different ways of collecting data; see Table 3.3. In qualitative research, four methodologies for gathering information are typically used; participant observations, direct

observations, interviews and documents or archival records (Marshall & Rossman, 1999; Yin, 1994).

Source of Evidence	Strengths	Weaknesses
Documentation	<ul style="list-style-type: none"> <li>- Stable, can be reviewed repeatedly</li> <li>- Unobtrusive, not created as a result of the case study</li> <li>- Exact, contains exact names, references, and details of an event</li> <li>- Broad coverage, long span of time, many events, and many settings</li> </ul>	<ul style="list-style-type: none"> <li>-Retrievability, can be low</li> <li>-Biased selectivity, if collection is incomplete</li> <li>-Reporting bias, reflects (unknown) bias of author</li> <li>-Access, may be deliberately blocked</li> </ul>
Archival Records	<ul style="list-style-type: none"> <li>-Same as above for documentation</li> <li>-Precise and quantitative</li> </ul>	<ul style="list-style-type: none"> <li>- Same as above for documentation</li> <li>- Accessibility due to privacy reasons</li> </ul>
Interviews	<ul style="list-style-type: none"> <li>- Targeted , focus directly on case study topic</li> <li>- Insightful, provides perceived causal inference</li> </ul>	<ul style="list-style-type: none"> <li>- Bias due to poorly constructed questions</li> <li>- Response bias</li> <li>- Inaccuracies due to poor recall</li> <li>- Reflexivity – interviews gives what interviewer wants to hear</li> </ul>
Direct Observations	<ul style="list-style-type: none"> <li>- Reality, covers events in real time</li> <li>- Contextual, covers context of event</li> </ul>	<ul style="list-style-type: none"> <li>- Time consuming</li> <li>- Selectivity, unless broad coverage</li> <li>- Reflexivity, events may proceed differently because it is being observed</li> <li>- Cost, hours needed by human observers</li> </ul>
Participant Observations	<ul style="list-style-type: none"> <li>- Same as above for direct observations</li> <li>- Insightful into interpersonal behaviour and motives</li> </ul>	<ul style="list-style-type: none"> <li>- Same as above for direct observations</li> <li>- Bias due to investigator's manipulation of events</li> </ul>
Physical Artefacts	<ul style="list-style-type: none"> <li>- Insightful into cultural features</li> <li>- Insightful into technical operations</li> </ul>	<ul style="list-style-type: none"> <li>- Selectivity</li> <li>- Availability</li> </ul>

*Table 3.3. The selection of appropriate data collection methodologies for different research situations (Yin, 1994).*

Data may be divided into primary or secondary. Data collected by the researcher for the purpose of the study is called primary data. Data already collected by other people and used by the researcher is called secondary data. (Dahmström, 1996)

Some advantages of secondary data are that it may be an easy and cheap way of receiving information. Some disadvantages are that it may be difficult to find relevant material and to assess the quality and usefulness of secondary data. As a related consequence the reliability may also be difficult to evaluate, when using secondary data. (Eriksson & Wiedersheim-Paul, 1997)

### 3.5.1 The Literature Study

Data was collected through a literature study in different databases and scientific journals.

First of all appropriate books were identified through LIBRIS (the National Swedish Library Data System). The database contains more than four million titles representing the holdings of about 300 Swedish libraries, mainly research libraries.

Different databases have been used to search for documents and research papers, e.g. Compendex, Science Citation Index, Raildok, Emerald, and Elsevier Science Direct.

Different related keywords were formulated: maintenance, risk, accidents, cause and disaster. These keywords were used in different combinations to search the different databases, resulting in a large number of hits. In order to find relevant data all headline titles were read and compared to the purpose of the study. This reduced the data of the material collected from the databases. Secondly, the abstracts of the remaining material were read carefully, which further reduced the material. Finally, the remaining full articles were read. The data collection approach used for databases is illustrated in Figure 3.1.

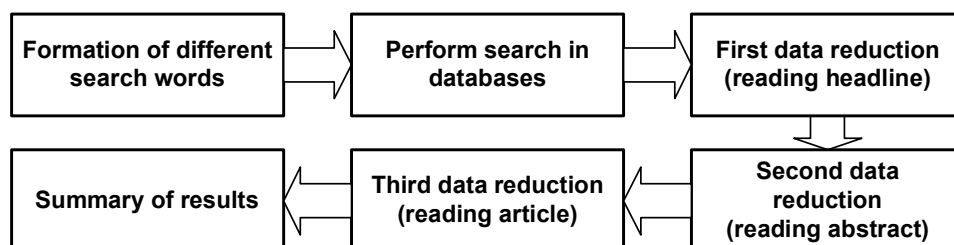


Figure 3.1. The data collection approach used for search in different databases. The arrows represent the steps taken to reduce the amount of information, and to find relevant information.

Data was also collected from different scientific journals; see Figure 3.2. The collection is limited to 1995-2002 due to on-line availability of the magazines, e.g. Safety Science; Reliability Engineering and System Safety; Journal of Loss Prevention in the Process Industries; Journal of Quality in Maintenance Engineering; International Journal of Pressure Vessels and Piping; and International Journal of Industrial Ergonomics. The magazines were chosen, based on the contents, in areas such as Risk Management and Maintenance Management.

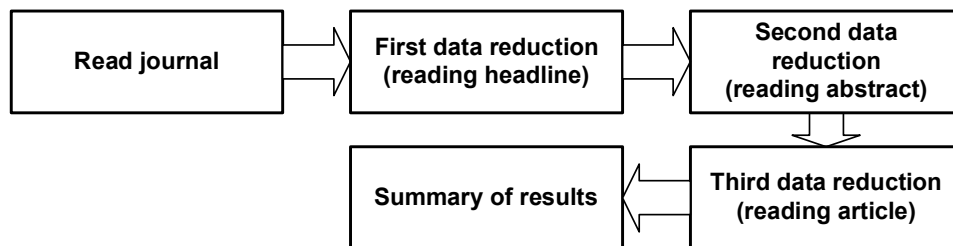


Figure 3.2. The data collection approach used for data collection in journals. The arrows represent the steps taken to reduce the amount of information, and to find relevant information.

### 3.5.2 The Database Study

Data needed to investigate causes of the maintenance related accidents at the Swedish State Railways was collected through an extensive study of secondary data, stored in a database called BOR.

The BOR database, which was created by Johan Bäckman as a part of his dissertation, see Bäckman (2002), contains train derailments and collisions at the Swedish State Railways. The database was created in Microsoft Access.

BOR contains passenger train derailments for the period 1988-2000 and passenger train accidents with passengers or train crew fatalities for the period 1960-2000. The database contains five different data sources, presented below. All in all, 973 incidents and accidents are reported in the database (Bäckman, 2002):

- BIS: The Swedish National Rail Administration has a computerised system called BIS, containing different modules for track information and for accident reporting from 1988 onwards.

- JAS: The Swedish Railway Inspectorate has a database called JAS which contains information from 1989 onwards. The criteria for the accidents to be reported in the database are either fatalities or injuries or material costs of at least approximately 100 000 USD.
- INCIDENT: SJ has a database called INCIDENT. SJ has been reporting accidents in that computerised database since February 1995, but the database was closed in December 1997.
- HÄR: The Swedish Railway Inspectorate administrated a database called HÄR between 1994 and 1998. It contains accidents as well as incidents.
- Sparre: A study conducted by Sparre on accident reports from the Swedish State Railways containing collisions, derailments and fires on the Swedish network between the years 1985 and 1994 has generated data that has been included in BOR.

Due to the fact that the Swedish State Railways went through a major organisational change, data before 1988 is excluded from the study in this thesis, based on BOR. The database contains 666 incidents and accidents between 1988 and 2000.

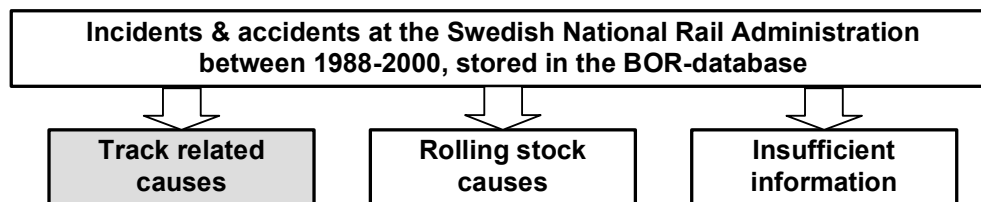
## 3.6 Data Analysis

It is important that every investigation should have a general analytic strategy to guide the decisions regarding what will be analyzed and for what reason (Yin, 1994). "Data analysis consists of examining, categorizing, tabulating, or otherwise recombining the evidence to address the initial propositions of a study" (Yin, 1994).

### 3.6.1 The Database Study

In order to identify maintenance related incidents and accidents data must be classified. Most of the incidents or accidents, which have been transferred from the different data sources described in 3.5.2, into the BOR database, contains a description of the primary causes and consequences.

The BOR database has been studied without consideration of previous classification, made with a different purpose in mind, to avoid being biased. One reason for this is that the classification is not made with maintenance related causes in mind. The accidents and incidents have been classified in three iterative steps, based on the description of the accident causation scheme, and the stated consequences. However, it was not always easy to find the causes on the basis of the description of the accident causation scheme. The first classification is made with respect to all railway accidents and incidents reported to the database 1988-2000; see Figure 3.3.



*Figure 3.3. The first classification of the data aims at dividing the railway related accidents and incidents between 1988 and 2000 into track related causes, rolling stock causes and insufficient information.*

The group track related consists of causes created by the railway line including the ballast, switches, sleepers and rail or objects placed on or near the track. The rolling stock causes are a collection of track bound vehicles, such as trains and trolleys. The group classified as insufficient information has a serious lack of information about the causes and consequences in the accident and incident reports. This study aims at investigating the track related causes; and therefore the rolling stock causes and insufficient information were excluded from the second classification step.

In the second classification step, track related causes were divided into maintenance related causes, railway operation, sabotage and uncertain, see Figure 3.4. However, this was done in order to identify maintenance related causes. The other groups, e.g. railway operation and sabotage, were made to gain comprehension of their occurrences.

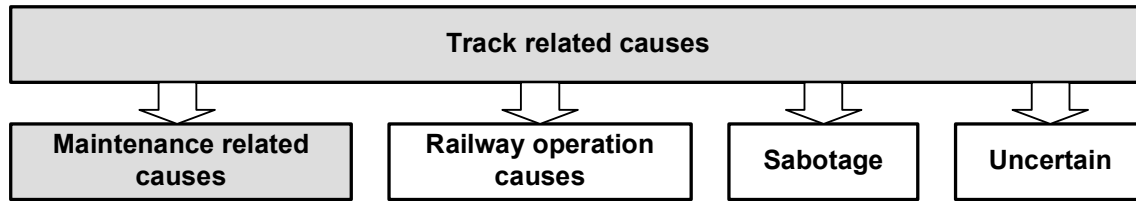


Figure 3.4. The second classification of the data in BOR is a further breakdown of the track related causes into maintenance related causes, railway operation, sabotage and uncertain.

The group maintenance related causes consists of events caused by direct or indirect maintenance activities. The group railway operation is a collection of various other events, e.g. train operation and switch operation, leading to incidents and accidents. The group sabotage consists of accidents when objects are placed on or nearby the track, presumably by vandals. The group uncertain contains causes due to insufficient information in the description of the primary causes or the consequences. All the other groups except maintenance related causes have been excluded in the third classification step, due to the main purpose of identifying maintenance related causes.

In the third classification step, maintenance related causes were divided into maintenance execution and lack of maintenance; see Figure 3.5. The reason for this classification is that it is of interest to see whether the cause is due to impact of maintenance, which is direct or indirect.

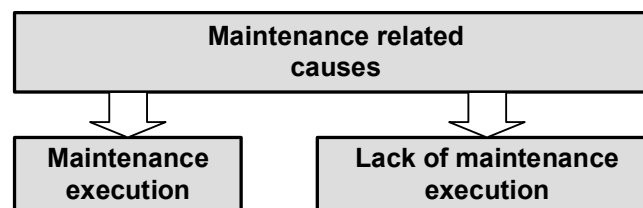


Figure 3.5. The third classification aims at dividing the Maintenance related causes into Maintenance execution and Lack of maintenance execution in order to determine if the impact of maintenance is direct or indirect.

The two groups, maintenance execution and lack of maintenance, have been closely analysed in order to identify the causes. The group maintenance execution is a collection of direct maintenance related causes occurring during the execution. The group lack of maintenance execution is a collection of various indirect events caused by lack of maintenance. Here the Loss Causa-



tion Model, illustrated in Figure 3.6, is used to structure the causes into the two different groups; basic causes and immediate causes, which precedes the losses.

The analysis of the maintenance related accidents and incidents, classified as maintenance execution and lack of maintenance, is then structured according to the Loss Causation Model in order to identify loss producing events, which are deviations from the ideal situation in different steps in the maintenance process. The most abstract level is lack of control, which may be related to the maintenance management. It would be desirable to identify the causal connection from losses to lack of control in all maintenance related accidents and incidents, but due to the variety of the quality of the data presented in BOR, this is not possible. However, the causes and effects have been studied in order to find the immediate causes and in most cases the basic causes.

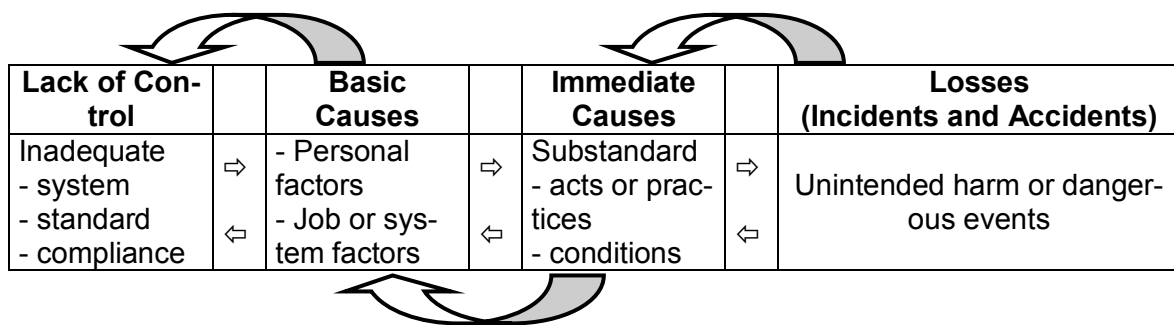


Figure 3.6. The data analysis model used for identification of causes of maintenance related losses is a modified Loss Causation Model, originally developed by Bird & Loftus (1976). The basic idea is to start the investigation at the losses, manifested in real incidents and accidents in order to find the chain of events leading to lack of control.

### 3.7 Reliability

Reliability demonstrates that the operations of a study, such as the data collection procedures, can be repeated by somebody else with the same results. High reliability may be seen as the absence of errors and biases in the study. With high reliability, it is possible for another researcher to achieve the same results on condition that the same methodology is used. One condition for high reliability is that the methodology used for data collection is clearly described. (Yin, 1994)

Therefore, the data collection and classification methodology has been described in Section 3.6.1. The incident and accident reports, transferred into BOR, are further described in Holmgren (2004) to strengthen the reliability of the study in this thesis.

### 3.8 Validity

Validity involves actions to determine the extent to which a measure does represent the intended proposition of the study (Dane, 1990).

The group classified as insufficient information, see Figure 3.3, has a serious lack of information about the causes and consequences in the accident and incident reports. This fact created some uncertainty in the data material which might affect the validity of the results. The insufficient information may contain track related accidents with maintenance related connections.

There was also some uncertainty involved in the description of the primary causes and the consequences in the BOR database. Although it has been possible to identify that the causes are track related, see Figure 3.4, it is hard to draw further conclusions from the data in that group with respect to the purpose of this study. The main problem was that the causes were in some cases briefly described. This uncertainty may affect the validity of this study. This could be avoided with more detailed incidents and accident reports, transferred to the BOR database.

Validity refers to the generality of the findings that were made during the research (Herzog, 1996). The results presented in this thesis were mainly derived from the database study. Aspects such as imperfect communication and rule violation during maintenance work are not unique to the railway. The research done in this thesis focuses on railway related incidents and accidents. For this reason, the external validity outside the railway context may be low.

### 3.9 The Research Process

The main activities of the research process are illustrated in Figure 3.7.

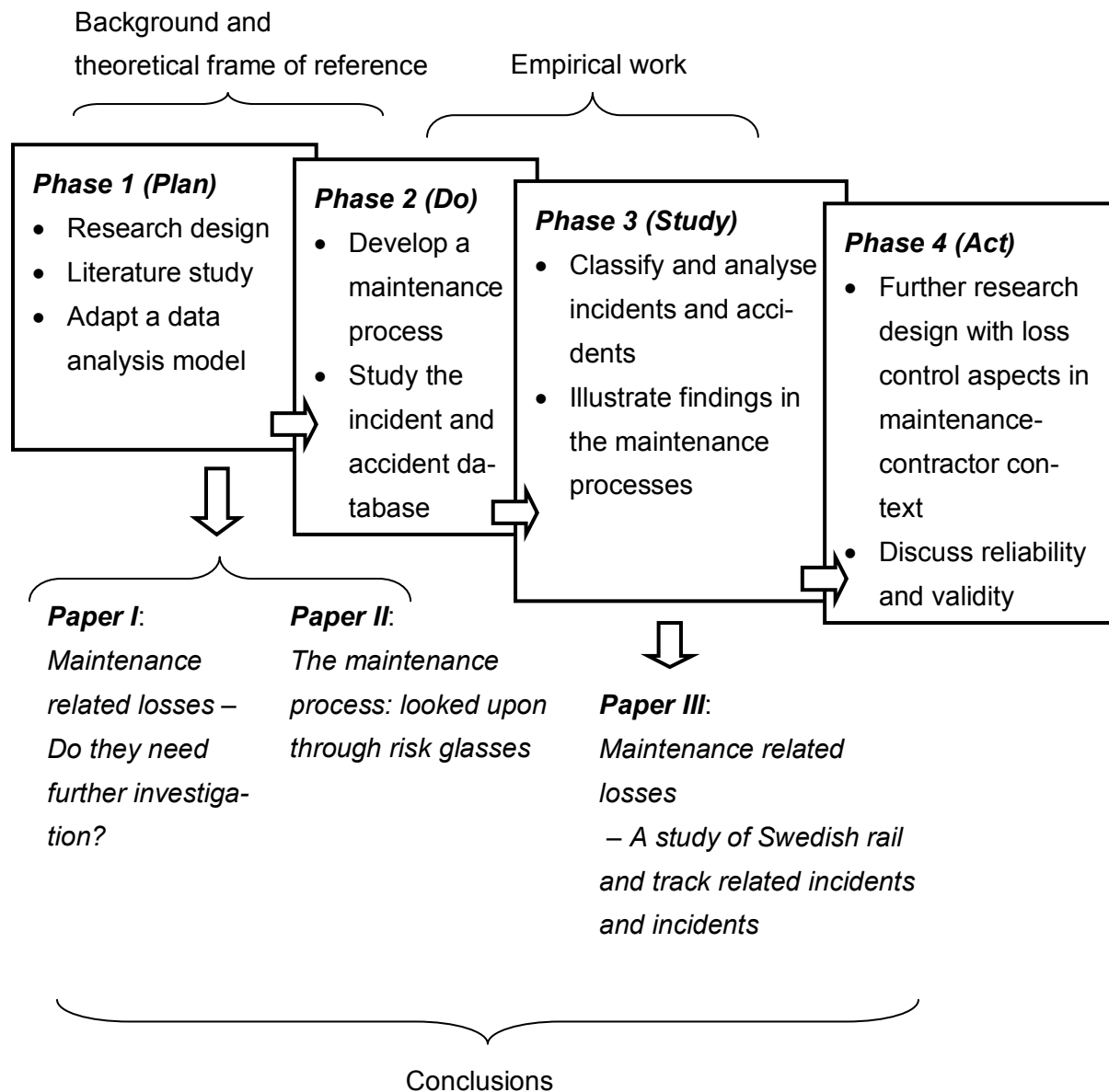


Figure 3.7. The main activities of the research process in this thesis. The different phases follow the continuous improvement cycle, presented in Section 2.1.1.

**Plan phase:** First of all, the research design was planned. A literature study was performed to identify the need for further investigation of maintenance related losses, manifested in different incidents and accidents. Finally, a data analysis model was adapted, based on identified accident causation models, which were identified during the literature study.

**Do phase:** The need for further investigation of maintenance related losses was identified in the plan phase. This fact leads to some questions regarding the definition of maintenance activities. And furthermore, how can maintenance work be illustrated? Two different maintenance processes were developed during this phase. A database study was also made in order to identify maintenance related incidents and accidents at the Swedish State Railways.

**Study phase:** The study phase focuses mainly on the identification of the causes of the maintenance related losses in a rail context. The loss control model that was adapted in the plan phase was applied to analyse railway related accidents and incidents in order to find the causes of their occurrence. The maintenance process was used in order to illustrate important steps in the maintenance processes where losses frequently occur.

**Act phase:** Continuous improvement work is always a matter of learning and gaining experience in order to avoid the same problem again. The research process conducted for this licentiate thesis has resulted in the identification of important causes that possibly affect rail safety, economy, and delays due to improper maintenance work. The next question is: What can be done in order to improve the control to avoid future losses due to maintenance work? Future research work is planned, to act and take advantage of the knowledge of loss contributing maintenance related causes, see Section 5.4. Finally, reliability and validity issues regarding the database study were discussed; see Section 3.7 and 3.8.

## 4 SUMMARY OF APPENDED PAPERS

*This chapter summarises the background, purpose, methodology and conclusions from each one of the three appended papers. For more information the reader is referred to the appended papers.*

### 4.1 Paper I

Holmgren, M. & Akersten, P.A. (2002a). Maintenance related risks – Do they need any further investigation? *Proceedings of the 3<sup>rd</sup> Edinburgh Conference on RISK: Analysis, Assessment and Management*, Edinburgh, Scotland, April 8-10, 2002.

#### 4.1.1 Background

Maintenance is performed in order to increase the safety and dependability of a system. Some authors state that maintenance is important for accident prevention. On the other hand, some authors also emphasize that maintenance may cause accidents if not performed properly. One interesting question is to what extent incorrectly performed maintenance causes accidents. If maintenance is a common trigger of accidents, it is important to investigate the causes of these accidents in order to explain their occurrences and prevent similar occurrences in the future. Therefore, this paper discusses if there is a need for further investigation of maintenance related losses.

#### 4.1.2 Purpose

The purpose of this paper is to explore the magnitude of maintenance related risks, manifested in different accidents.

#### 4.1.3 Methodology

The methodology used for this paper was a literature study. Different keywords were used and the search was performed in different databases. A number of on-line magazines, within the Risk Management and Maintenance Management area, were also studied.

#### 4.1.4 Conclusions

The study indicates that badly performed maintenance or lack of inadequate maintenance is a common trigger of some of the major accidents in history. Incorrectly performed maintenance due to human error is responsible for some direct causes of accidents. These accidents affect the maintenance personnel directly, during execution, or the system and its surroundings due to latent failures induced during maintenance execution. For instance, the Bhopal accident in 1984 was, according to Khan & Abbasi (1999), caused by incorrectly performed maintenance execution.

The latent, or hidden failures, are often hard to detect. These faults can remain invisible until the start-up phase of the system. Kang (1999) has found that 15% of 93 studied chemical accidents happened during the start-up phase, caused by incorrectly performed maintenance. Furthermore, Kang (1999) has found that 34% of the accidents were caused by incorrectly performed maintenance. As an example, the Piper Alpha platform accident in 1988 was caused by maintenance induced defects, resulted in a major disaster with grave consequences in the start-up phase (Hale et al., 1998). Therefore, the present writer claims that maintenance related losses need further investigation, and the causes of these losses have to be found, in order to prevent further occurrences.

## 4.2 Paper II

Holmgren, M. & Akersten, P.A. (2002b). The maintenance process: looked upon through risk glasses. *Proceedings of the 16<sup>th</sup> International Maintenance Congress Euromaintenance 2002*, Helsinki, Finland, June 3-5, 2002, 267-273.

### 4.2.1 Background

All equipment is prone to break down sooner or later. Some activities are required to restore these defect items to a functioning state. This is achieved by corrective maintenance. Maintenance is also performed as a preventive task to stop the degradation of different systems and their components in order to ensure safety and dependability of the system. However, maintenance work is often complex. It is therefore necessary to have a model of the maintenance work as fundamental reference in all decision making regarding maintenance aspects and for the investigation of maintenance related losses.

### 4.2.2 Purpose

The purpose of this paper is to describe how maintenance related incidents and accidents can be illustrated and analysed. One aim of the paper is to identify a generic maintenance process that can be used to illustrate maintenance related risks.

The purpose is divided into two objectives:

- Create a general maintenance process that clarifies different maintenance related risks.
- Identify a model suitable for the investigation of maintenance related incidents and accidents.

### 4.2.3 Methodology

An extensive literature study was made. Mainly books and articles in the Maintenance Management area were investigated in order to identify current Maintenance Processes. The search for a suitable model for an accident investigation focused mainly on literature on Risk Management and Loss Control Management.

### 4.2.4 Conclusions

Two fairly generic Maintenance Processes were identified in the literature study. These two Maintenance Processes were modified to better illustrate the steps that may contribute to risky situations in the maintenance execution phase, see Figure 4.1 and 4.2. The Maintenance Processes are illustrated in three dimensions: work flow, information, and material and resources. The dark grey boxes represent the logical work flow in the process description. These steps are supported by information flow, illustrated by the white boxes, and the material and resources flow illustrated by the light grey boxes. This representation, in three dimensions, is chosen to illustrate the importance of considering all these dimensions in the Risk Identification Process.

A model for investigation of maintenance related losses was also identified in the literature study. This Loss Causation Model, see Figure 4.1, should be considered in relation to the presented Maintenance Processes, illustrated in Figures 4.2 and 4.3.

Lack of Control		Basic Causes		Immediate Causes		Incident		Loss
Inadequate - system - standard - compliance	⇒ ⇐	- Personal factors - Job or system factors	⇒ ⇐	Sub-standard - acts or practices - conditions	⇒ ⇐	Event	⇒ ⇐	Unintended harm or danger

Figure 4.1. The Loss Causation Model, LCM, that was identified to serve as a data analysis tool for the study of maintenance related incidents and accidents presented in Paper III. (From: Holmgren & Akersten, 2002b)

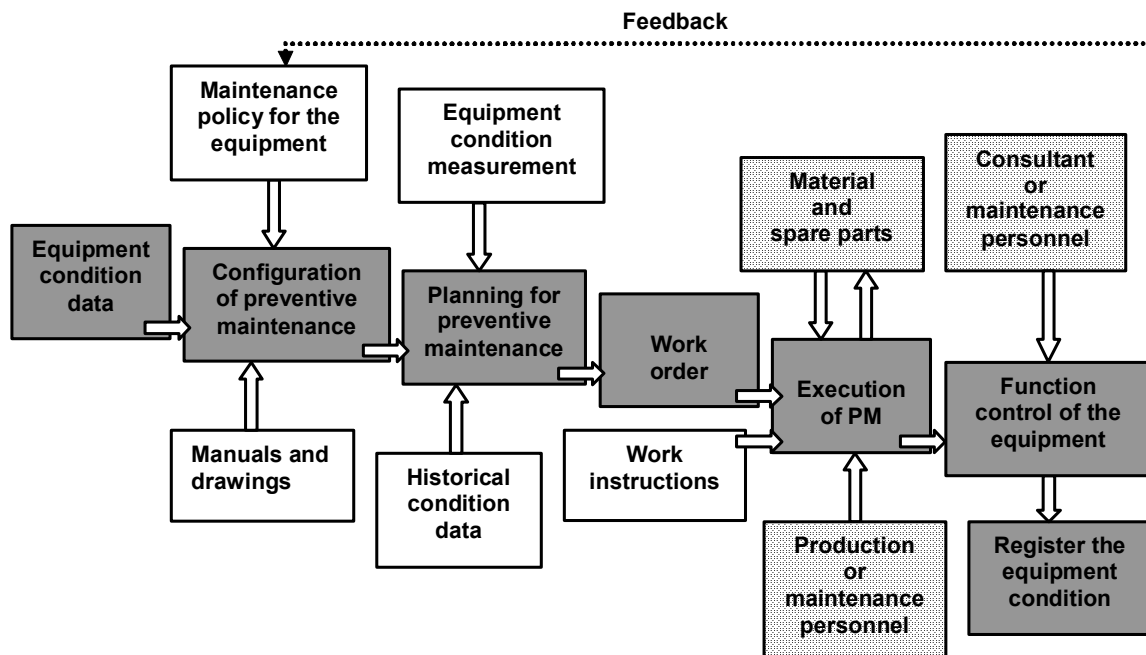


Figure 4.2. A preventive maintenance process, illustrated in three dimensions, logical work-flow, information flow, and material and resources flow. The dark grey boxes represent the logical work flow in the process description. These steps are supported by information flow, illustrated by the white boxes, and the material and resources flow illustrated by the light grey boxes. (From: Holmgren & Akersten, 2002b)



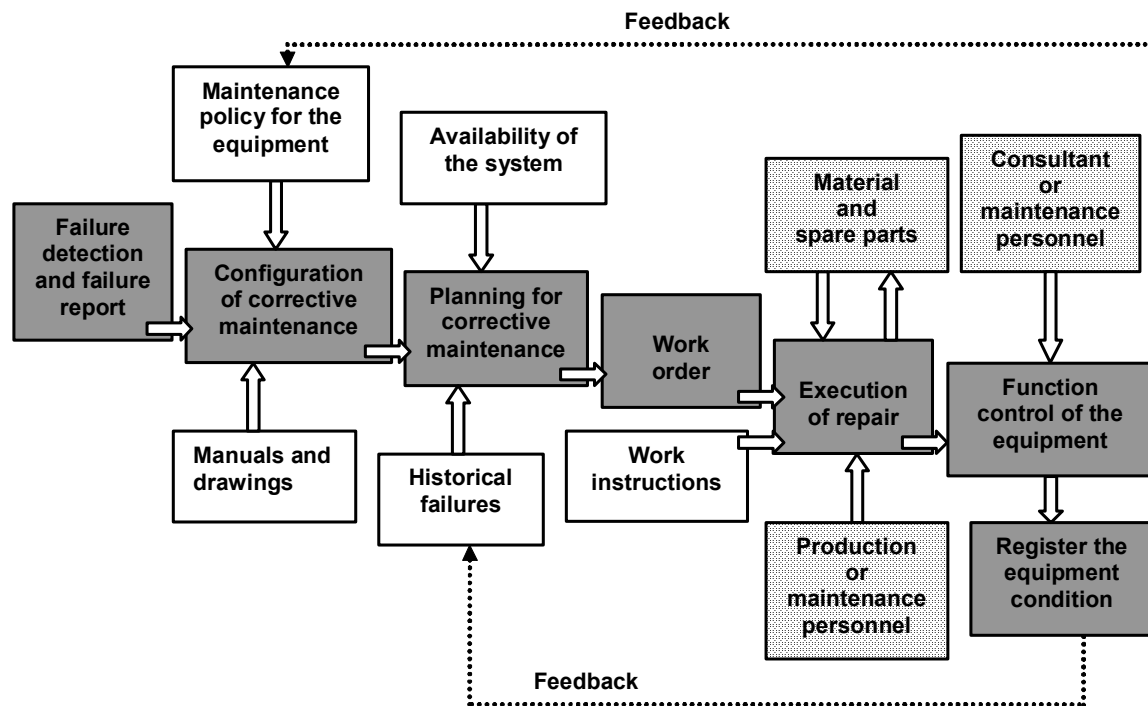


Figure 4.3. A corrective maintenance process, illustrated in three dimensions, logical work flow, information flow, and material and resources flow. The dark grey boxes represent the logical workflow in the process description. These steps are supported by information flow, illustrated by the white boxes, and the material and resources flow illustrated by the light grey boxes. (From: Holmgren & Akersten, 2002b)

## 4.3 Paper III

Holmgren, M. (2003). Maintenance related losses – A Study of Swedish rail and track related accidents and incidents. *Submitted for publication.*

### 4.3.1 Background

The railway track is used for both freight and passenger transportation. High load, extreme weather conditions and locomotives with wagons all affect the railway track, which causes degradation of the railway track. Therefore, maintenance is needed to correct failures and prevent further degradation of the track. Although maintenance is performed to maintain a certain safety level, incorrectly performed maintenance work affects the safety of the railway in a negative way. Therefore, it is important to identify the magnitude of these maintenance-induced losses. Maintenance work can be better controlled if the causes to these loss-producing actions are known.

### 4.3.2 Purpose

The purpose of this paper is twofold. Firstly, the aim is to identify maintenance related losses in order to explain deviations in the maintenance process that contribute to accidents and incidents. Secondly, the aim is to classify the maintenance related accidents and incidents in order to create a taxonomy of the causes.

### 4.3.3 Methodology

The methodology used in this study was archival analysis. A database, called BOR, containing a collection of different data sources was studied. This database contains all reported railway related accidents and some incidents at the Swedish State Railways from 1988 to 2000. This material needed to be classified in order to find maintenance related accidents. The analysis of the maintenance related accidents and incidents was structured according to the Loss Causation Model (LCM), see Figure 3.6, presented in Section 3.6.1, in order to identify loss producing events, which are deviations from the ideal situation in different steps of the maintenance activities. The five-why methodology was used supplementary to the structure in the original LCM model, illustrated in Figure 4.1, to identify the causes to the maintenance related incidents and accidents.

### 4.3.4 Conclusions

One result was a classification of all incidents and accidents reported to the BOR database. All in all there were 666 reported incidents and accidents between the years 1988 and 2000 stored in the BOR database. Of the studied reports in the database 263 incidents or accidents (or approximately 40%) were track related, and 77 (or approximately 30%) of these track related incidents or accidents were maintenance related. Another result was a taxonomy containing the primary causes of the maintenance related incidents and accidents, see Figure 4.4. About 80% of the maintenance related accidents happened during the execution phase. Failures due to lack of maintenance were not very common, about 20% of the maintenance related accidents. However, when looking at these numbers we must be aware of that insufficient data in the database were deleted in the first and second classification steps, see Figures 3.3 and 3.4. Among the accidents caused by lack of maintenance, the

dominant primary cause was defect switches. Lack of maintenance caused the track position to move in some cases. Track fraction defects, possibly caused by natural degradation or impact from the rolling stock, were also identified.

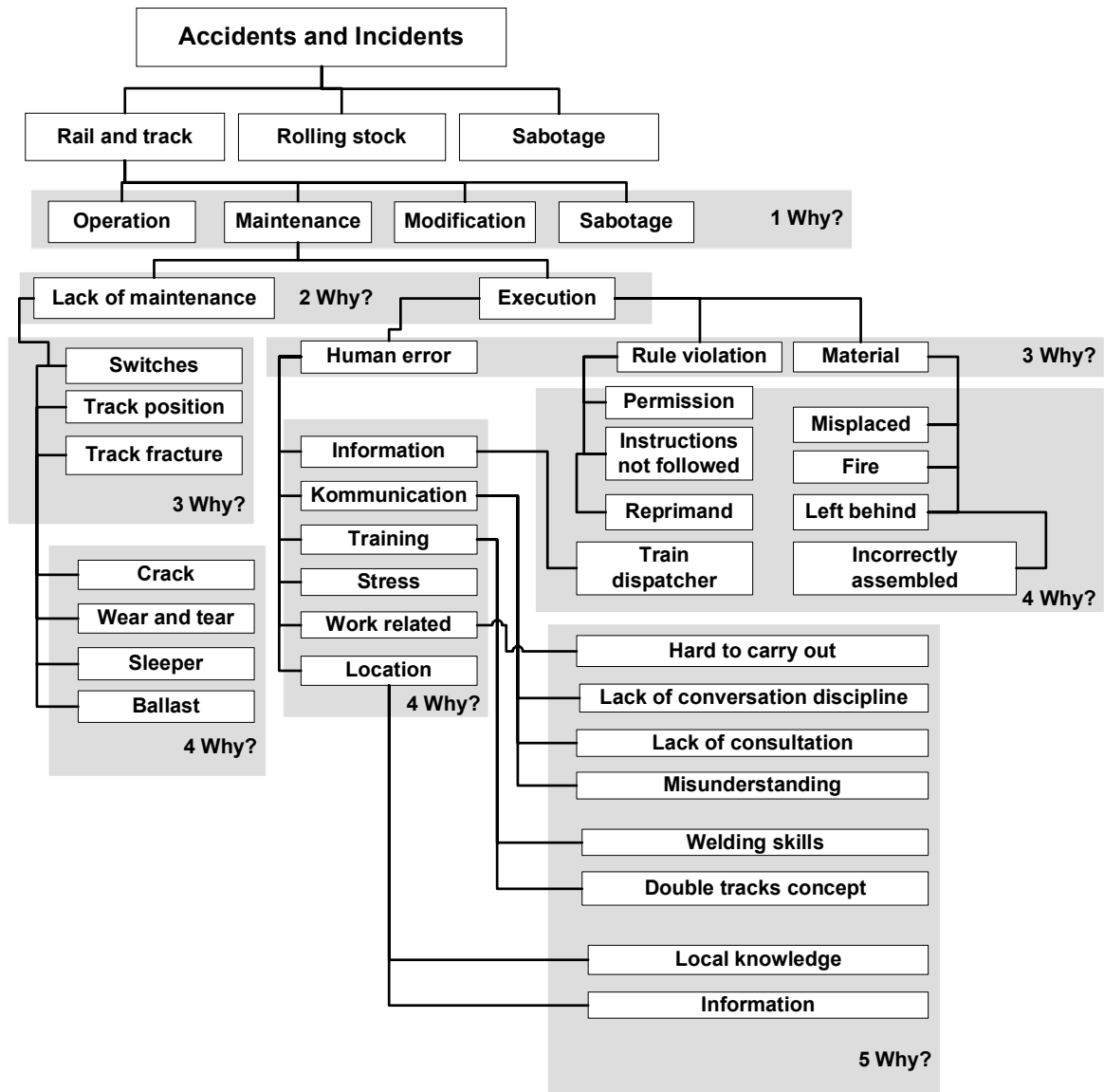


Figure 4.4. A schematic description based on the primary causes of the identified maintenance related accidents and incidents at the Swedish Railway network during the period 1988-2000. All in all there were 666 reported incidents and accidents stored in the BOR database during this time period. (From: Holmgren, 2003)

The dominant cause of incidents and accidents due to maintenance execution was human error. This was primarily caused by insufficient information, such as lack of communication between the maintenance personnel and the train dispatcher. In some cases, misunderstanding was caused by improper communication between different maintenance teams working together. The second most common cause was rule violations, especially lack of permission to perform maintenance work on the track. In some cases instructions were not followed. However, the regulations at the Swedish National Rail Administration are extensive. Therefore, causes which have been classified as rule violations in the cause description might instead be caused by other reasons. Some other identified causes were related to lack of local knowledge, which in turn was caused by lack of information.

## 5 CONCLUSIONS AND DISCUSSION

*This chapter summarises the findings of the present thesis. The findings are related to the stated purpose and research questions. Furthermore, some aspects of the findings will be discussed. Finally some suggestions for further research will be presented.*

### 5.1 Conclusions

The purpose of this thesis is “to explore and describe different deviations from the intended maintenance activities that result in losses, manifested in incidents and accidents.” The main aim of this is to control the contracted maintenance work better, and thereby ensure safety for passengers and personnel at the Swedish National Rail Administration. The results are intended to be a part of the continuous improvement work at the Swedish National Rail Administration.

The purpose of the study has been transferred to the following research questions:

1. How can maintenance related losses, manifested in incidents and accidents, be analysed?
2. What are the primary causes of the maintenance related losses at the Swedish National Rail Administration?
3. How can the maintenance related losses be illustrated in relation to the maintenance processes?

#### 5.1.1 Findings Regarding Research Question 1

Some models useful for the investigation of maintenance related losses have been identified in the literature study. These models are presented in Section 2.4; see also Figures 2.10, 2.11 and 2.12. One model, based on the Loss Causation Model, originally developed by Bird & Loftus (1976), was adapted to serve as a data analysis tool in the study of maintenance related losses at the Swedish State Railways, see Figure 3.6. This model represents the chain of events, which starts with the lack of control and ends in the actual losses. This model is used to identify the underlying causes leading to the lack of control. See Section 3.6.1 for the application of this model.

### 5.1.2 Findings Regarding Research Question 2

Some primary causes to maintenance related losses at the Swedish National Rail Administration were identified using the BOR database. The dominant primary cause to incidents and accidents due to incorrect maintenance execution was human error. This cause was in turn primarily caused by information shortages, such as lack of communication between the maintenance personnel and the train dispatcher. In some cases, misunderstanding was caused by improper communication between different maintenance teams working together.

The second most common cause to the track related accidents were rule violations, especially lack of permission to perform maintenance work. Rule violations, due to failure to follow instructions, were identified in some cases.

Among the losses caused by lack of maintenance, the most dominating primary cause was defect switches. Lack of maintenance caused the track position to move, in some cases. Track fraction defects, possibly by natural degradation or impact by the rolling stock, were also identified.

### 5.1.3 Findings Regarding Research Question 3

Maintenance related losses at the Swedish National Rail Administration were identified in the database study. The maintenance processes, presented in Section 4.2.4, see Figures 4.2 and 4.3, were modified to better reflect steps in the Maintenance Processes that contribute to the maintenance related losses. The result of this modification is illustrated in Figures 5.1 and 5.2. The dark grey boxes, illustrated in Figures 5.1 and 5.2, represent the logical work flow in the maintenance processes. These steps are supported by information flow, illustrated by the white boxes, and the material and resources flow illustrated by the light grey boxes. The grey arrows represent deviations from the intended step in the Maintenance Process. Some of the deviations found in the Maintenance Processes are due to unclear work orders and work instructions impacting the execution of maintenance tasks.

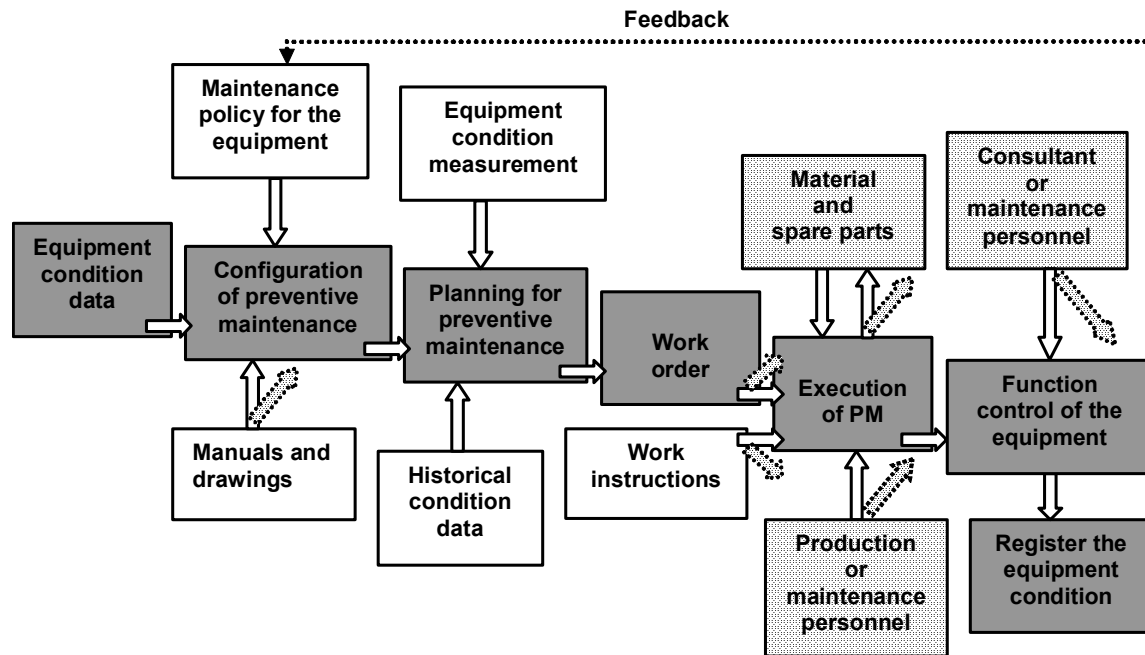


Figure 5.1. The Preventive Maintenance Process presented in three dimensions; work flow, information and resources. The grey arrows represent different deviations from the intended Maintenance Process, found in the empirical study of incidents and accidents in the BOR database. (Source: Holmgren & Akersten, 2002b)

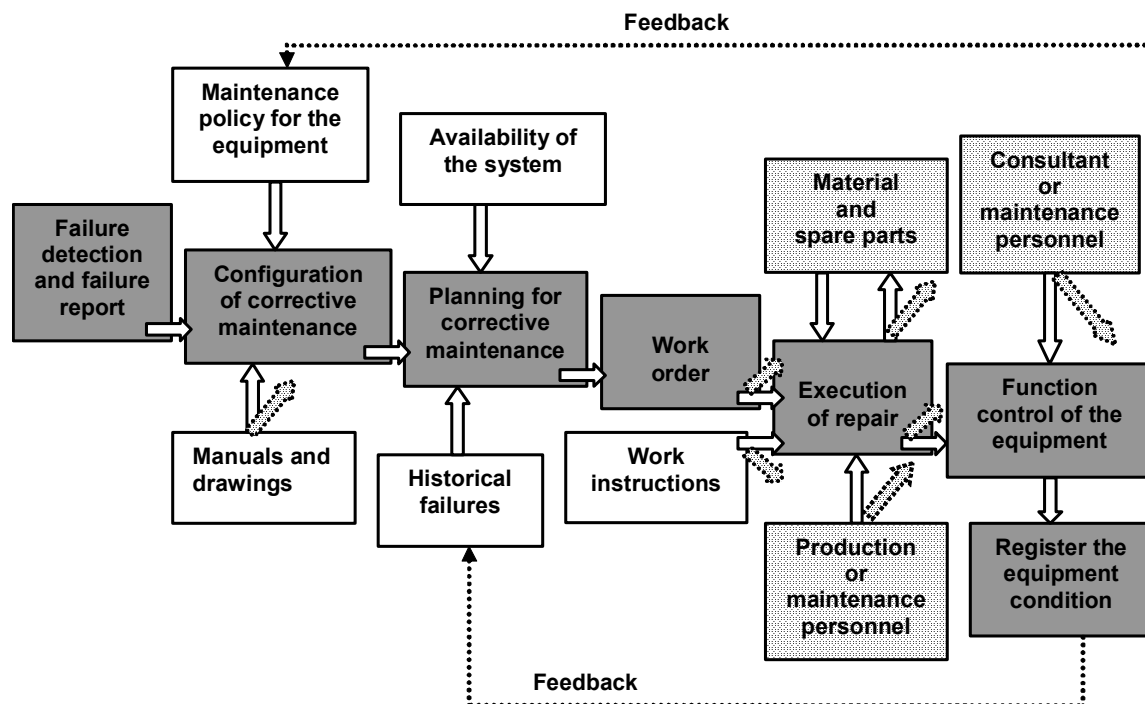


Figure 5.2. The Corrective Maintenance Process presented in three dimensions; work flow, information and resources. The grey arrows represent different deviations found at the empirical study of incidents and accidents in the BOR database. (Source: Holmgren & Akersten, 2002b)

## 5.2 Discussion

Maintenance related losses are caused by improper maintenance execution or lack of adequate maintenance. The results in this thesis show that most of the maintenance related losses on the railway track happen during the maintenance execution, rather than as a consequence of lack of maintenance. Although not included in this study, an indication was given that improper maintenance activities at the rolling stock also cause some accidents. These accidents, caused by the rolling stock, were demarcated in the first classification step due to the purpose of this study. It is hard, for instance, to determine if a track fracture is caused by neglected maintenance or by a train with some defective wheels, e.g. flat sections due to heavy braking with locked wheels. All in all, it has been difficult to determine if the causes of the losses were maintenance related or not.

When looking at the results we must be aware that some data in the BOR database was excluded when the data was classified. Therefore, the number of maintenance related losses that are presented may be too small. This fact underlines the importance of making accurate and detailed reports of all the incidents and accidents occurring on the railway. These descriptions must also be transferred into the current database at the Swedish National Rail Administration. However, during the research process, the author has found that more detailed descriptions exist in different accident reports of investigations already performed. The main problem was that these accident reports were not easily accessible. These reports are stored in separate registers at the different region offices. Nevertheless, it may be possible to trace the causes in the chain of events leading to losses further back, with the aid of these reports. A recommendation would therefore be to transfer comprehensive descriptions of the causes and consequences stated in these accident reports to the current database at the Swedish National Rail Administration. It is also important to adapt databases that are compatible with the railway operators' databases, so that current incident and accident information can be easily exchanged. However, current work at the Swedish National Rail Administration is focusing on the possibility of adapting a standardisation, regarding which type of database should be used.

Due to the lack of information in some cause descriptions in the BOR database, it was not easy to identify the underlying causes that trigger the pri-



mary causes in the accident initiation sequence. However, this study was limited to identifying the immediate causes of the losses. If the causes of the losses were clearly described, it would be easier to make fact-based decisions in order to prevent further similar occurrences, and thereby improve the safety of the railway. The causes of the incidents and accidents can, due to the limitations in the cause descriptions in the database, only be traced back to the immediate causes in the Loss Causation Model. In a few cases the basic causes, have been identified. It is important to remember that the immediate causes are the direct triggers of the accidents, but these are caused by deficiencies in the basic causes and lack of control of the operations, which are managerial responsibilities. Further research to identify the basic causes of the maintenance related losses should be based on the accident investigations instead of the BOR database. However, due to lack of time at this stage of the project, this was not possible.

Due to the regulation controlling the rail traffic, all accidents on the railway must be reported and an investigation made. Therefore, most of the accidents that have occurred should be present in the BOR database. Furthermore, quite a few incidents are reported to the BOR database. If incidents were reported more frequently, it would be possible to reduce the causes of their occurrence in the continuous improvement work conducted at the Swedish National Rail Administration. Used properly, the incidents can be a valuable source of information for reducing substandard acts that might lead to severe accidents. Anyway, the incidents create economic losses for both the railway operator and the administrator, if not affecting the safety of the railway.

The taxonomy that was presented in Section 4.3.4, see Figure 4.4, illustrates the primary causes of the maintenance related losses and the basic causes that precede the primary causes, when they have been found. Human error is the dominant primary or basic cause of the incident and accident initiation scheme, illustrated in the Loss Causation Model. However, it is difficult to explain why human error occurs. One possible explanation is the lack of proper information caused by insufficient communication. This may lead to misunderstandings and incorrect interpretations. Therefore, proper information about the performance of the maintenance work must be communicated in order to maintain, or increase, the safety level found today on the railways. Stress, caused by lack of time to perform maintenance work, is another possible explanation of human error. Stress may occur if there is lack of time when

the track is available for work. However, due to narrow timetables, it is often hard to get substantial time for the maintenance work. If the traffic volume will further increase, then there will be even less time for preventive maintenance on the tracks. This fact will challenge the planning of maintenance work in the future.

Rule violations are also a common cause of maintenance related losses. However, one should bear in mind that if the procedures are covered by regulations at the Swedish National Railway Administration, deviations from the maintenance procedures will cause rule violations. Therefore, it is important to understand why rules are broken, rather than to create new rules to cover the eventualities causing the losses. Troublesome rules and routines may also tempt the personnel to take shortcuts, in an attempt to gain time in order to get the job done, when there is lack of time. Another important aspect of routines is that they must be consistent, meaning that no contradictory demands should be present. Furthermore, it is important to reduce and condense the amount of documents regulating rail safety, so that contradictory demands are kept to a minimum. This aspect was not investigated in this study. However, the maintenance is already bought from maintenance contractors, and this outsourcing strategy will further increase the need for clearly stated and easily interpreted requirements regarding rail safety.

However, these problems regarding outsourced maintenance are not specific to the railway. Improper communication during the maintenance execution is most likely occurring in other industries where the maintenance is performed by outside contractors. The primary causes to the maintenance related incidents and accidents, illustrated in Figure 4.4, may therefore be useful outside the rail context.

## 5.3 Further Research

One result presented in this thesis is that maintenance related losses are caused by human error during maintenance execution. Some possible explanations of human error, identified in the railway study, were the lack of proper information and communication. The insufficient communication between the maintenance personnel and rail operators indicates the need for better exchange of information between them. The maintenance personnel, especially those who lack local knowledge, need proper communication and

the transfer of adequate risk information. Furthermore, information must be communicated in order to maintain, or increase, the safety level found today on the railways. The continuous improvement work should therefore focus on ways of achieving better communication between the maintenance executor and the operator or the administrator of the railway.

The Swedish State Rail Administrator has already begun to purchase maintenance from contractors. The maintenance contractor situation, especially with the involvement of contractors that lack local knowledge, will further increase the need for transfer of adequate risk information and requirements. Therefore, further research should focus on the identification of requirements for different stakeholders on the maintenance process that affect rail safety. Different activities that affect the managerial control and the basic causes are important to focus on due to their pre-initiation of the accident sequences presented in this thesis. It is the managerial responsibility to design and evaluate the inquiries for maintenance contracts. An interesting aspect to investigate is if these inquiries for maintenance contracts cover, or clearly express, safety critical demands. Furthermore, it is important to focus on how to make the existing regulations clearer, and not to focus on the creation of new extensive regulations.



# REFERENCES

Akersten, P.A. & Klefsjö, B. (2003). Total Dependability Management. *Handbook of Reliability Engineering*. Springer, London, 559-565.

Alvesson, M. & Sköldberg, K. (1994). *Tolkning och reflektion. Vetenskapsfilosofi och kvalitativ metod*. Lund, Studentlitteratur (In Swedish).

Aven, T. (1992). *Reliability and risk analysis*. Amsterdam, Elsevier Publishing Company.

Backlund, F. (1999). *Reliability-centered maintenance. Identification of management and organisational aspects of importance when introducing RCM*. Licentiate Thesis, Division of Quality Technology & Statistics, Luleå University of Technology, Luleå, Sweden.

Banverket "The Swedish National Rail Administration" (2003). *Information for suppliers*. ([http://www.banverket.se/templates/StandardTtH\\_\\_\\_\\_3575.asp](http://www.banverket.se/templates/StandardTtH____3575.asp)) (2003-06-15)

Baron, M.M. & Paté-Cornell, E. (1999). Designing risk-management strategies for critical engineering systems. *IEEE Transactions on Engineering Management*, 46(1): 87-100.

Bergman, B. & Klefsjö, B. (1997). *Tillförlitlighet*. Luleå tekniska universitet, Luleå (In Swedish).

Bergman, B. & Klefsjö, B. (2003). *Quality from customer needs to customer satisfaction*. Studentlitteratur, Lund.

Bird, F.E. Jr. & Germain, G.L. (1996). *Practical loss control leadership*. Det Norske Veritas, Loganville.

Bird, F.E. Jr. & Loftus, R.G. (1976). *Loss control management*. Institute Press, Loganville.

Bäckman, J. (2002). *Railway safety: risks and economics*. Doctoral Dissertation, Department of Infrastructure and Planning, The Royal Institute of Technology, Stockholm, Sweden.

Carey, S. (1994). *A beginner's guide to scientific method*. Wadsworth Publishers, Belmont.

Clifton, R.H. (1974). *Principles of planned maintenance*. Edward Arnold Publishers, London.

Coetzee, J. (1998). *Maintenance*. Maintenance Publishers, Hatfield.

Crosby, P. (1979). *Quality is free*. McGraw-Hill, New York.

Dahmström, K. (1996). *Från datainsamling till rapport: att göra en statistisk undersökning*. Studentlitteratur, Lund (In Swedish).

Dane, F. C. (1990). *Research methods*. Brooks/Cole Publishing Company, Pacific Grove.

Deming, W.E. (1986). *Out of the crisis*. Cambridge University Press, Cambridge.

Deming, W.E. (1994). *The new economics for industry, government, education*. Massachusetts Institute of Technology: Center for Advanced Engineering Study, Cambridge.

Denzin, N. & Lincoln, L. (1994). *Handbook of qualitative research*. Sage, Thousand Oaks.

EFNMS Building Maintenance Working Group (2000). 2081: *EUROENVIRON-MAINTENVIR: "Building Maintenance under ecological and economical aspects"*, 2(3). UTEK, Stockholm.

Eriksson, L. & Wiedersheim-Paul, F. (1997). *Att utreda, forska och rapportera*. Liber ekonomi, Stockholm (In Swedish).

Ferry, T.S. (1988). *Modern accident investigation and analysis*. Wiley, New York.

Groeneweg, J. (1998). *Controlling the controllable: the management of safety*. DSWO Press, Leiden.

Groote, P.D. (1994). Trends in maintenance management in Europe. *Maintenance*, 9(5): 3-7.

Hale, A.R.; Heming, B.H.J.; Smit, K.; Rodenburg, F.G.; & van Leeuwen, N.D. (1998). Evaluating the safety in the management of maintenance activities in the chemical process industry. *Safety Science*, 28(1):21-44.

Harms-Ringdahl, L. (2001). *Safety analysis. Principles and practice in occupational safety*. Taylor & Francis, London.

Heinrich, H.W. & Petersen, D. & Roos, N. (1980). *Industrial accident prevention: a safety management approach*. McGraw-Hill, New York.

Hellsten, U. & Klefsjö, B. (2000). TQM as a management system consisting of values, techniques and tools. *The TQM Magazine*, 12(4): 238-244.

Holmgren, M. & Akersten, P.A. (2002a). Maintenance related risks – Do they need any further investigation? *Proceedings of the 3<sup>rd</sup> Edinburgh Conference on RISK: Analysis, Assessment and Management*, Edinburgh, Scotland, April 8-10, 2002.

Holmgren, M. & Akersten, P.A. (2002b). The maintenance process: looked upon through risk glasses. *Proceedings of the 16<sup>th</sup> International Maintenance Congress Euromaintenance 2002*, Helsinki, Finland, June 3-5, 2002, 267-273.

Holmgren, M. (2003). Maintenance related losses – A study of Swedish rail and track related accidents and incidents. *Submitted for publication*.

Holmgren, M. (2004). Maintenance related incidents and accidents at the Swedish National Rail Administration. *Forthcoming research report*.

Herzog, T. (1996). *Research methods in the social sciences*. HarperCollins, New York.

HSE (Health and Safety Executive) online (<http://www.hse.gov.uk/>) (2002-01-03)

Hunt, N.M. & Wierman, T.E. (1990). RAM methodology selection. *Proceedings of the 17<sup>th</sup> Inter RAM Conference for the Electric Power Industry*, May, San Francisco.

Hywel, W.J. (1994). *Condition-based maintenance and machine diagnostics*. Chapman & Hall, London.

IEC (1995). 60300-3-9: *Dependability Management-Part 3: Application guide selection 9: Risk Analysis of technological systems*. CEI/IEC 300-3-9: 1995, International Electrotechnical Commission, Geneva.

IEV (International Electrotechnical Vocabulary) online. Geneva: International Electrotechnical Commission, Geneva.  
(<http://domino.iec.ch/iev/iev.nsf/Welcome?OpenForm>) (2002-01-15)

Jones, S. & Kirchsteiger, C. & Bjerke, W. (1999). The importance of near miss reporting to further improve safety performance. *Journal of Loss Prevention in the Process Industries*, 12(1): 59–67.

Kang, S-J. (1999). Trends in major industrial accidents in Korea. *Journal of Loss Prevention in the Process Industries*, 12(1): 75–77.

Kelly, A. (1999). *Maintenance strategy: business-centred maintenance*. Butterworth-Heinemann, Oxford.

Khan, F. & Abbasi, S.A. (1999). Major accidents in process industries and an analysis of causes and consequences. *Journal of Loss Prevention in the Process Industries*, 12(5): 361-378.

Kletz, T. (1988). *What went wrong?: Case histories of process plant disasters*. Gulf Publishing, Houston.

Kletz, T. (2001). *Learning from accidents*. Butterworth-Heinemann, Oxford.



Kumar, U. & Svanberg, J. (1999). Selection of maintenance strategy for mechanized and automated systems. *Proceedings of the 5<sup>th</sup> International Symposium on mine Mechanization and Automation and Telemin*, Sudbury, Ontario, 11-19.

McKinnon, R. (2000). *Cause, effect, and control of accidental loss with accident investigation kit*. Lewis Publishers, London.

Marshall, C. & Rossman, G.B. (1999). *Designing qualitative research*. Sage, London.

Melchers, R.E. (2001). On the ALARP approach to risk management. *Reliability Engineering & System Safety*, 71(2): 201-208.

Merriam, S. (1998). *Qualitative research and case study applications in education*. Jossey-Bass, San Francisco.

Miles, M.B. & Huberman, A.M. (1994). *Qualitative data analysis: an expanded sourcebook*. Sage, Thousand Oaks.

Miyake, D.I. & Enkawa, T. (1999). Matching the promotion of total quality control and total productive maintenance: An emerging pattern for nurturing of well-balanced manufactures. *Total Quality Management*, 10(2): 243-269.

Nakajima, S. (1988). *Introduction to TPM: total productive maintenance*. Productivity Press, Cambridge.

Nowlan, F.S. & Heap, H.F. (1978). *Reliability-centered maintenance*. US Department of Commerce, Virginia.

Ollila, A. & Malmipuro, M. (1999). Maintenance has a role in quality. *TQM Magazine*, 11(1): 17-21.

Paté-Cornell, E. & Fischbeck, P.S. (1993). PRA as a management tool: Organizational factors and risk-based priorities for the maintenance of the tiles of space shuttle orbiter. *Reliability Engineering and System Safety*, 40(3): 239-257.

- Patel, R. & Davidson, B. (1994). *Forskningsmetodikens grunder: att planera, genomföra och rapportera en undersökning*. Studentlitteratur, Lund (In Swedish).
- Petersen, D. (1988). *Safety management: a human approach*. Alora, New-York.
- Reason, J. (1990). *Human error*. Cambridge University Press, Cambridge.
- Ridley, J. & Channing, J. (1999). *Risk management*. Butterworth-Heinemann, Oxford.
- Schlechter, W. (1995). Process risk assessment – Using science to “do it right”. *International Journal of Pressure Vessels & Piping*, 61(2-3): 479-494.
- Sherwin, D. (2000). A review of overall models for maintenance management. *Journal of Quality in Maintenance Engineering*, 6(3):138-164.
- SIS (2000). *ISO 9000*. SIS Förlag, Stockholm.
- SIS (2001). *SS-EN 13306: Maintenance terminology*. SIS Förlag, Stockholm.
- Stamatis, D.H. (1994). *Failure mode and effects analysis. FMEA from theory to execution*. ASQ Press, Milwaukee.
- Taguchi, G. & Wu, Y. (1979). *Introduction to off-line quality control*. Central Japan Quality Control Association, Tokyo.
- Taylor, S.J. & Bogdan, R. (1984). *Introduction to qualitative research methods: the search for meanings*. Wiley, New York.
- Tchankova, L. (2002). Risk identification – basic step in risk management. *Environmental Management and Health*, 13(3): 290-297.
- Tsang, A. (2002). Strategic dimensions of maintenance management. *Journal of Quality in Maintenance Engineering*, 8(1): 7-39.
- Uth, H-J. (1999). Trends in major industrial accidents in Germany. *Journal of Loss Prevention in the Process Industries*, 12(1): 69-73.

van der Meer-Kooistra, J. & Vosselman, E. (2000). Management control of interfirm transactional relationship: the case of industrial renovation and maintenance. *Accounting, Organizations and Society*, 25(1): 51-77.

Yin, R. (1994). *Case Study Research, Design and Methods*. Sage, Thousand Oaks.



## APPENDED PAPERS

# PAPER I

Maintenance related risks –  
Do they need any further investigation?

Holmgren, M. & Akersten, P.A. (2002). Maintenance related risks – Do they need any further investigation? *Proceedings of the 3<sup>rd</sup> Edinburgh Conference on RISK: Analysis, Assessment and Management*, Edinburgh, Scotland, April 8-10, 2002.

# Maintenance related risks – Do they need any further investigation?

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**Keywords:** maintenance; risk management; accidents; risk; losses; cause and effect

**Abstract:** *The purpose of maintenance is to ensure safety and dependability of a system. The maintenance personnel perform different maintenance activities. In Sweden there exist regulations, to some extent covering maintenance and operation of technical systems. The purpose of these regulations is to reduce the risk for the humans, the environment and the property. Still, many accidents occur in connection with maintenance or service. Reasons for this are, e.g., that procedures are not followed, proper training is lacking, or the maintainability of the system is poor.*

*In an ongoing study at the Centre for Dependability and Maintenance at Luleå University of Technology, a number of company representatives are interviewed and incident reports and accident investigations from a number of different papers and scientific reports are studied with respect to possible maintenance related causes and corresponding effects. The purpose of this study is to perform an investigation in order to answer the question: Do maintenance related risks need further investigation? In this paper some preliminary findings will be presented.*

## Introduction

The normal operation of different technical systems, for example aircraft, steelworks, oil-rigs, mines or paper mill will gradually decrease the performance of the system. Wear, dirt, corrosion or/and overloading are some contributing causes for the degradation of the production system. To ensure safety and optimal performance of the system some repair or preventive actions must be conducted. These actions are guided by the maintenance strategy for the system and supported by different tools such as Fault Tree Analysis (FTA); or FMECA Sheet (Akersten & Klefsjö, 2001). By this reason there is a continuous need to optimise the maintenance strategies and tools taking safety, reliability and economic factors into account.

Maintenance is by definition: “the combination of technical and administrative actions such as supervision actions intended to retain an item in or restore it to a state in which it can perform a required function” (IEC191-07-01, 2002).

Maintenance can briefly be divided into preventive- and corrective actions. These two actions and some safety considerations are looked upon through a process perspective in Holmgren & Akersten (2002). There are numerous of different maintenance methodologies applied within different industries. A methodology i.e. ways to work within the organisation to reach the goals; consists of a number of activities performed in a certain order (Akersten & Klefsjö, 2001). Some examples of methodologies that are frequently used are: Total Productive Maintenance (TPM) (Nakajima, 1998); Reliability Centred Maintenance (RCM) (Andersson & Neri, 1990) and/or Failure mode and effects analysis (FMEA) (Stamatis, 1994).

Maintenance activities are performed, depending of maintenance strategy, by the maintenance personnel and sometimes even by the production personnel in different sections of the system. There are two different types of maintenance actions; Preventive maintenance and Corrective maintenance. By definition Preventive maintenance is *"The maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item."* (IEC191-07-07, 2002). The definition of Corrective maintenance is *"The maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function."* (IEC191-07-07, 2002)

The preventive maintenance actions are often performed in sections of the system that are shut down and isolated from the rest of the system. This makes it safer for the maintenance personnel to perform desired actions. These actions are necessary for the assurance of the dependability and safety of the plant in the long run. Although preventive actions are taken some breakdowns always occur. The frequency of these breakdowns is often related to the amount of preventive maintenance and the potential consequences/damage of the system and its surroundings.

Immediate breakdowns are taken care of by corrective maintenance actions. The situation for the maintenance personnel differ slightly compared to the preventive maintenance actions. The system is often up and running during the corrective actions which makes the risk of being harmed or cause immediate losses to the system greater than for the case of a well isolated and non-operative plant.

Later on in this paper the Loss Causation Model (Bird & Germain, 1996) and some examples of immediate and hidden causes of maintenance risks will be presented. These maintenance-related causes can be identified for a substantial number of severe accidents occurring in different types of industries.

## **Study approach**

This paper is based on literature studies of different scientific literature in the area of maintenance, risk assessment, human error and major accident investigations related to maintenance causes. Different databases have been used. Different related keywords with truncations in different combinations e.g. *maintenance\**; *risk\**; *accidents\**; *cause\** and *disaster\** have been used in the database search which



resulted in a large number of hits. In order to sort out relevant data all abstract titles have been read. This reduced the data of the material collected from the databases. Secondly the abstracts of the remaining material were read carefully which further reduced the material. Finally the full articles were read and some findings that summarises the area of maintenance relates risks are presented in this paper.

Furthermore different scientific journals e.g. Safety Science; Reliability Engineering and System Safety; Journal of Loss Prevention in the Process Industries and International Journal of Industrial Ergonomics have been read, covering issues between 1995 and 2002. This material was treated in the same way as for the database findings.

### **Maintenance related risks**

Beside the risk of being injured during maintenance actions there are other types of maintenance-related risks, related to, e.g.

- lack of maintenance
- incomplete or poorly performed maintenance
- maintenance in connection with system modifications

The performance of maintenance activities poses different types of demands. Such demands are, e.g., information, skill, material, maintainability of the equipment, and access to the equipment. If these demands are not fulfilled, the performance of maintenance is associated with several risks. According to Spencer and Davis (2001) lack of communication, slips and lapses can cause risky situations for the individuals and the system as a whole. The authors would like to point out that maintenance is not always dangerous for the person or persons who actually perform maintenance work. Wrong or inappropriate maintenance can affect those who run the system, the surrounding systems or our global environment. Human reliability is another important aspect. The nuclear accidents in Tree Mile Island in 1979 (Britkov et al., 1998) or Chernobyl 1986 (Kletz, 1994) are examples of events caused by inappropriate human actions.

The fact that humans develop maintenance and safety routines makes human error and human interpretations important to deal with when understanding maintenance accidents. A study conducted by Morris et al. (1998) indicates that 80% of all maintenance related accidents depend on incorrect human action or human error.

Maintenance-related risks are related to the performance of maintenance activities and the corresponding demands on information, skill, material, etc. This strongly motivates a process-oriented approach in order to clarify and satisfy the different needs for persons involved in the maintenance process. This concept will be further developed in (Holmgren & Akersten 2002).

## Maintenance related losses

Maintenance related accidents can result in loss of human life or money. Det Norske Veritas (DNV) has developed a Loss Causation Model, which is a part of the Loss Control Management approach (Bird & Germain, 1996).

A Loss can be related to an accident, to inadequate maintenance performance or to sub-standard operation of the equipment. The Loss Causation is briefly described by the following figure:

Lack of Control		Basic Causes		Immediate Causes		Incident		Loss
Inadequate - system - standard - compliance	⇒ ⇐	- Personal factors - Job or system factors	⇒ ⇐	Sub-standard - acts or practices - conditions	⇒ ⇐	Event	⇒ ⇐	Unintended harm or danger

Figure 1. The Loss Causation Model (from Akersten, 2000).

Risks are manifested through **losses** or **incidents**. The losses are starting points as well as end points. Real losses should be starting points for reporting and cause investigations, and anticipated losses are end points of predictive consequence analyses. Incidents, identified by events not leading to losses, are likewise important to report and analyse. They give valuable information of potential losses and their causes, as well as information of loss preventing circumstances.

The category **immediate causes**, i.e. substandard acts or conditions, should act as triggers for maintenance activities, preventive or corrective. The **basic causes** and **lack of control** categories are connected to another kind of maintenance - maintenance of personal knowledge and skill, maintenance of procedures and work equipment and maintenance of management system.

## Maintenance related accidents – some examples

Maintenance activities are often involving both maintenance and production personnel who require good communication and information flow. If wrong or inadequate information is supplied a risky situation can occur because of improper or wrong actions taken by the maintenance personnel. These incomplete or poorly performed actions can lead to fault or failures of the systems (Kirwan, 1994).

If maintenance aspects are seen indirectly, the lack of maintenance actions can lead to a hazardous degrading production system. The chemical release and fire at the Associated Octel Company Limited, Ellesmere Port, Cheshire in 1994 was most likely caused by overseen preventive maintenance actions which led to the failure of a corroded securing flange between the fixed pipeline and the discharge port of a pump that circulates highly flammable liquids (HSE, 2001).

By definition preventive maintenance work does not include modifications of the equipment (IEV 191-07-07, 2002). Modifications are nevertheless included as a daily activity in the preventive work in Total Productive Maintenance (TPM) (Nakajima, 1988). It is obvious that unrecorded modifications can impair the safety for both the production system and the surroundings (Kletz, 1993).

The authors of this paper would like to state that the potential hazards that maintenance activities causes are often overlooked (Hopkins, 1999). Some examples of maintenance related failures will be presented below to highlight the importance of safe and well-known maintenance processes.

A major disaster occurred at the end of October 1989 at Philips petrochemical plant in Pasadena, Texas. A heavy explosion of two iso-butane tanks resulted in the death of 23 employees and another 130 employees were injured. Maintenance work was performed incorrectly on a pipe section. The isolation valve, which is used to seal off the flammable liquid, was not used properly. Because of the similarity of the air connections, the maintenance personnel mixed up the air connections and opened the valve fully instead of closing it before the maintenance actions were conducted, which led to a major gas leakage. The accident was caused by human-error of the maintenance personnel due to improper system design (Khan & Abbasi, 1999).

The Accident in the Union Carbide plant at Bhopal, India on 3 December 1984 is still one of the worst accidents that have occurred in the chemical industry so far. A leak of over 25 tonnes of methyl isocyanate (MIC) spread beyond the plant boundary. The official death figure was 2153 people killed, but there are according to Kletz (1998) possible that over 10.000 people were killed and approximately 200.000 people injured. The people among the plant lived in slum districts which contribute to the uncertainty in the figures. There are several possible explanations to why the accident did occur. A possible explanation is was sabotage followed by protective equipment which did not work properly. This theory was controversial according to Kletz (1994). Another possible explanation is improper maintenance actions. A section of the piping system was washed out and the maintenance personnel forgot to isolate eg. forgot to insert a slip plate in the pipe-section before carrying out the repair work. Khan & Abbasi (1999) states that if Union Carbide would have conducted proper risk analysis this accident could be avoided.

A study of the chemical accidents stored in the FACTS database was performed by Koehorst (1989). He found that approximately 39% of the accidents when dangerous materials were released from the on-site plant had taken place during the maintenance phase. Hurst et al. (1991) found that 38.7% of 900 studied pipe-work related accidents have their origins in the maintenance pace.

In Korea, 93 major chemical industrial accidents between 1988 and 1997 were investigated by Kang (1999). The result of the study was that operation error is the dominating cause to accidents, 46% of all the accidents were triggered by incorrect human actions due to:

- Lack of well trained operators in the chemical plants.
- Lack of safety inspection and preventive maintenance
- Lack of safety consciousness or safety culture.

Kang (1999) also classified the accidents due to the circumstances, the result was that the maintenance is the most accident contributing phase with 34% followed by the normal operating phase which contributed to 28% of all the accidents. It should also be noticed that the start-up (15%) and shut down phase contributes (23%) the rest of the accidents.

It is sometimes hard to determine if the maintenance or modification work were performed adequately since the effect of the actions are not immediate. The start up phase is therefore a risky moment. Kang (1999) showed that 15% of 93 studied chemical accidents happened during the start-up phase. It is the 'latent' or hidden failures which will be visualised during start-up.

Another example of start-up accidents is the Piper Alpha accident in 1988 was caused by maintenance actions and the plant failed dangerously at start up which resulted in the death of 165 peoples and substantial economical losses (Hale et al., 1998).

An example of insufficient maintenance followed by a conscious rule violation by the production personnel is the Siberian accident which occurred in 1989 near Nizhnevartovsk. The pipeline pressure dropped, due to a leakage in the pipeline system. The Engineers did not investigate the trouble; instead they increased the pumping rate to maintain the system pressure. The leakage caused a huge cloud of highly flammable liquefied gas. The smell of gas was reported by the valley settlements in the area, but still no actions were taken to investigate the problem. Two trains were passing by the gas filled area and it was probably the brakes of one of the train that ignited the cloud of gas. 462 persons were killed in the accident and another 796 were hospitalised with grave burn wounds (Khan & Abbasi, 1999).

## **Human error aspects**

Human error is common, everyone commits at least some each day. It could be small ones such as misspelling a word or larger ones such as decision on an investment, which later loses its financial value. In every day life these mistakes do not have a great impact on our lives. In the professional work situation, these mistakes can have much greater impact. For example the pilots, or operators in a chemical or nuclear plant, cannot afford to make such mistakes or else accidents involving fatalities possible including the lives of themselves may be the result (Kirwan, 1994).

As highlighted above in the accidents section, improper maintenance causes incidents and accidents. Jones et al. (1999) describes the importance of near misses and incidents to improve the system safety. This information is according to them important in order to gain knowledge and therefore be able to prevent further incidents which could result in real accidents.

One important factor is human error in general and 'latent' failures in specific. Kirwan (1994) defines latent failures as hidden failures which remain hidden until either the system is tested or maintained or at a later date an incident or accident occurs. In the Human Reliability Analysis (HRA) this type of human error is the primary consideration in the risk assessment.

An accident can be initiated by several factors, for instance hardware error, material fatigue, and overload or incorrect processes. Kirwan (1994) points out the importance to focus on the human error initiation of the accident sequence.

In order to deal with the human error contribution in accidents it is important to follow routines and clearly adopt and follow written procedures and pre defined work sequence. However Lawton (1998) discusses the aspects of over regulation and the human ability to not follow written procedures when they make it more difficult for the maintenance personnel to perform their work. This is not an easy issue, but in our opinion a necessary task to reduce the amount of incorrect human actions. The difficulty is to adopt necessary but not overregulated permit-to-work system to ensure safety. Kletz (1998) describes some incidents regarding permit-to-work system and the lesson learnt is that the procedures does not cover, or seem to cover, all circumstances or the permission has been withdrawn without further notice to the maintenance personnel.

One aspect of human error contribution is the information flow. Kletz (1993) describes the importance of clearly write or explain what should be done and how it should be done. Instructions such as repair; recondition or overhaul the broken equipment can lead to the loss of maintenance skills. Experienced personnel perform the required work acquired by experience, but inexperienced personnel have a great potential in doing the work wrong according to the unknown demands of the system. In our opinion this is an important aspect to consider when maintenance work is to be bought from maintenance contractors. Other important factors that impact the system safety are the man-machine-interaction for the plant, not only for the production personnel but also for the maintenance staff. Lacks of time do according to Kletz (1993) contribute to an increasing amount of human error.

## Discussion and further research

In this article some of the major accidents related to maintenance have been identified and the causes presented by different authors have been highlighted. Still there is not a simple task to explain why different accidents do occur or what really causes them. The authors of this paper are convinced that maintenance related risks do need further investigation! Different risks that impact **lack of control** and the **basic causes** are according to the authors of this paper important to focus on in the Loss Causation Model due to their initiation of the accident sequences presented in this paper.

Furthermore a study of the involvement of maintenance contractors will be conducted and different risks with their involvement in the maintenance process will

be analyzed. The reason for further study of the involvement of maintenance contractors is according to Kletz (1993) that their involvement sometimes increases the risk for the system. Maintenance contractor involvement will impact the ***lack of control*** for those responsible for the system safety if information about system changes and repair fail to come off.

## References

- Akersten, P-A. (2000). Loss Control Management – Some Aspects. In: *Proceeding of the 15th International Maintenance Congress, Euromaintenance 2000*, Stockholm, Sweden, Mars 7-10, 2000, 361-365.
- Akersten, P-A. & Klefsjö, B. (2001). Dependability Management as a Management system consisting of Core Values, Methodologies and Tools. *Proceedings of The Twelfth European Conference on Safety and Reliability, ESREL 2001*, Turin, Politecnico di Torino, 245-252.
- Andersson, R.T. & Neri, L. (1990). *Reliability-Centered Maintenance. Management and engineering methods*. London: Elsevier Applied Science.
- Bird, F.E., Jr. & Germain, G.L. (1996). *Practical Loss Control Leadership, Rev. Ed.* Loganville: Det Norske Veritas (U.S.A.).
- Britkov, V. et al. (1998). Risk management: role of social factors in major industrial accidents. *Safety Science*, 30(1-2): 173-181.
- Hale, A.R, et al. (1998). Evaluating safety in the management of maintenance activities in the chemical process industry. *Safety Science*, 28(1): 21-44.
- Holmgren, M. & Akersten, P-A. (2002). The maintenance process: looked upon through risk glasses. *To be presented at: The 16th International Maintenance Congress, Euromaintenance 2002*. Helsinki, Finland, 3-5 June 2002
- Hopkins, A. (1999). For whom does safety pay? The case of major accidents. *Safety Science*, 32(2-3): 143-153.
- HSE (Health and Safety Executive) (1989). *Dangerous Maintenance*. London: HMSO.
- HSE (Health and Safety Executive) Online (<http://www.hse.gov.uk/>) (2002-01-03)
- IEV (International Electrotechnical Vocabulary) Online. Geneva: International Electrotechnical Commission. (<http://domino.iec.ch/iev/iev.nsf/Welcome?OpenForm>) (2002-01-15)
- Jones, S. et al. (1999). The importance of near miss reporting to further improve safety performance. *Journal of loss prevention in the Process Industries*, 12. 59-67.
- Kang, S.J. (1999). Trends in major industrial accidents in Korea. *Journal of loss prevention in the Process Industries*, 12(1): 75-77.
- Khan, F. & Abbasi, S.A. (1999). Major accidents in process industries and an analysis of causes and consequences. *Journal of loss prevention in the Process Industries*, 12(5): 361-378.

Kirwan, B. (1994). *A guide to human reliability assessment*. London: Taylor & Francis Ltd.

Kletz, T. (1993). *Lessons from disasters: How organisations have no memory and accidents recur*. Warwickshire, Institution of Chemical Engineers.

Kletz, T. (1994). *Learning from accidents*. Oxford: Butterworth-Heinemann.

Kletz, T. (1998). *What went wrong? : Case histories of process plant disasters*. Houston, Tex.:Gulf Pub.

Lawton, R. (1998). Not working to rule: Understanding procedural violations at work. *Safety Science*, 28(2), 77-95.

Morris, I. E. et al. (1998). Control of maintenance errors. In: *Proceedings of the Safety and Reliability Conference, Balkema, Rotterdam, 1998*.

Nakajima (1988). *Introduction to TPM: total productive maintenance*. Cambridge: Productivity Press.

Stamatis, D.H. (1994). *Failure mode and effects analysis. FMEA from theory to execution*. Milwaukee: ASQ Press.



# PAPER II

## The maintenance process: looked upon through risk glasses

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# The maintenance process: looked upon through risk glasses

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**Keywords:** maintenance; risk management; maintenance process; losses; cause and effect

**Abstract:** *In the maintenance process several possibilities of adverse inputs, activities and outputs can be identified. These may result in losses of different kinds: safety, health, environment, quality or money. The magnitude of these losses is not easily estimated, and the awareness of maintenance related risks is sometimes lacking in companies and other organisations.*

*Still, many accidents happen during maintenance or service, e.g. because procedures are not followed, proper training is lacking, or the maintainability of the system is poor. In an ongoing study at the Centre for Dependability and Maintenance at Luleå University of Technology, incident reports and accident investigations from a number of companies are studied with respect to possible maintenance related causes and magnitude of losses, potential or real. In this presentation, the spectrum of risks related to maintenance is described, structured according to a fairly general description of the maintenance process.*

## Introduction

The performance of the production system will gradually decrease during normal operation due to wear and dirt. Some kinds of activities must therefore be conducted in order to ensure trouble free operation and optimal performance of the production system. Preventive and corrective maintenance are often used for this purpose. By definition maintenance is “*the combination of technical and administrative actions such as supervision actions intended to retain an item in or restore it to a state in which it can perform a required function*” (IEC191-07-01, 2002).

Later on in this paper a fairly general description of the maintenance concept will be presented and discussed in both technical and administrative dimensions.

Maintenance activities are performed by both maintenance- and production personnel in different sections of a plant. They are necessary for the assurance of the dependability and safety of the plant. The activities are performed in the whole production system; sometimes during normal operation. Maintenance-related causes can be identified for a substantial number of severe accidents occurring in industry. Beside the accident risks there are other types of maintenance-related risks, related to, e.g.

- lack of maintenance
- incomplete or poorly performed maintenance
- maintenance in connection with system modifications

The performance of maintenance activities poses different types of demands. Such demands are, e.g., information, skill, material, maintainability of the equipment, and access to the equipment. If these demands are not fulfilled, the performance of maintenance is associated with several risks. According to Spencer and Davis (2001) lack of communication, slips and lapses can cause risky situations for the individuals and the system as a whole. The authors would like to point out that maintenance is not always dangerous for the person or persons who actually perform maintenance work. Wrong or inappropriate maintenance can affect those who run the system, the surrounding systems or our global environment. Human reliability is another important aspect. The nuclear accidents in Three Mile Island in 1979 or Chernobyl 1986 are examples of events caused by inappropriate human actions (Britkov et al., 1998).

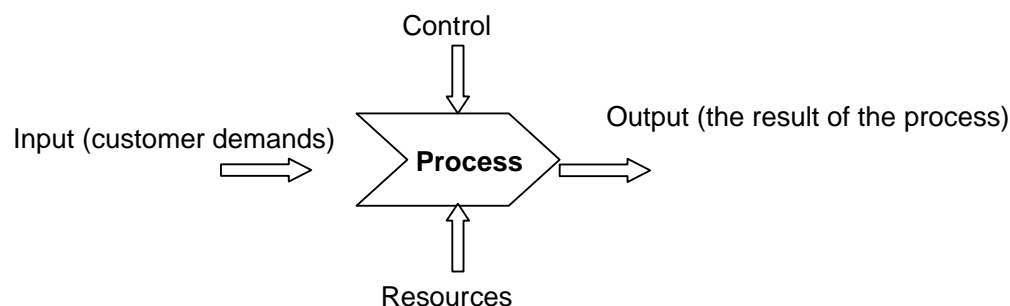
The fact that humans develop maintenance and safety routines makes human error and human interpretations important to deal with when understanding maintenance accidents. A study conducted by Morris et al. (1998) indicates that 80% of all maintenance related accidents depend on incorrect human action or human error.

Maintenance-related risks are related to the performance of maintenance activities and the corresponding demands on information, skill, material, etc. This strongly motivates a process-oriented approach.

### **The process concept**

For those who are not familiar to the process concept, a short description of a general process will be given below.

A general process can be described as a set of activities that are repeated in time (Bergman & Klefsjö, 2001). A general process transforms different kinds of input, for example information or material, to a desired output for example goods and services. The requirement of the process is to produce the desired output with a minimum of waste and few (or zero) deficiencies. A Process has a beginning and an end; it also has a customer and a supplier.



*Figure 1. A schematic description of a general process (Egnell, 1994).*

## Maintenance processes

A general description of the maintenance process is needed to highlight the activities involved in the maintenance work. A fairly general description of the maintenance processes are presented in both the preventive- and corrective maintenance processes below. The maintenance processes are looked upon through risk glasses in three dimensions: work flow, information and material/resources. The shaded boxes represent the logical work flow in the process description. These steps are supported by information flow, illustrated by the white boxes, and the material/resources flow illustrated by the dot filled boxes. By this representation the authors wish to illustrate the importance to consider all these dimensions as well isolated and in the interaction of each other in the risk management and risk identification process.

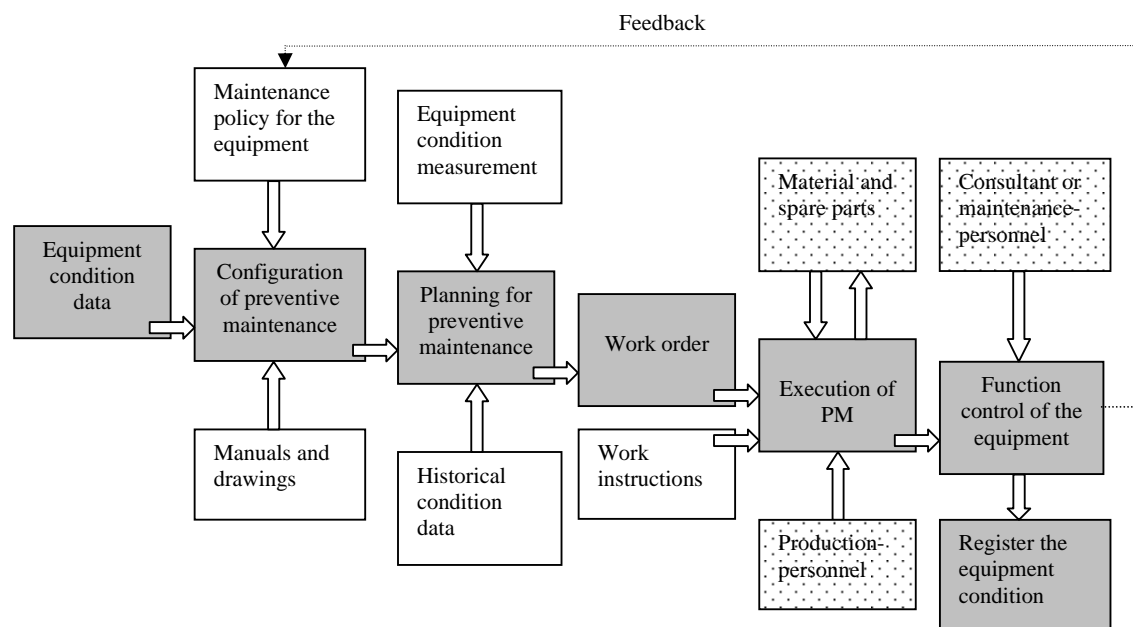


Figure 2. Activities in the preventive maintenance process (PM) (inspired by EUROENVIRON-MAINTENVIR maintenance process for Building Maintenance)

The corrective maintenance process (CM) is similar to the preventive maintenance process (PM). There are though differences due to the nature of the input to the maintenance process. The preventive maintenance process is used in order to prevent equipment failure and breakdowns. The input to this process is equipment condition data, obtained from different kind of sources. Actions are taken before the equipment develops the failure state. A failure is the termination of the ability of an item to perform a required function (IEV 191-04-01, 2002) and the equipment has a failure state.

Sometimes unexpected failures arise. Depending on the impact on the productivity and the system safety, a corrective action must be conducted. Sometimes there are possible to continue to operate the equipment at a reduced capacity, other times actions must be taken

immediately. The corrective maintenance process starts with the failure detection and report. Hidden failures can not be corrected in this process, because we are not aware of them.

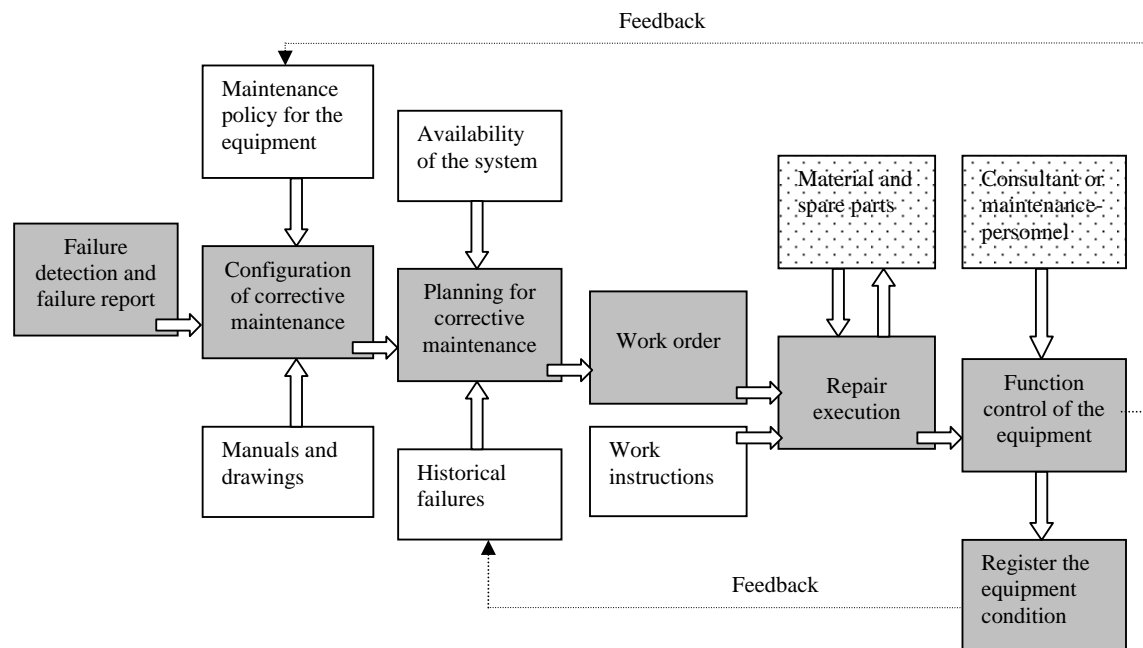


Figure 3. Activities in the corrective maintenance process (CM) (inspired by EUROENVIRON-MAINTENVIR maintenance process for Building Maintenance)

## Maintenance related losses

Maintenance related accidents can result in loss of human life or money. Det Norske Veritas have developed a Loss Causation Model, which is a part of the Loss Control Management approach. The authors of this paper have chosen to apply the Loss Control approach to a modification of the maintenance model developed by EFNMS (2001).

A Loss can be related to an accident, to inadequate maintenance performance or to sub-standard operation of the equipment. The Loss Causation Model (Bird & Germain, 1996) is briefly described by the following figure:

Lack of Control		Basic Causes		Immediate Causes		Incident		Loss
Inadequate - system - standard - compliance	⇒  ⇐	- Personal factors - Job or system factors	⇒  ⇐	Sub-standard - acts or practices - conditions	⇒  ⇐	Event	⇒  ⇐	Unintended harm or danger

Figure 4. The Loss Causation Model.

Risks are manifested through **losses** or **incidents**. The losses are starting points as well as end points. Real losses should be starting points for reporting and cause investigations, and anticipated losses are end points of predictive consequence analyses. Incidents, identified by events not leading to losses, are likewise important to report and analyse. They give valuable

information of potential losses and their causes, as well as information of loss preventing circumstances.

The category **immediate causes**, i.e. substandard acts or conditions, should act as triggers for maintenance activities, preventive or corrective. The **basic causes** and **lack of control** categories are connected to another kind of maintenance - maintenance of personal knowledge and skill, maintenance of procedures and work equipment and maintenance of management system.

## Maintenance related risks

Maintenance activities are often involving both maintenance and production personnel who require good communication and information flow. If wrong or inadequate information is supplied a risky situation can occur because of improper or wrong actions taken by the maintenance personnel. These incomplete or poorly performed actions can lead to fault or failures of the systems (Kirwan, 1994).

If maintenance aspects are seen indirectly, the lack of maintenance actions can lead to a hazardous degrading production system. The chemical release and fire at the Associated Octel Company Limited, Ellesmere Port, Cheshire in 1994 was most likely caused by overseen preventive maintenance actions which led to the failure of a corroded securing flange between the fixed pipeline and the discharge port of a pump that circulates highly flammable liquids (HSE, 2001).

By definition preventive maintenance work does not include modifications of the equipment (IEV 191-07-07, 2002). Modifications are nevertheless included as a daily activity in the preventive work in Total Productive Maintenance (TPM) (Nakajima, 1988). It is obvious that unrecorded modifications can impair the safety for both the production system and the surroundings.

The authors of this paper would like to state that the potential hazards that maintenance activities causes are often overlooked (Hopkins, 1999). Some examples of maintenance related failures will be presented below to highlight the importance of safe maintenance processes.

A major disaster occurred at the end of October 1989 at Philips petrochemical plant in Pasadena, Texas. A heavy explosion of two iso-butane tanks resulted in the death of 23 employees and another 130 employees were injured. Maintenance work was performed incorrectly on a pipe section. The isolation valve, which is used to seal off the flammable liquid, was not used properly. Because of the similarity of the air connections, the maintenance personnel mixed up the air connections and opened the valve fully instead of closing it before the maintenance actions were conducted, which led to a major gas leakage. The accident was caused by human-error of the maintenance personnel due to improper system design (Khan & Abbasi, 1999).

An example of insufficient maintenance followed by a conscious rule violation by the production personnel is the Siberian accident which occurred in 1989 near Nizhnevartovsk. The pipeline pressure dropped, due to a leakage in the pipeline system. The Engineers did not investigate the trouble; instead they increased the pumping rate to maintain the system pressure. The leakage caused a huge cloud of highly flammable liquefied gas. The smell of gas was reported by the valley settlements in the area, but still no actions were taken to investigate the problem. Two trains were passing by the gas filled area and it was probably the brakes of one of the train that ignited the cloud of gas. 462 persons were killed in the accident and another 796 were hospitalised with grave burn wounds (Khan & Abbasi, 1999).

The effect of maintenance actions are not necessarily detected during the maintenance phase, in some cases the effect of the inappropriate actions taken to ensure safety and reliability of the system can appear in the start up phase of the equipment. The Piper Alpha accident in 1988 was caused by maintenance actions and the plant failed dangerously at start up which resulted in the death of 165 peoples and substantial economical losses (Hale et. Al., 1998).

## **Further research**

The purpose of the ongoing study is to generate knowledge about why maintenance related accidents occur and to identify the steps in the maintenance process that mainly contributes to risks and potential accidents and losses. The results of the case studies will be presented at the annually Dependability days, to be held at Luleå University of technology in 2003.

The objectives in the study are to:

- Identify the risks for the system and it surroundings due to contracted maintenance work.
- Illustrate steps in the maintenance process that contribute to risks and potential losses.

## References

- Akersten, P.A. (2000). Loss Control Management – Some Aspects. In: *Proceedings of Euromaintenance 2000*. Stockholm: UTEK, p.361-365.
- Bergman, B. & Klefsjö, B. (2001). *Kvalitet från behov till användning*. 3:e uppl. Lund: Studentlitteratur. ISBN 91-44-01917-3
- Bird, F.E.,Jr. & Germain, G.L. (1996). *Practical Loss Control Leadership, Rev. Ed*. Loganville: Det Norske Veritas (U.S.A.). ISBN 0-88061-054-9.
- Britkov, V. et al. (1998). Risk management: role of social factors in major industrial accidents. *Safety Science*, 30, 173-181. ISSN 0925-7535.
- Egnell, P-O. (1994). Processledning. En arbetsmodell samt erfarenheter från svenska organisationer. Licentiatuppsats. Avdelningen för kvalitetsteknik & Statistik, Luleå tekniska universitet.
- Hale, A.R, et al. (1998). Evaluating safety in the management of maintenance activities in the chemical process industry. *Safety Science*, 28, 21-44. ISSN 0925-7535.
- Hopkins, A. (1999). For whom does safety pay? The case of major accidents. *Safety Science*, 32. 143-153. ISSN 0925-7535.
- HSE (Health and Safety Executive) (1989). *Dangerous Maintenance*. London: HMSO. ISBN 0-11-883957-8.
- HSE (Health and Safety Executive) Online <http://www.hse.gov.uk/> (2002-01-03)
- IEV (International Electrotechnical Vocabulary) Online. Geneva: International Electrotechnical Commission. <http://domino.iec.ch/iev/iev.nsf/Welcome?OpenForm> (2002-01-15)
- Khan, F. & Abbasi, S.A. (1999). Major accidents in process industries and an analysis of causes and consequences. *Journal of loss prevention in the Process Industries*, 12. 361-378. ISSN 0950-4230
- Kirwan, B. (1994). *A guide to human reliability assessment*. London: Taylor & Francis Ltd. ISBN 0-7484-0111-3
- Morris, I. E. et al. (1998). Control of maintenance errors. In: *Proceedings of the Safety and Reliability Conference, Balkema, Rotterdam, 1998*. ISBN 90-5410-966-1.
- Nakajima (1988). *Introduction to TPM: total productive maintenance*. Cambridge, Mass.: Productivity Press. ISBN 0-915299-23-2.
- The EFNMS Building Maintenance Working Group (2000). *2081: EUROENVIRON-MAINTENVIR: "Building Maintenance under ecological and economical aspects"*.Vol 2(3). Stockholm: UTEK.



# PAPER III

## Maintenance related losses – A Study of Swedish rail and track related accidents and incidents

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# **Maintenance related losses**

– A study of Swedish rail and track related accidents and incidents

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## **Keywords**

Maintenance, Loss Causation Model, Accidents, Contractor, Railway

## **Abstract**

The railway is a complex technical system used for both freight and passenger transportation. High-speed trains reduce the safety margin and increase the potential losses due to accidents. Passenger safety and punctuality are highly prioritized and traffic accidents should be reduced as far as possible. Maintenance is one way to achieve safety and dependability of the railway. However, at the same time badly performed maintenance can also cause accidents.

In this paper incident and accident reports from 666 derailments and collisions at the Swedish State Railway 1988-2000, stored in the BOR-database, are studied with respect to possible maintenance related causes. The purpose of this study is twofold. Firstly, the aim is to identify maintenance related losses in order to explain deviations in the maintenance process that contribute to accidents and incidents. Secondly, the aim is to classify the maintenance related accidents and incidents in order to create a taxonomy of the causes.

The study shows that maintenance related accidents represent 30% of all track related incidents and accidents represented in the database. About 80% of the maintenance related accidents happen during the execution phase. The most common cause of maintenance related accidents is imperfect communication and information between the maintenance personnel and the operators. Rule violations, especially lack of permission to perform maintenance work on the track, are the second most frequent cause.

## **Definitions**

An accident is an unplanned and uncontrolled event in which the action or reaction of an object, substance, person, or radiation results in personal injury or the probability thereof. (Heinrich et al., 1980)

Maintenance is defined as a combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function (SS-EN 13306, 2001).

Maintenance management is defined as all activities of the management that determine the maintenance objectives, strategies, and responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, improvement of methods in the organisation including economical aspects (SS-EN 13306, 2001).

## **Introduction**

The railway is a complex technical system used for both freight and passenger transportation. The Swedish State Railways was the only railway operator on the Swedish rail network before 1988. Then the company was divided into an infrastructure authority, the Swedish National Rail Administration (Banverket) and the state-owned passenger traffic operator (SJ) (Bäckman, 2002). The Swedish Railway Inspectorate was now created in order to supervise and promote safety within all Swedish rail traffic, but also to investigate the accidents that may occur. The Swedish Railway Inspectorate is an independent governmental authority, but is associated with the Swedish National Rail Administration for administrative purposes (Swedish Railway Inspectorate, 2003).

The Swedish National Rail Administration must ensure that passenger safety is high and has therefore adopted a zero vision, meaning that nobody is to be killed or seriously injured as a consequence of a traffic accident (Banverket, 2003). Besides safety aspects, derailments and collisions affect the surroundings and give the administrator and the operator a bad reputation. Therefore maintenance issues have been prioritized during the last few years.

Normal operation of the railway will gradually impair the performance of the railway system. Wear, dirt, corrosion and overloading are some contributing causes of the degradation of the track and switches. Therefore, the management must determine maintenance strategies and objectives to ensure the functioning of the railway system. Both preventive and corrective maintenance actions are performed by the railway personnel. However, although maintenance is performed in order to increase the safety, badly performed maintenance can reduce the safety and cause incidents and accidents.

Before 1988 maintenance work was only performed by the in-house maintenance personnel at the Swedish State Railways. This changed when the Swedish National Rail Administration decided to take the decision to open up their maintenance to the free market in July 2001. Instead of conducting the work within their own organisation, entrepreneurs were invited to attend in the bidding for maintenance contracts regarding some sections of the track in 2002. (Banverket, 2003).

The use of contractors to undertake important work is not a new issue, nor specific to the railways. It is common nowadays that companies worldwide try to focus on their core business and contract out other functions in order to achieve cost reduction (HSE, 2002). Although maintenance contractor involvement in some cases will reduce the direct cost it will affect the lack of control for the administrator, especially if proper information about system changes and repair is missing (Kletz, 1993). The involvement of maintenance contractors will therefore increase the need

to transfer adequate information and communication in order to control different risks due to maintenance activities.

A study performed by Edkins & Pollock (1996) shows that rail and track maintenance causes problems in Australia. Among thirteen railway problem factors at the passenger division, staff attitude was the most important factor followed by operating equipment and maintenance. At the freight division maintenance work was the second most important factor contributing to problems regarding the quality, consistency and delays of the repairs.

In the United Kingdom, several accidents have occurred at British Rail due to the involvement of maintenance contractors. Some recent examples are the derailments at Ladbroke Grove and Hatfield (HSE, 2002).

In October 1999 a major derailment and collision occurred at Ladbroke Grove. As a result of the collision 31 people died and 227 were taken to hospital. The investigators of that accident expressed concern about the privatisation and the use of contractors. Two major conclusions were drawn. Firstly, the process for the judgement of contracts was not being operated with due regard for training and preparation of the contract workforce. Secondly, the managerial control of the work performed by maintenance contractors and sub-contractors was inadequate. Therefore, there is a need for improving the managerial control (HSE, 2002).

In October 2000 four people were killed in a derailment near Hatfield. The accident investigation shows that the immediate cause of the derailment was a fragmentation of the rail caused by neglected maintenance actions. The contractor was recommended to review the procedures for the movement of managerial staff within contractor organisations and the recruitment of the contractors (HSE, 2002).

That indicates that badly performed maintenance operations and routines are an important cause of railway accidents. Accidents due to maintenance work might occur when there are deviations from an ideal maintenance process. The outcome of the process will differ from the desired result when the steps are biased due to different reasons, resulting in losses that are manifested in incidents and accidents. Holmgren & Akersten (2002) present a discussion about different deviations in the preventive and corrective maintenance processes.

It is therefore important to identify the past deviations, manifested in incidents and accidents, in the maintenance process in order to get a basis for improvement in order to reduce the number of new undesired deviations in the future. As illustrated in the examples, maintenance contractor involvement can create risky situations at the railway, if not managed properly. The maintenance contractor situation thus requires higher demands on the transfer of information in order to control different risks due to this involvement

The purpose of this study is therefore to identify maintenance related losses at the Swedish railway system in order to explain deviations in the maintenance process that contribute to accidents and incidents, but also to classify the maintenance related accidents and incidents in order to create a taxonomy of the causes.

## **Methodology**

It is important to learn from past accidents and draw conclusions about their causes in order to reduce the future occurrence of similar accidents. Therefore it is important to create and study accident databases. Data must also be classified and arranged systematically, in order to see patterns and connections. The analysis of the data requires a structured data analysis model. Conclusions based on the analysis of the collected data can then be drawn.

### **Data collection**

This study is based on a database containing train derailments and collisions at the Swedish railways, which was created by Johan Bäckman as a part of his Ph.D. thesis. The database was created in Microsoft Access and is called BOR.

The database contains passenger train derailments for the period 1988-2000 and passenger train accidents with passenger or train crew fatalities for the period 1960-2000. The database contains five different data sources, all in all 973 incidents and accidents, presented below (Bäckman, 2002):

- BIS: The Swedish National Rail Administration has a computerised system called BIS, containing different modules for track information and for accident reporting from 1988 onwards.
- JAS: The Swedish Railway Inspectorate has a database called JAS which contains information from 1989 onwards. The criteria for the accidents to be reported in the database are either fatalities or injuries or material costs of at least approximately 100 000 USD.
- INCIDENT: SJ has a database called INCIDENT. SJ has been reporting accidents in that computerised database since February 1995, but the database was closed in December 1997.
- HÄR: The Swedish Railway Inspectorate administrated a database called HÄR between 1994 and 1998. It contains accidents as well as incidents.
- Sparre: A study conducted by Sparre on accident reports from the Swedish State Railways containing collisions, derailments and fires on the Swedish network between the years 1985 to 1994 has generated data that has been included in BOR.

Due to the fact that the Swedish State Railways went through a major organisational change, data before 1988 is excluded from this study based on BOR. The database contains 666 incidents and accidents between 1988 and 2000.

### **Data analysis model**

British Rail uses a model called REVIEW developed by Reason (1993) in order to identify deficiencies in the managerial activities, which can result in losses. The model measures latent failures that have been common denominators in major accidents. The model assumes that accidents arise from fallible decisions and line management deficiencies, organisational policies and procedures. However, there

are other loss causation models as well. In 1981 Heinrich presented a domino theory, which is a precursor to more recent loss causation models (Heinrich et al., 1980). Bird & Germain (1996) presented a Loss Causation Model (LCM), based on Heinrich's domino theory, which is used by Det Norske Veritas as part of their Loss Control Management approach. The steps in the Loss Causation Model are briefly described in Figure 1. This Loss Causation Model was further developed by McKinnon (2000) to include more steps including luck factors. See also Akersten (2000) and Holmgren & Akersten (2002) for a description of LCM application in the maintenance domain.

Lack of Control		Basic Causes		Immediate Causes		Incident		Loss
Inadequate - system - standard - compliance	⇒ ⇐	- Personal factors - Job or system factors	⇒ ⇐	Sub-standard - acts or practices - conditions	⇒ ⇐	Event	⇒ ⇐	Unintended harm or danger

*Figure 1. The Loss Causation Model which is used in order to find the chain of events from real losses to lack of control (Source: Akersten, 2000).*

The LCM model is designed to systematically identify a chain of events from incidents and accidents to lack of control that is leading to the losses. Therefore, it is appropriate to apply the model in the study of past railway incidents and accidents in order to identify the causes at different levels leading to losses. The LCM model serves as a tool in this study, to analyse the data stored in the investigated database to identify the causes of the maintenance related incidents and accidents. The focus is on the Immediate and Basic causes due to the fact that they precede the losses, manifested in incidents and accidents.

Real losses, incidents or accidents, should be starting points for the investigations of the causes. The category Immediate causes acts as the direct triggers maintenance related accidents. However, the accidents directly initiated by the front line operators are merely the inheritors of system defects created higher up within the operating system (Edkins & Pollock, 1996). These deficiencies can be found in the categories Basic Causes and Lack of Control.

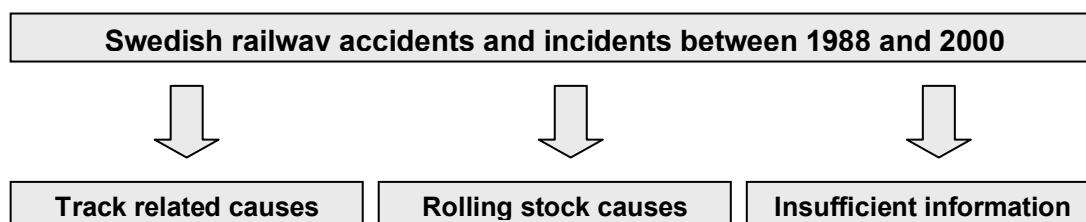
### **Data classification**

In order to identify maintenance related accidents and incidents data must be classified. Therefore, accidents and incidents are studied to seek for maintenance related causes. The analysis work performed by professional railway investigators has resulted in accident reports with a description of the primary causes of and consequences for the railway related accidents and incidents, which are stored in the BOR-database, used for this study.

However, there are additional problems with studying past accidents. There is, for instance, an excessive reliance on accident reports, which are usually incomplete or inaccurate, even when conducted by experienced accident investigators (Edkins & Pollock, 1996).

The BOR-database has been studied without consideration of previous classification, made with a different purpose in mind, to avoid being biased. The accidents and incidents have been classified in three iterative steps, based on the stated primary causes and consequences. See Figures 2-4 for the three classification steps.

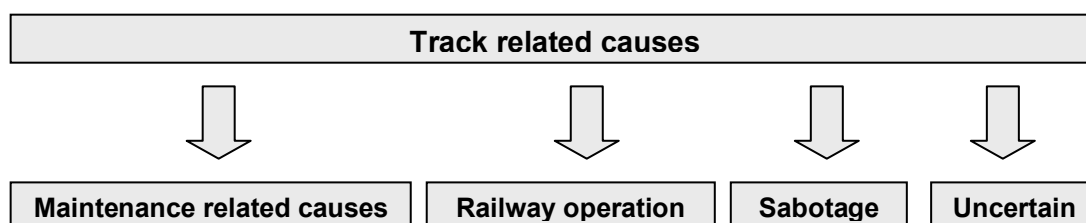
The first classification is performed with respect to all railway accidents and incidents reported to the database 1988-2000, see Figure 2.



*Figure 2. The first classification of the data aims at dividing the railway related accidents and incidents between 1988 and 2000 into Track related causes, Rolling stock causes and Insufficient information.*

The group Track related are causes created by the railway line including the ballast, switches, sleepers and rail or objects placed on or near the track. The Rolling stock causes are a collection of track bound vehicles such as trains and trolleys. The group classified as Insufficient information does have a serious lack of information on the causes and consequences in the accident and incident reports. This fact created some uncertainty in the data material and will affect the validity of the results. This study aims at investigating the track related causes; and therefore the Rolling stock causes and Insufficient information were excluded from the second classification step.

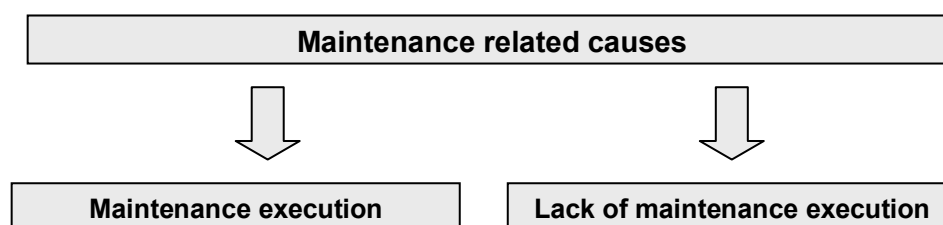
In the second classification step, Track related causes have been divided into Maintenance related causes, Railway operation, Sabotage and Uncertain, see Figure 3.



*Figure 3. The second classification of the data in BOR is a further breakdown of the Track related causes into Maintenance related causes, Railway operation, Sabotage and Uncertain.*

The group Maintenance related causes consists of events caused by direct or indirect maintenance activities. The group Railway operation is a collection of various other events leading to incidents and accidents. The group Sabotage consists of accidents when objects are placed on or nearby the track. The group Uncertain contains causes due to insufficient information in the description of the primary causes or the consequences. Although it has been possible to identify that the causes are track related, it is hard to draw further conclusions of data in that group with respect to the purpose of this study. This uncertainty will affect the reliability of this study, but could be avoided with more detailed reports. All the other groups except Maintenance related causes, have been excluded in the third classification step, due to the main purpose of identifying maintenance related causes.

In the third classification step, maintenance related causes have been divided into maintenance execution and lack of maintenance, see Figure 4.



*Figure 4. The third classification aims at dividing the Maintenance related causes into Maintenance execution and Lack of maintenance execution in order to determine if the impact of maintenance is direct or indirect.*

The two groups, Maintenance execution and Lack of maintenance, have been closely studied in order to identify the immediate causes and in some cases the basic causes in the Loss Causation Model, illustrated in Figure 1. The group Maintenance execution is a collection of direct maintenance related causes during the execution. The group Lack of maintenance execution is a collection of various indirect events caused by lack of maintenance.

### **Data analysis**

The analysis of the maintenance related accidents and incidents, classified as Maintenance execution and Lack of maintenance, is then structured according to the Loss Causation Model in order to identify loss producing events, which are deviations from the ideal situation in different steps in the maintenance process. The most abstract level is lack of control, which can be related to the maintenance management. It would be desirable to identify the causal connection from losses to lack of control in all maintenance related accidents and incidents, but due to the variety of the quality of the data this is not possible. However, the causes and effects have been studied in order to find the immediate causes and in most cases the basic causes.

The “five why” methodology has been used supplementary to the structure in the LCM model to find the real causes, not only the symptoms, of the accidents and

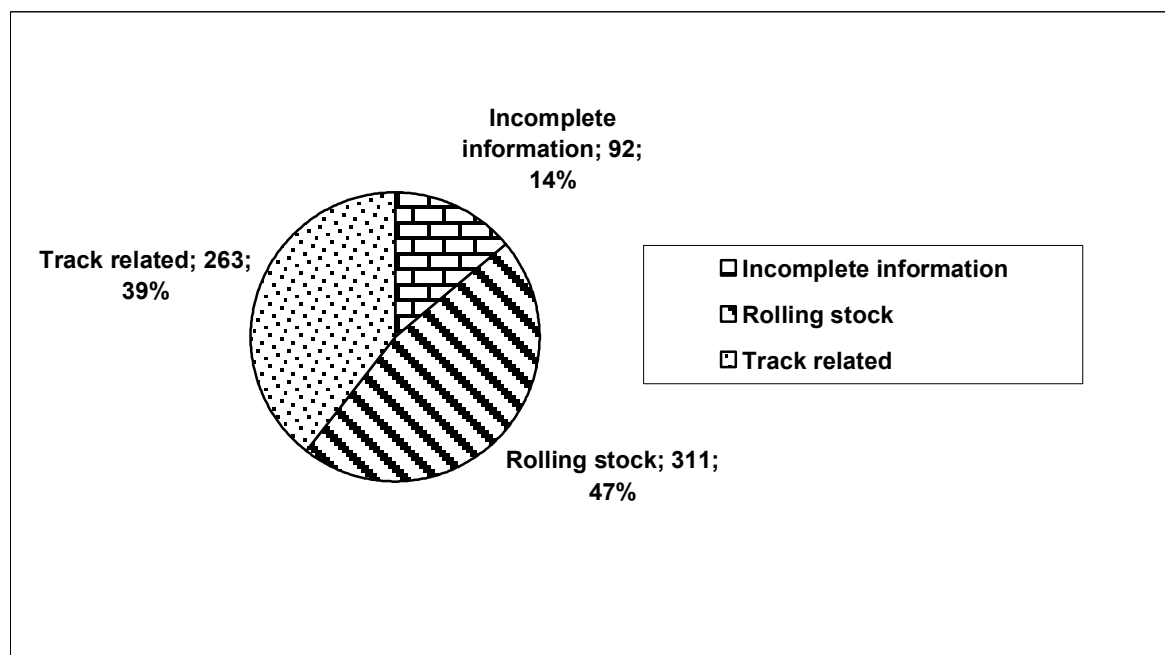


incidents. See Tetsuichi & Kazuo (1990) for a description of the “five why” methodology. The first question is why the Rail and track related incident or accidents happened. If the cause was maintenance related, a second question was asked to identify if the cause was due to the execution of maintenance work or caused indirectly by lack of maintenance work. The result of the first two questions is illustrated in Figure 5-7, and the first “two why” in Figure 8.

The third to fifth questions expose the underlying causes of the maintenance related course of events. The underlying maintenance related causes have been analysed with respect to the description of the causes and consequences of the incidents and accidents. The results of this analysis can be found in the “third to fifth why” in Figure 8.

## Results

The result of the first classification step is illustrated in Figure 5, which describes the distribution of the 666 railway related accidents and incidents in Sweden during 1988-2000 stored in the database.



*Figure 5. The causes of the 666 railway related accidents and incidents in Sweden, between the years 1988-2000, stored in the BOR-database.*

The result of the second and third classification step fulfils the first purpose of this study, namely to identify the maintenance related accidents and incidents at the Swedish railway system. The result is illustrated in Figures 6 and 7.

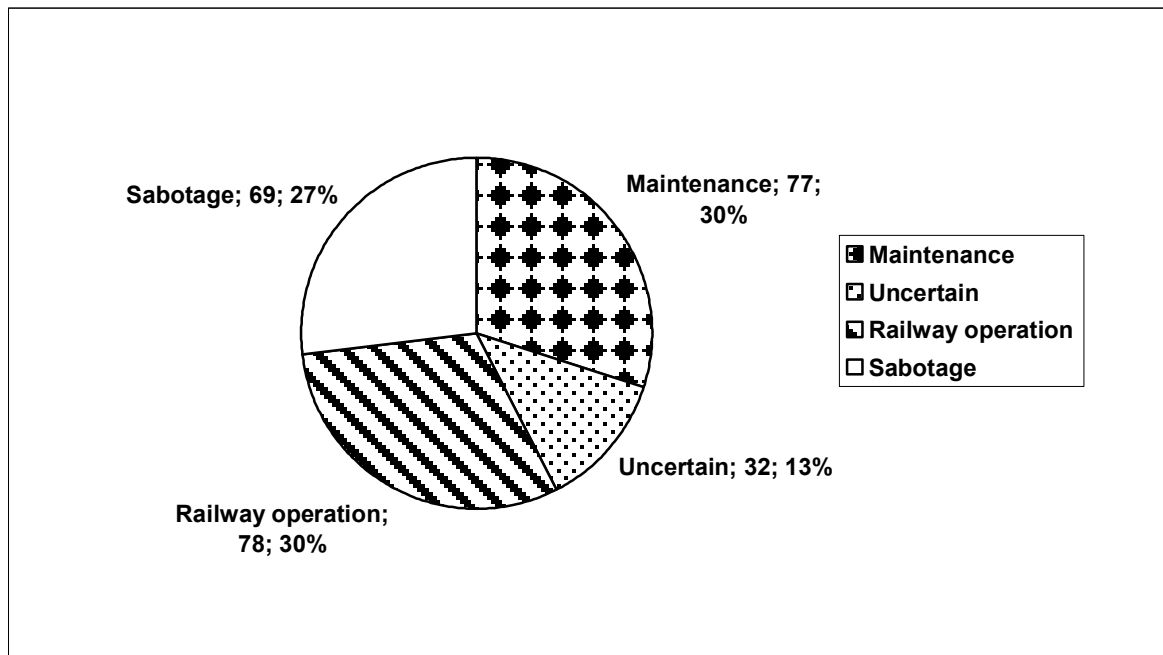


Figure 6. The figure describes different causes of the track related accidents stored in the BOR-database. The distribution and percentages are related to the Track related accidents and incidents in Figure 5.

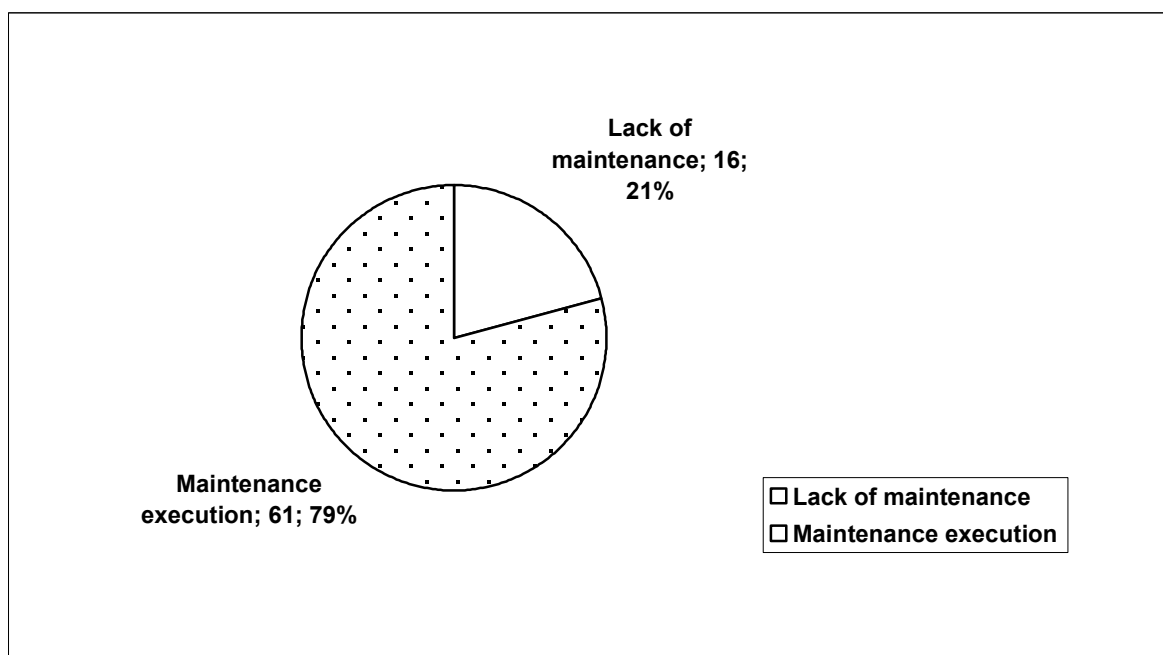


Figure 7. The figure describes the causes of the maintenance related accidents. The percentages are related to the Maintenance related accidents and incidents in Figure 6.

The second purpose of this study was to create a taxonomy of the maintenance related causes. The taxonomy is structured according to the “five why” methodology. The result of that classification is illustrated in Figure 8.

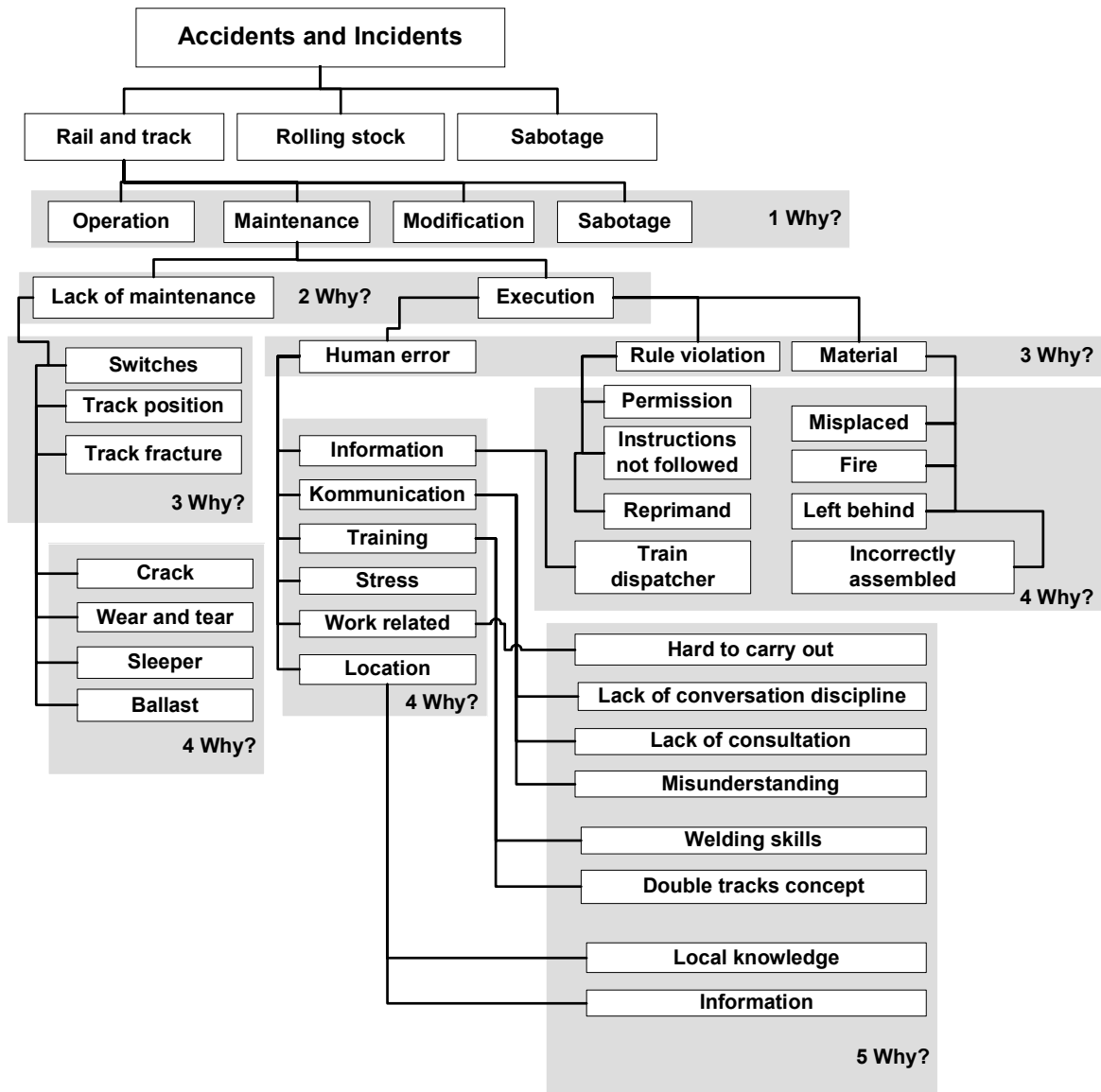


Figure 8. A schematic description based on the primary causes of the identified maintenance related accidents and incidents at the Swedish Railway network during the period 1988- 2000.

## Discussion

The results show that 30% of the total number of track related incidents and accidents in the database are maintenance related. Among the maintenance related accidents, the execution of maintenance work is the primary cause in 79% of the all maintenance related accidents and incidents. Only 19% of the accidents found in the database are caused by neglected maintenance, such as wear and tear on the track and switches. Although not included in this study, an indication was given that maintenance activities at the rolling stock also cause some accidents. These accidents were demarcated in the first classification step, due to the purpose of this study. When looking at these numbers we must be aware that insufficient data in the database was deleted both in the first and the second classification steps, see Figures 2-3. This underlines the importance of routines for reporting incidents and

accidents and gives an accurate description of the causes and consequences. It is not a simple task to explain why different accidents do occur or identify the underlying causes that trigger the primary causes in the accident initiation sequence.

This study of Swedish railway incidents and accidents has resulted in the taxonomy found in Figure 8. This taxonomy describes the primary causes of the maintenance related losses and the underlying causes that precede the primary cases, when they have been found.

It is clear that most of the maintenance related accidents happen during the execution phase. The most common cause of the maintenance related incidents and accidents is imperfect communication and information between the maintenance personnel and the train dispatcher or the operators. The defective communication between the maintenance personnel and rail operators indicates the need for better exchange of information between them. The future involvement of maintenance contractors, especially foreign ones who may lack local knowledge, increases the demands for communication and the transfer of adequate risk information. Proper information must be communicated in order to maintain, or increase, the safety level found today at the railways. The continuous improvement work should focus on ways of achieving better communication between the maintenance executor and the operator of the railway. Kletz (1993) describes the importance of clearly writing or explaining what should be done and how it should be done. Vague instructions for the recondition or overhaul of the broken equipment can lead to losses, and to the skills of the maintenance personnel not being fully used. Experienced personnel perform the required work acquired by experience, but inexperienced personnel will possibly perform the work badly according to the unknown demands of the system. This is an important aspect to consider when maintenance work is to be bought from maintenance contractors without local knowledge.

According to the Loss Causation Model, the causes of the incidents and accidents can be traced to the immediate, and in some cases the basic, causes. The information stored in the database has shortcomings because detailed information of the causes is sometimes missing. Therefore, it is hard to find what causes the lack of control, which is the most abstract level of the maintenance management. However, the chain of events can in most cases be traced back the basic causes in the Loss Causation Model. It is important to remember that these immediate causes are the direct trigger of the accidents, but these are caused by deficiencies in the basic causes and lack of control of the operations, which are managerial responsibilities.

Rule violations, especially lack of permission to perform maintenance work at the track, are the second most dominating cause as illustrated in Figure 8. Human error due to various causes is a common trigger of maintenance related accidents. One way of reducing the human error contribution in the accidents is to follow routines and written procedures. It is on the other hand very difficult to adopt a necessary but not over-regulated permit-to-work system to ensure system safety. Kletz (1988) describes some incidents involving a permit-to-work system and the

lesson learnt when the procedure does not cover all circumstances or when the permission has been withdrawn without further notice to the maintenance personnel.

On the other hand, Lawton (1998) discusses the aspects of over-regulation and the human reluctance to follow written procedures when they make it more difficult to perform the required work. Troublesome rules and routines tempt the personnel to take shortcuts in order to get the job done, when there is lack of time.

Indirect maintenance related causes have also been found. These are illustrated in Figure 8. Of these 16 accidents, the most dominating primary cause is defect switches. Other causes are incorrect rail positions, rail fractures and broken sensors. This aspect of indirect maintenance causes is twofold, either an explanation of natural degradation is possible or overseen maintenance work. On the other hand, if some causes can be explained by natural degradation, maintenance routines should cover these and ensure rail safety.

## **Conclusions**

The total reported derailments and collisions at the Swedish State Railways between the years 1988 and 2000 are 666 according to the BOR-database. Among these derailments and collisions 263 were track related. Maintenance, direct or indirect, caused 77 of these accidents. In this study 61 of the accidents were caused by incorrect maintenance execution. The execution of maintenance work is guided by the maintenance process, which is found in the maintenance strategy. Different deviations from the desired maintenance process will affect the outcome of the process creating losses, some manifested in incidents and accidents although other smaller deviations from the ideal maintenance process still remain hidden.

The most frequent cause of accidents during the execution phase is imperfect communication and information between the maintenance personnel and the train dispatcher or the operators. Rule violation is the second most important cause of accidents during the maintenance execution. Bearing in mind that, if the procedure is covered by the rulebook, deviations from maintenance procedures in a regulated business will cause rule violations.

The Health and Safety Executive in the United Kingdom has listed the following issues that may contribute towards a major accident due to maintenance (HSE, 2003):

- Failure of safety critical equipment due to lack of maintenance;
- Human error during maintenance;
- Incompetence of maintenance staff; and
- Poor communication between maintenance and production staff.

The result of this study confirms three of the four categories above. Human error during the execution was, in some cases, explained by the lack of proper information due to communication issues. Another possible explanation of human error is, according to Kletz (1993), lack of time, which may contribute to an increasing amount of human error. In the case of railway maintenance, stress can

occur when work should be done during a short period of time on the timetable when the track is available.

In some cases dealt with in this study no explanation of human error can be found other than unconscious slips and lapses, which contribute to human error. See Kirwan (1994) for a description of slips and lapses. These are commonly called the "human factor". The category Incompetence of the maintenance staff has only been found in one accident of the maintenance related causes. This may be explained by the long experience and proper education the Swedish National Rail Administration's own maintenance personnel

have. During the years 1988-2000 maintenance work has mainly been performed by Banverket Production, a division of their own management. When maintenance is to be bought from contractors this can change if unclear demands are stated in the maintenance contracts. Some fundamental demands are already claimed in the TransQ, a joint prequalification system for suppliers to Scandinavian transport organisations in which the Swedish State Railways is one of the participating organisations.

## **Further research**

The increasing globalisation affects the national markets. The railways, which are being opened up to foreign ownership are no exception. Competition is also increasing, bringing changes in how to manage safety in the newly privatised railway companies (Hale, 2000). The Swedish Rail Administrator has already begun to purchase maintenance from contractors, and foreign ones will not be excluded in the future. The maintenance contractor situation, especially with the involvement of contractors that lack local knowledge, will further increase the need for transfer of adequate risk information and requirements. Therefore, further research will focus on the identification of requirements for different stakeholders to the maintenance process that affect rail safety. Different activities that affect Lack of control and the Basic causes are important to focus on due to their pre-initiation of the accident sequences presented in this paper. It is the managerial responsibilities to design and evaluate the inquiries for maintenance contracts. An interesting aspect to investigate is if these inquiries for maintenance contracts cover, or clearly express, safety critical demands. In the future it is important to focus on how to make the existing regulations clearer, not to create new regulations. The reason for this is, according to Hale (2000), that the railway industry already has, together with the nuclear and the chemical industries, a long tradition of extensive regulation. Accidents have, according to Hale (2000), traditionally been analysed up to the point where it became clear that someone had broken a rule or that there was no rule for this causality. This approach will ultimately get a rule for everything and safety issues will no longer require thinking because it will all be covered in an extensive rule system.

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## References

- Akersten, P. A., 2000. Loss Control Management – Some maintenance aspects. Proceedings of the 15<sup>th</sup> International Maintenance Congress, Euromaintenance 2000, Gothenburg, Sweden, 7-10 March 2000.
- Banverket, 2002. Banverkets entreprenörer. Tillsynsrapport 2002:9. Sweden. ([http://www.jarnvagsinsp.se/tillrapp/t2002\\_9.pdf](http://www.jarnvagsinsp.se/tillrapp/t2002_9.pdf)) (2003-03-04) (in Swedish)
- Banverket, 2003. Information for suppliers. ([http://www.banverket.se/templates/StandardTtH\\_\\_\\_\\_3575.asp](http://www.banverket.se/templates/StandardTtH____3575.asp)) (2003-06-15)
- Bird, F.E. Jr., Germain, G.L., 1996. Practical Loss Control Leadership. Det Norske Veritas, Loganville.
- Bäckman, J., 2002. Railway safety: risks and economics, Department of Infrastructure and Planning, The Royal Institute of Technology, Stockholm, Sweden.
- Edkins, G. D., Pollock, C., 1996. Pro-Active Safety Management: Application and Evaluation within a Rail Context. Safety Science, 24(2): 83-93.
- Hale, A. (2000). Railway Safety Management: The Challenge of the new Millennium. Safety Science. Monitor 4. (<http://www.ipso.asn.au/vol4/issue1/vol4idx.htm>) (2003-06-10)
- Heinrich, H. W., Petersen, D., Roos, N., 1980. Industrial accident prevention: a safety management approach. McGraw-Hill, New York.
- Holmgren, M., Akersten, P. A., 2002. The maintenance process: looked upon through risk glasses. Proceedings of the 16<sup>th</sup> International Maintenance Congress, Euromaintenance 2002, Helsinki, Finland, 3-5 June 2002.
- Health and Safety Executive (HSE), 2002. The use of Contractors in the Maintenance of the Mainline Railway Infrastructure. (<http://www.hse.gov.uk/hsc/contrail.pdf>) (2003-04-10)
- Health and Safety Executive (HSE) Online <http://www.hse.gov.uk/> (2003-01-27)
- Jones, S., Kirchsteiger, C., Bjerke, W., 1999. The importance of near miss reporting to further improve safety performance. Journal of loss prevention in the Process Industries, 12(1): 59-67.
- Kirwan, B., 1994. A guide to human reliability assessment. Taylor & Francis Ltd., London.
- Kletz, T., 1993. Lessons from disasters: How organisations have no memory and accidents recur. Institution of Chemical Engineers, Warwickshire.
- Kletz, T., 1994. Learning from accidents. Butterworth-Heinemann, Oxford.



Kletz, T., 1998. What went wrong?: Case histories of process plant disasters. Tex:Gulf Pub, Houston.

Lawton, R., 1998. Not working to rule: Understanding procedural violations at work. Safety Science, 28(2): 77-95.

McKinnon, R., 2000. Cause, effect, and control of accidental loss with accident investigation kit. Lewis Publishers, London.

Reason, J., 1992. Human Error. Cambridge University Press, Cambridge.

Reason, J., 1993. Review. British Railways Board, London.

SIS (2001) "Underhåll – terminologi (Maintenance terminology)". Svensk Standard SS-EN 13306, Utgåva 1. SIS Förlag AB, Stockholm. (In Swedish)

Swedish Railway Inspectorate, 2003. (<http://www.jarnvagsinsp.se/indexeng.htm>) (2003-06-07)

Tetsuichi, A., Kazuo O., 1990. Handbook of quality tools, the Japanese approach. Productivity Press, Cambridge.