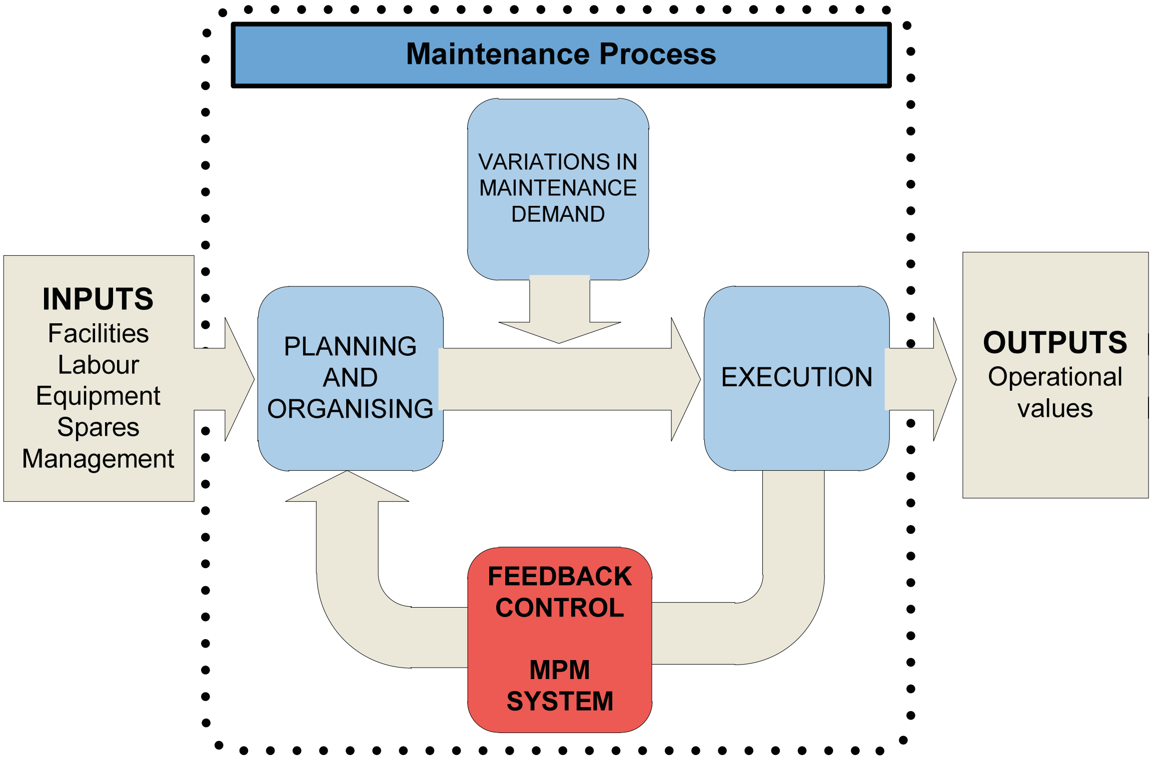
TECHNICAL REPORT

Maintenance Performance Measurement of Railway Infrastructure with Focus on the Swedish Network



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Technical Report

Maintenance Performance Measurement of Railway Infrastructure with Focus on the Swedish Network

by

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Preface

This technical report is a part of the literature review within the research project “Link and Effect Model of Maintenance Investment for Infrastructure Effectiveness Improvement”, co-ordinated by Luleå Railway Research Center (JVTC) and funded by Trafikverket (Swedish Transport Administration). The project analyses performance indicators for managing railway infrastructure, identifies relationships among them, and connects them to the technical and organisational levels using data aggregation, to form a maintenance performance measurement system (MPM system).

The report considers some important aspects of performance measurement of railway infrastructure, and maps performance indicators being used and suggests others to be considered for implementation. A high level mapping of the maintenance activities at Trafikverket has also been carried out to form a general understanding of railway systems.

I would like to thank my supervisors at Luleå University of Technology (LTU), Docent Aditya Parida, Docent Diego Galar and Prof. Uday Kumar for their supervision. I would also like to thank my supervisors Vivianne Karlsson and Per Norrbin at Trafikverket, Docent Peter Söderholm at Trafikverket, Dr. Ulla Juntti at LTU/Performance in Cold, Adjunct Prof. Per-Olof Larsson-Kråik at LTU/Trafikverket, and my fellow graduate students for valuable discussions and suggestions.

The following persons at Trafikverket deserve recognition for their contribution as well: Ulla Ericson, Helena Eriksson, Stefan Jonsson, Veronica Henriksson, Hans Morin, Monika Knutsen, Håkan Sjödin, Per Hurtig, Jan Spänner and Per Kvick.

The cover figure shows a general input-process-output model (IPO model) of the maintenance function, with a maintenance performance measurement system (MPM-system), added as the fourth component.

Abstract

Railway traffic has increased over the last decade and it is believed to increase further with the movement of transportation from road to rail, due to the increasing energy costs and the demand to reduce emissions. Efficient and effective maintenance is required in order to assure maximum dependability and capacity of the existing railway infrastructure. To manage maintenance successfully within the scope and set objectives, the effect of maintenance activities must be measured and monitored. Performance indicators (PIs) for reliability, capacity, punctuality, etc., are extensively used by infrastructure managers (IMs) in decisions making. However, they are often ad-hoc and seldom standardised. Performance measurements can give large savings and bring business safety by more proactive management, while there are additional costs associated with measuring. It is therefore important to thoroughly analyse what, where, when and how to measure. Thus, there exists a need to study the railway infrastructure PIs used by different IMs, to find out which ones are the most important, which are required and which are not required.

In this technical report, a study was undertaken to review the maintenance PIs used by researchers in the field of railway maintenance, as well as reviewing European railway project reports, and also documentations of the Swedish infrastructure manager Trafikverket, like policy documents, handbooks, etc. Interviews were also carried out to get additional inputs. In order to understand the different PIs, a high-level study of the maintenance of railway infrastructure in Sweden was carried out as well.

The listed indicators form a basis for constructing a maintenance performance measurement system for railway infrastructure.

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1 Introduction

This chapter gives a short background to this report and Trafikverket (TRV, Swedish Transport Administration), the infrastructure manager (IM) of roads and railways, and strategic planner of ship transports and aviation in Sweden.

1.1 Background

Railway traffic has increased over the last decade and it is believed to further increase with the movement of transportation from road to rail, due to the increasing energy costs and the demand to reduce emissions (BV et al. 2009b, European Commission 2010, European Commission 2011, TRV 2011n, TRV 2011j). The key goals of the White Paper 2011 on the European transport system include a 50 % shift of medium distance intercity passenger and freight journeys from road to rail and waterborne transport, and a 60 % cut in transport CO_2 emissions by 2050 (European Commission 2011). In 2008, annual oil production decline rate was 6.7 % in fields that had passed their production peak; this rate of decline is expected to reach 8.6 % by 2030 (IEA 2008). The available capacity of the railways has to be enhanced in order to meet these new demands in transportation.

As railways and their components have a long life span, their management requires a long term sustainable strategy. Ongoing technical and economic assessments are necessary to optimise the performance of railway infrastructure and receive the best return on investment (ROI). Long-term asset management objectives and strategies must steer operation and maintenance activities in the right direction. Overarching objectives must be broken down into quantitative operation and maintenance objectives to achieve a high level of robustness, punctuality and capacity within the operational budget, at the lowest life cycle cost, with no or an acceptable level of risk. See (Espling et al. 2004) for further discussion on developing maintenance strategies for railway infrastructure.

To manage assets effectively within the agreed objectives, the effect of maintenance activities must be measured and monitored. Key metrics in the form of performance measures or indicators for reliability, availability, maintainability and safety (RAMS), life cycle cost (LCC), etc. must be developed for, and applied to, railway infrastructure maintenance activities. Measuring entails data collection, but since raw data does not give any information by itself, it must be analysed. This consumes resources, especially if wrong things are measured, which are not aligned to the overall organisational objectives. However, a good performance measurement system does not necessarily require a high level of precision (Kaydos 1991). It is more important to know whether the trend is up or down and how the current value compares to historical measures. Consistency is therefore especially important in order to capture long term trends, predict future development and take the appropriate corrective actions at an early stage. Thus, if the methods for measuring or analysing are changed, the old information or analysis method should be kept for some time to safeguard the trend tracking. It is crucial to thoroughly analyse what to measure, as large costs and equally large savings are associated with measuring.

This report is a part of the state of the art study within the research project “Link and Effect Model of Maintenance Investment for Infrastructure Effectiveness Improvement”, funded by Trafikverket (TRV). It is a continuation of the earlier project “Maintenance Performance Indicators (MPIs) for Railway Infrastructure: Identification and Analysis for Improvement” (Åhrén 2008). It is also related to several other projects funded by TRV which have focused on LCC, RAMS, punctuality and switches. The present project analyses indicators currently being used and suggests others that might be considered. It studies the links and effects among indicators as well, seeking to create a maintenance performance measurement system (MPM-system) with deployment of a top-down – bottom-up methodology. Top-down approach addresses the breakdown of overall objectives at the strategic, or top management level, to the tactical and operational level. Bottom-up approach is the aggregation of the resulting outputs at the lower levels, giving indicators that are used to measure weather outputs are in line with what was intended.

This technical report considers some important aspects of performance measurement of railway infrastructure, and maps performance indicators (PIs) being used and suggest others to be considered for implementation. A high level mapping of the maintenance management process at TRV has also been carried out to form a general understanding of railway systems.

1.2 Problem statement

Several Swedish and European railway projects are considering how to increase the capacity of railways so that transportation can shift from roads to railways. This stems from the need to reduce CO_2 emissions and reduce dependence on petroleum (European Commission 2011). To ensure efficient and effective maintenance, it is essential to ensure maximum reliability and capacity of the existing railway infrastructure.

To manage assets effectively within the agreed objectives, the effect of maintenance activities must be measured and monitored. PIs for capacity, punctuality etc. are continuously developed to support infrastructure managers (IMs) to identify performance killers and in making more efficient and effective decisions, but they are often ad-hoc and seldom standardised. This process can be improved by mapping the different PIs used in the maintenance of railway infrastructure.

1.3 Purpose

Following the problem statement, the purpose of this technical report is to map performance measurement indicators of railway infrastructure with focus on the Swedish network.

A good understanding of railway authorities and their maintenance processes is necessary to improve the railway maintenance process. Lack of basic understanding can result in assumptions with fundamental errors, leading to poor project outcomes. The maintenance management of railway infrastructure at TRV has therefore been described in this report.

The research method used is exploratory and qualitative review of literature. Interviews of people working within railways have also been carried out for confirmation and better understanding.

1.4 Objectives

More specifically, the objectives to carry out are the following:

- Mapping of performance indicators used in the maintenance of railway infrastructure with focus on the Swedish network

- High-level mapping of the maintenance management of the Swedish railway infrastructure at TRV

- Highlight issues and challenges of the performance measurement of the maintenance of railway infrastructure in order to increase capacity

1.5 Outline of the report

A general description of TRV and the management of transportation in Sweden are found in the next chapter, followed by a description of the maintenance processes at TRV in Chapter 3. Indicators used in railway infrastructure are presented in Chapter 4, followed by scorecards and benchmarks in Chapter 5. Chapter 6 gives discussion and concluding remarks. Terminology used in this report is described in an appendix.

2 The Swedish infrastructure manager – Trafikverket

Trafikverket (TRV) is a government agency in Sweden whose responsibility is the strategic planning of roads, railways, ship transport and aviation (Näringsdepartementet 2010b). TRV was created in 2010 when Banverket (BV, Swedish Rail Administration) and Vägverket (VV, Swedish Road Administration) ceased to function. Another agency launched at the same time, Trafikanalys (Swedish Transport Analysis), replaced SIKA (Swedish Institute for Transport and Communications Analysis). This reorganisation of the Swedish transportation devolved from a transport administration investigation to achieve synergy effects, e.g. cost savings.

Other agencies affected by this investigation were LFV (Swedish Civil Aviation Administration), Sjöfartsverket (Swedish Maritime Administration) and Transportstyrelsen (Swedish Transport Agency). Some of their responsibilities were transferred to other agencies, such as TRV, or to private companies. For a summary, see Table 1.

Table 1: Swedish agencies with responsibilities for transportation in Sweden.

Swedish agency	Main responsibility	Predecessors	Changes since
Trafikverket (TRV) (Transport Administration)	Strategic planning of road, railway, ship transport and aviation. Its responsibility is also investments and operation & maintenance of roads and railway (Näringsdepartementet 2010b)	- Banverket (BV, Swedish Rail Administration) - Vägverket (VV, Swedish Road Administration) - Also some other responsibilities from other organisations	Founded 2010-04-01
Trafikanalys (Transport Analysis)	Analyse and evaluate proposed and implemented measures within the sphere of transport policy. In addition. also responsible for official statistics in the transport and communication sectors	- SIKA (Institute for Transport and Communications Analysis)	Founded 2010-04-01
Transportstyrelsen (Transport Agency)	Drafts rules and checks that they are observed, with respect for the consequences for citizens and businesses. In addition. also to provide society with information about means for transport and drivers	Agency's responsibilities formerly within railway, road, aviation and maritime agencies	Founded 2009-01-01
LFV (Civil Aviation Administration)	Air traffic control	Still the same agency	Ownership and operation & maintenance of airports were transferred to the new company Swedavia. See responsibilities of Transportstyrelsen
Sjöfartsverket (Maritime Administration)	To keep sea lanes open and safe	Still the same agency	See responsibilities of Swedish Transport Agency

Rikstrafiken (Swedish National Public Transport Administration) and VTI (Swedish National Road and Transport Research Institute) are also important to the present study. The former's main task is to procure, develop and coordinate public transport within the Swedish borders; the latter is an internationally recognised applied research institute with about 190 employees.

Besides Swedavia, mentioned in Table 1, the following companies were incorporated: Infranord AB, formerly part of Banverket (BV), and Vectura, an amalgamation of two divisions from Banverket and Vägverket (VV). Infranord is a Swedish railway contractor in construction and maintenance, and Vectura is a consultant in roads and railways.

2.1 Regulation of Trafikverket

Näringsdepartementet, the Swedish Ministry of Enterprise, Energy and Communications (Ministry of Enterprise) oversees TRV. In an annual appropriation letter, the Ministry sets out tactical or mid-term goals and provides funds for reaching them. The appropriation letter is based on a 12-year strategic plan for the transport system developed by TRV and formally established in a government bill (Näringsdepartementet 2009b, Näringsdepartementet 2010a). The strategic plan for 2010-2021 was developed by Vägverket, Banverket, Luftfartsverket and Transportstyrelsen before Banverket and Vägverket merged to form TRV (BV et al. 2009a). Figure 1 shows how the plan was developed. The strategic plan also contains a comprehensive plan for the maintenance of the transport system (BV et al. 2009c). A newer version of the plan, prepared by TRV, is also available (TRV 2011i).

Figure 1: Development of the strategic plan 2010 – 2021 of TRV.

The main goal of the strategic plan is to:

"Ensure the economically efficient and sustainable provision of transport services for people and businesses throughout the country."

– (Näringsdepartementet 2009a)

The plan has two sub-goals, a functional goal and an impact goal, as stated below:

“The Functional Goal – The design, function and use of the transport system will contribute to provide everyone with basic accessibility of good quality and functionality and to development of capacity throughout the country. The transport system will be gender equal, meeting the transport needs of both women and men equally.”

“The Impact Goal – The design, function and use of the transport system will be adapted to eliminate fatal and serious accidents. It will also contribute to the achievement of the environmental quality objectives and better health conditions.”

– (Näringsdepartementet 2009a)

The accomplishment of goals is assessed every four years. The most recent report was prepared by Trafikanalys, the agency that replaced SIKA (Trafikanalys 2011).

Since Sweden is a member of the European Union, it follows EU objectives. These will include the objectives of the White paper on transport (European Commission 2011), by 2050:

- No more conventionally-fuelled cars in cities
- A 40 % use of sustainable low carbon fuels in aviation; at least 40 % cut in shipping emissions
- A 50 % shift of medium distance intercity passenger and freight journeys from road to rail and waterborne transport
- All of which will contribute to a 60 % cut in transport emissions

TRV, as all other authorities in Sweden, shall ensure that operation is conducted efficiently, in accordance with applicable laws and the obligations resulting from Sweden's European Union membership, and present its performance in a reliable and fair manner (Finansdepartementet 2007).

Related to this is also the Swedish public administration policy goal:

“An innovative and collaborative government administration that is fair and effective, has high degree of quality, service and availability, and thereby contributes to Sweden's development and an effective EU work.”

– (Finansdepartementet 2009)

Moreover, for contemporary social and environmental analysis carried out by TRV, see (BV et al. 2009b, TRV 2011j).

2.2 Organisational structure

TRV is organised into six departments with a number of support functions, see Figure 2.

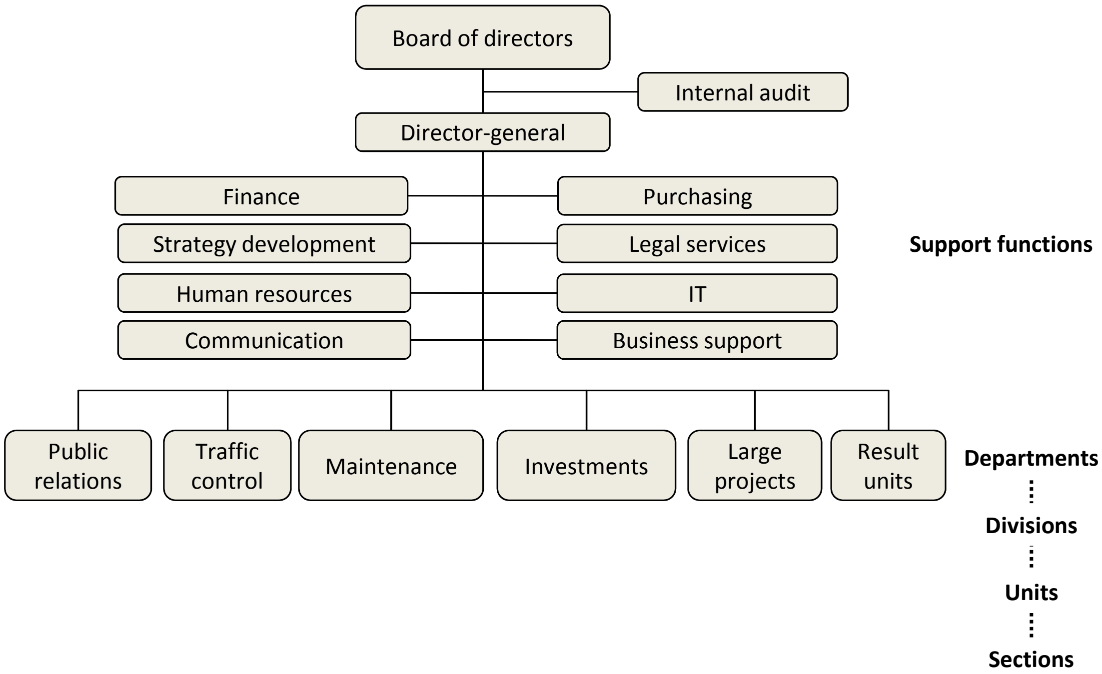


Figure 2: Organisational chart of TRV.

There are a number of divisions in each department. This report focuses on the maintenance department, see Figure 3. The dashed areas represent the most relevant branches for this report. Planning has the functional responsibility of public relations; handles mid- and long-term maintenance planning. The four main responsibilities of the road and railway data unit can be seen at the bottom of Figure 3.

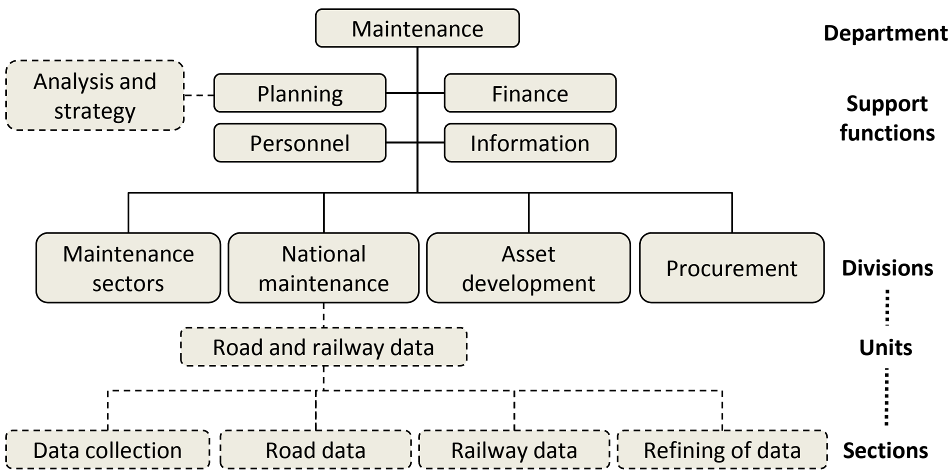


Figure 3: Branches of the Maintenance department of TRV.

2.3 Policies

A policy is a course or principle of action adopted or proposed by an organisation or individual (Oxford Dictionary 2011). Policies answer what an organisation's desired outcomes are, forming a basis for the objectives and strategies that answer the how, where and when. TRV's policies can be found on their official homepage. These include quality (TDOK 2010:51), procurement (TDOK 2010:119), communication (TDOK 2010:120), safety & security (TDOK 2010:118), business travel (TDOK 2010:219), business cars (TRV 2010i) and environment (TDOK 2010:50).

One objective of the quality policy is to find a traffic solution that best meets stakeholders' requirements. This implies finding a balance between road and railway traffic, while considering environmental goals and policies. The quality policy also seeks to be productive and proactive.

For its part, the procurement policy includes the life cycle costing principle. It talks about fair competition, the need for information built on a scientific basis and the necessity of following EU guidelines. Meanwhile, the communication policy stresses openness and to meet stakeholders with professionalism.

The safety and security policy, seeks zero fatalities in transportation. Continuous improvements are stressed in order to increase safety, as is an effective, available and dependable transportation system.

Business travel, business cars and environment policies are concerned with health, safety and environment (HSE). The Environment Policy has a four step principle: first, identifying a need to improve transportation; second, devising a way to change or redirect transportation; third, making minor reinvestments; and fourth, making major investments.

2.3.1 Maintenance policy and strategy

Maintenance is the combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function (IEC 1990a). Several similar definitions exist. The definition can give several insights: one is that a fault is defined by the user, not necessarily when a physical damage exists; another is the multidisciplinary aspect of the maintenance.

TRV's maintenance policy and strategy can be found in TRV's 12-year strategic plan for the transport system and in TRV's intermodal traffic strategy (BV et al. 2009c, TRV 2011i, TRV 2011a). It stresses on sustainability, cost effectiveness, quality of service (see Section 5.1.1), being a professional client and carry out proactive maintenance. Going back to TRV's predecessor Banverket, a maintenance handbook for railways can also be found, describing the maintenance strategy and the policy for railways in more detail (BV 2007b).

TRV applies European standard EN 13306 for maintenance terminology and dividing of maintenance activities (Figure 4) (BV 2003a, TRV 2011p, CEN 2011).

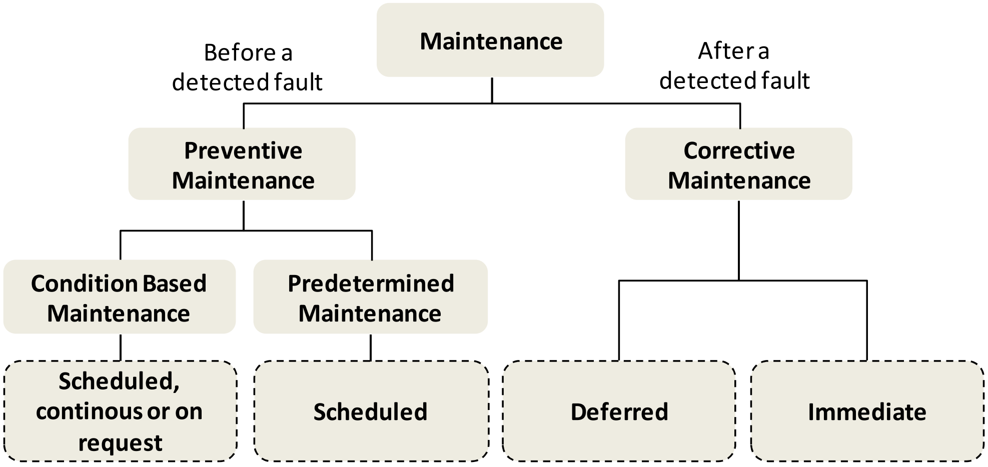


Figure 4: Overview of preventive and corrective maintenance. Adapted from (CEN 2011).

Since TRV takes a proactive approach to maintenance, preventive maintenance is its first choice. In addition, condition based maintenance (CBM) is recommended before predetermined (scheduled) maintenance. Naturally, cost effectiveness has to be considered as well; in some low traffic areas, this can result in the choice of reactive maintenance. Besides being proactive, TRV stresses best practices (BV et al. 2009c).

Corrective maintenance consist of both reported faults and safety inspection remarks labelled “Urgent” or “Week”. The latter indicates that action should be taken within two weeks. Also rail failures classified as group one failures and severe track geometry deviations identified by recording cars are classified as corrective maintenance.

2.4 Strategy, goals and objectives

The main goal and the two subgoals of the Swedish transport system have been presented in Section 2.1. Accordingly, TRV’s vision statement says that:

“*All travellers arrive to their destinations in a smooth, environmentally friendly and safe manner.”*

– (TRV 2011q)

Its mission statement says:

“Transport Administration is a developer of the society, which develops and manage smart infrastructure in collaboration with other stakeholders to make everyday life easier in Sweden.”

– (TRV 2011q)

Long term goals are found in the strategic plan of the transport system 2010-2021 (Figure 1) and the tactical or mid-term goals are found in annual appropriation letters. Working with the overarching goals, TRV’s board of directors continues the work on strategic and tactical planning, formulating objectives which are then delegated to the appropriate departments and support functions. At this point, the departments take over the tactical planning, formulate their own objectives and delegate tasks to the divisions who carry out the operational planning and work.

Soft and hard indicators are used to measure how well the work is carried out. These indicators are based on data collected in daily operations. They are evaluated and compared with the objectives and goals to see the extent to which they agree. The indicators constitute the output; if they coincide well with the objectives, it indicates that the outcome can be good. The outcome is stakeholder satisfaction and public welfare. A schematic of this process is found in Figure 5.

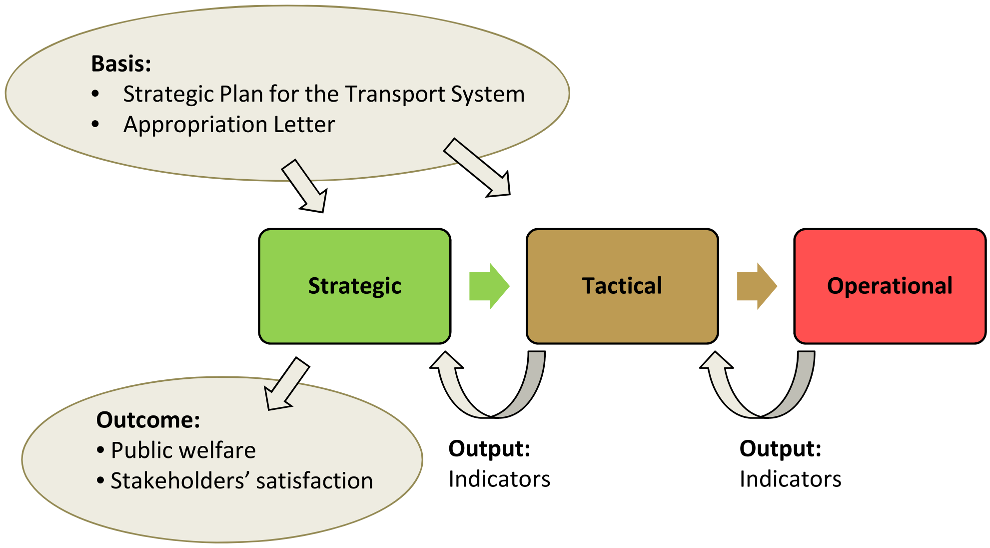


Figure 5: Schematic of the long to short term planning of TRV.

For this purpose, TRV uses a scorecard based on the balanced scorecard by Kaplan and Norton, but with five perspectives instead of four. The model can be seen in Figures 6 and 7:

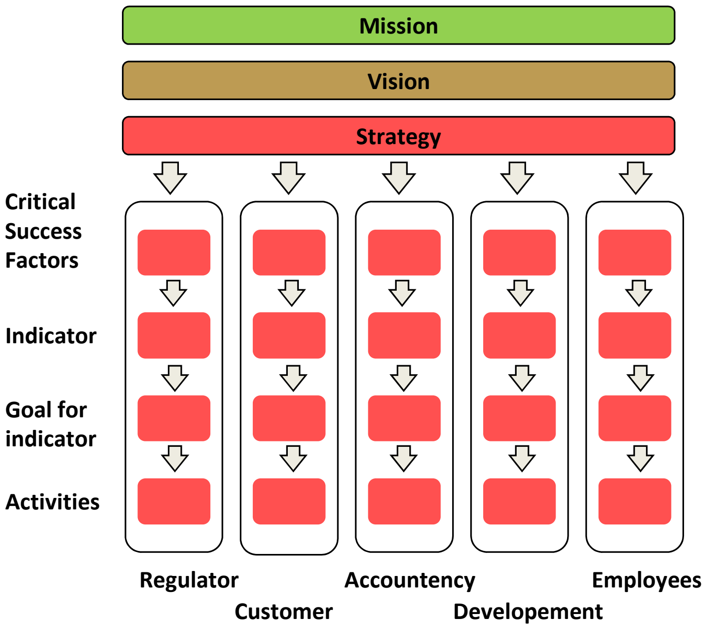


Figure 6: Overall sketch of the scorecard used by TRV. Adapted from (TRV 2010m, Söderholm et al. 2011).

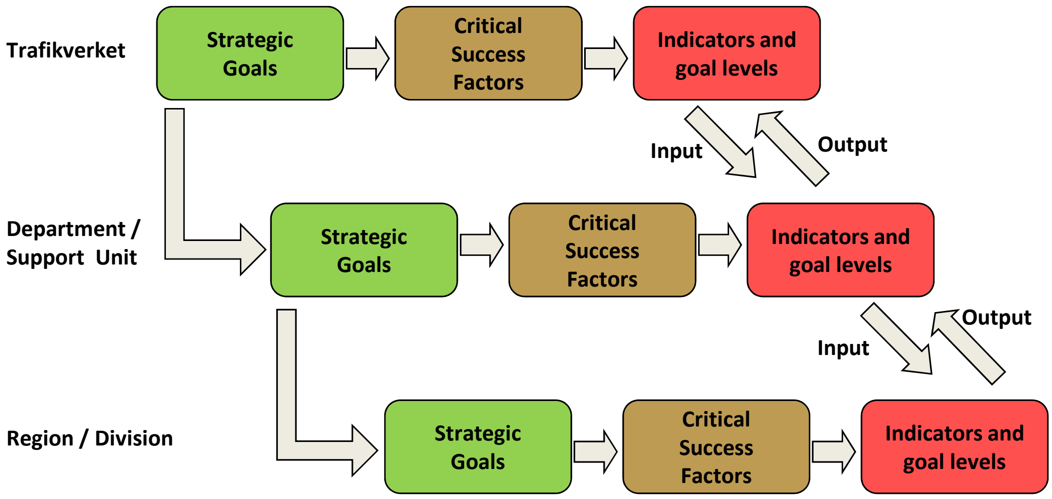


Figure 7: Overall sketch of the scorecard used by TRV. Adapted from (TRV 2010m).

Maintenance objectives can be found in the strategic plan of the transport system 2010-2021 (BV et al. 2009c, TRV 2011i). The objectives are divided into areas called quality of service (QoS), see Section 5.1.1, which forms a scorecard (Söderholm et al. 2011). The QoS are the following six: punctuality, robustness, traffic information, comfort, safety and usability (BV et al. 2009c). Each QoS has one to three indicators connected, rated according to three levels of accomplishment: "Base", "+" and "++", where each are corresponding to a quantitative target, e.g. the respective values for the indicator punctuality are: 82 %, 87 % and 93 %. TRV uses different time margins to evaluate punctuality, frequently, on time plus five minutes are used, i.e. no later than six minutes (Söderholm et al. 2011). The comfort QoS is measured by a track quality index (TQI), in Sweden called Q-number, and by a customer satisfaction index (CSI). The three respective targets for the Q-number are 65, 88 and 94. In addition to the QoS, environmental considerations are part of the operation and maintenance planning. See Figure 8 for the breakdown of strategic goals into operation and maintenance objectives.

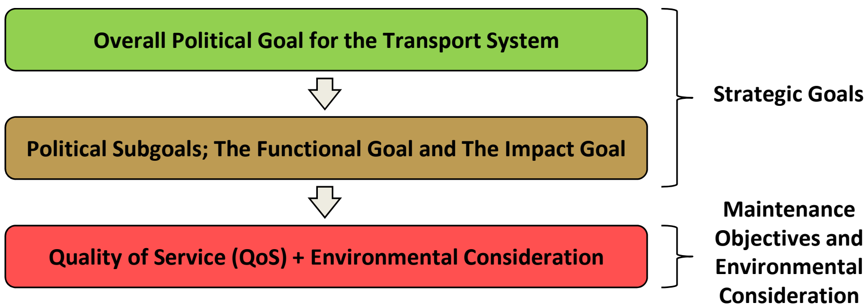


Figure 8: Top-down break down of strategic goals into operation and maintenance objectives.

While environmental consideration does not have an overall quantitative values or objectives, several subgoals and objectives are to be met during 2010-2021 (BV et al. 2009c, TRV 2011i), following a three-step priority principle. The first step is to prioritise measures that benefit environmental and economic aspects. The second is to choose the most environmentally friendly action if the cost is the same for other similar actions. Third, if there is an environmentally friendly choice but the cost is high, TRV will look into socioeconomic benefits and regulations.

The main environmental goals of the long term plan are to reduce energy usage, clean polluted ballast, reduce noise from roads and railways, and to clear land near railways and roads (BV et al. 2009c). Energy savings include changing light-bulbs to LED-lights, rail grinding, improving the heating systems for switches and improving the usage of light systems, estimated to save 44 million SEK. It is further estimated that the use of silent road materials that will reduce vehicle noise will result in maintenance costs of up to six times the present costs. This stands in contradiction to other environmental goals and raises the question that the subgoal of reducing noise may fall into QoS as a comfort goal. Noise and vibration from roads and railways can be reduced by redeeming properties, replacing windows, mounting noise barriers etc. (BV et al. 2009a). More on this with a comprehensive assemblage of the environmental goals can be found in TRV's environmental analysis 2010 (TRV 2011n).

If it is necessary to prioritise between the QoSs, punctuality and safety come in first hand (TRV 2010a).

TRV's goal of the maintenance can be found in a number of documents, e.g. (TRV 2010a, TRV 2011o):

"Maintenance is carried out in order for traffic to be able to operate as the quality of service objectives implies, both now and in the future."

Efficiency and effectiveness must be improved. The Swedish National Audit Office (SNAO) has audited TRV and has made recommendations on how to increase the efficiency and effectiveness.

2.5 Enterprise resource planning systems of Trafikverket

TRV has a number of enterprise resource planning (ERP) systems that will be mentioned in Chapter 3. Table 2 provides a quick reference to some of these systems. For further details, read WSP Group's report on the ERP systems (WSP 2011). In the report, WSP describes the overall content of each system with comments regarding the quality of the data stored.

Table 2: List of some of the ERP systems used within TRV.

System	Function
Basun	Traffic information system. One of its applications is registration of faults in the railway track
BESSY	Program used for registration of safety and maintenance inspections in track with the possibility to use a PDA (Personal Digital Assistant) or a mobile phone (TRV 2011c)
BIS	Railway engineering assets register. Every time an asset is changed in some way it has to be registered in BIS, e.g. component replacements (TRV 2011d)
Duvan	Duvan is a tool for maintenance analysis. It is possible to search for reports with data assembled from Ofelia, BESSY, BIS and train delays (TRV 2011f)
LUPP	LUPP is the successor to Duvan, it has the old functions as Duvan, plus some additional ones, like searching data of train delays and the reasons for the delays (TRV 2011h)
Ofelia	Ofelia is used for following up reported faults, i.e. handling of corrective maintenance work orders (TRV 2010b, TRV 2011k). All work orders initiated by faults found in the track are found in Ofelia. Work orders started in Basun is followed-up and closed in Ofelia
Optram	An online Java based software for analysis of data from track measurement cars. It has data from both track geometry cars and ultrasonic testing cars, which is put together with the asset structure from BIS (TRV 2011l)
Rufus	Used for registration of measures taken due to scheduled inspections or maintenance actions (TRV 2011m)

3 Description of the maintenance processes of Trafikverket

Before looking closer at TRV's maintenance, we need to know the related processes. The main advantages of rail transport are the large capacity and low energy consumption, but there are drawbacks. The limited number of loading and unloading stations is problematic, as is the fact that railway authorities must start planning their timetable about two years before it comes into effect. If an operator wants to organise traffic, she or he must apply to do so about one year in advance. The timetable application procedure is regulated by the Transport Agency; thus, TRV must apply for track capacity along with all other operators. As all applications are sent to and processed by TRV, TRV sends its application to itself – albeit to another department within TRV. The whole process is monitored by the Transport Agency.

3.1 Planning of engineering works

To be able to plan well into the future, it is important to understand the planning of engineering work (BAP). BAP is a major process within the maintenance department of TRV. According to the Council Directive 2001/14/EC, each rail IM is obligated to publish a description of the railway network, called network statement (JNB), in collaboration with concerned stakeholders, primarily those who require railway capacity (Europeiska kommissionen 2001, European Commission 2001). In Sweden, TRV is commissioned by the Swedish government to issue a network statement according to Railway Act 2004:519 (Näringsdepartementet 2004). The aim is to have a single source of relevant and non-discriminating information on the railway networks. The network statement contains the principles governing the right to operate traffic, infrastructure information, regulations governing applications for capacity and fees related to the operation of traffic. Major engineering work (PSB) which is part of the planning of engineering work (BAP) is also found in the network statement.

TRV is a member of the RailNetEurope (RNE), an organisation for railway IMs in Europe. RNE facilitates cross-border railway services and promotes harmonisation of the network statement.

At TRV, the annual planning of major engineering work (PSB) has to be finished before the network statement, so they can be published together one year before the final annual timetable is completed. This implies that the planning of major engineering work (PSB) has to start a year and a half in advance. After the major works are planned, the ad-hoc process for engineering works starts; it ends about a half year before publication of the annual timetable. At the same time as the annual timetable is published, the track use plan (BUP) is published; this consists of the major engineering work (PSB) and various ad-hoc projects. All work in the track use plan (BUP) affects train traffic in some way.

In brief, all maintenance, performance measuring and other procedures must be planned at an early stage, see Figures 9 and 10. A detailed study of track use planning has been carried out by (Björklund 2003).

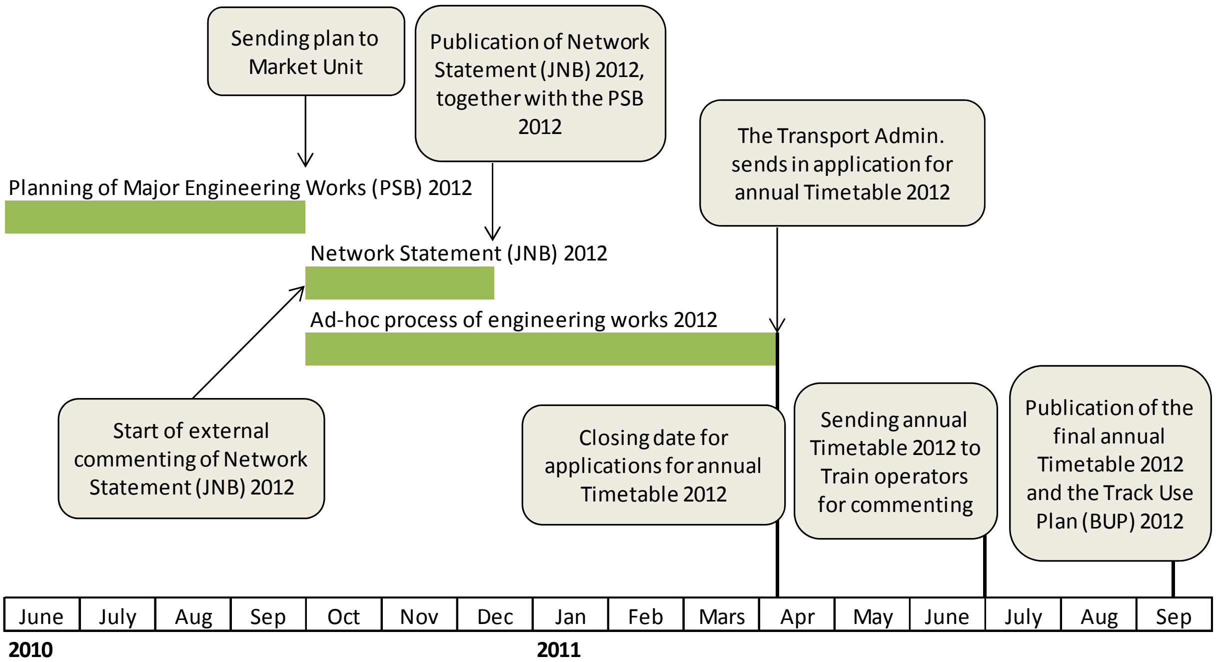


Figure 9: Planning of Engineering Work (BAP) by TRV. Planning starts one and a half year before annual timetable starts. Exact dates are left out.

The Planning of Engineering Work (BAP) is a main part of the organisational planning of TRV and is done on a yearly basis. Before planning can start, one must collect data and analyse the infrastructure condition, needs and requirements (Figure 10). The planning of engineering work at TRV is mainly carried out by the maintenance department in collaboration with the other departments and support functions.

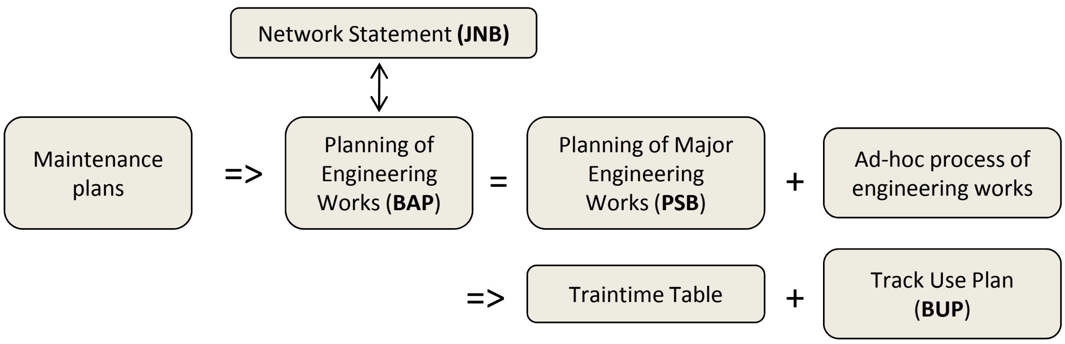


Figure 10: Relationship of TRV's JNB, BAP, PSB, BUP, ad-hoc process and train timetable.

The network statement (JNB), the track use plan (BUP) and the train timetable are on TRV's homepage for all railway sections, making it possible to see the planned maintenance activities for each day.

For a state of the art review on strategic planning of track maintenance, see (Andersson 2002).

3.2 Outsourcing railway maintenance

Statens Järnvägar (SJ) (Swedish State Railways), founded in 1856, was a Swedish agency responsible for operating and maintaining the state's railways. In 1988, the railways and the infrastructure management were separated from SJ to form a new agency, Banverket (BV) (Swedish Rail Administration) (Spaven 1993, Bruzelius et al. 1994, Hultén 2000, Jensen et al.

2007, Alexandersson et al. 2008). Ten years later, new policies in 1998 divided Banverket into a client and contractor in order to increase efficiency and effectiveness (Espling et al. 2008). The first outsourcing of maintenance started shortly thereafter (BV 2008). The demonopolisation in the EU began in 1991 when the various European states were commissioned to separate the operation of traffic from the IMs, sprang from directive 91/440/EEC (European Commission 1991). It is difficult to directly compare states' deregulation processes, as their approaches differ. Alexandersson and Hultén call the Swedish process the incremental approach, the British process the rationalist process, and the German and Dutch process the wait and see incremental process (Alexandersson et al. 2008). Comparing with the US, the deregulation of railways in started 15-25 years before the EU deregulation, but the process is different, as it is predominantly a freight market (Alexandersson et al. 2008). More work on railway deregulation processes can be found in: (Nash 2008, Bulcsu 2011, Mäkitalo 2011, Laisi 2011).

In 2001, the Swedish railway operator SJ was disbanded and incorporated into six to eight companies, all owned by the government (Alexandersson et al. 2008, Espling et al. 2008). Two of the companies are train operators, SJ AB and Green Cargo. The monopoly of the train operation was ended in 2009, allowing free competition. In 2010, 42 operators submitted applications for the annual timetable of 2011 (TRV 2010g). TRV is one of the applicants, e.g. for maintenance activities.

TRV continuously works to outsource the railway maintenance. In September 2010, 87 % of the primary regional maintenance contracts were out under free competition; 13 % were contracted to Infranord, formerly part of Banverket, without free competition (TRV 2010e). The goal of free competition is to make the procurement process of maintenance more efficient and effective. TRV uses performance-based contracts whereby the condition of the track is assessed before a contract is set up. A bonus and fee system connected to the contracts will come into effect if the condition of the assets is changed. There are around 35 contracts for primary regional operation and maintenance with a total annual value of 1.5 billion SEK (TRV 2010e). All new contracts are performance-based with fixed payments for five years with an option of two more years. Although uniform contracts are preferable, there are a number of older contracts with different agreements. See (Famurewa et al. 2011) for discussion on performance-based railway infrastructure contracting.

Today, there are five entrepreneurs in the railway maintenance business in Sweden: Infranord AB, Balfour Betty Rail AB, Strukton Rail AB, VR-track, and Infratek AB. The Norwegian company, Infratek, is a new arrival, receiving its first five year contract in 2010.

The deregulation and demonopolisation of the Swedish network is an ongoing process, and the outcome is not clear. Alexandersson and Hultén found that the tendering of passenger services in Sweden led to a reduction in operation subsidies of 20 %; similarly, the freight sector gained from reduced costs and new business concepts (Alexandersson et al. 2008). In a 2011 statistical analysis, VTI found that contracting out maintenance has resulted in 14 % lower costs, with no effect on failure rate in Sweden (VTI 2011). Espling studied several aspects of outsourcing maintenance, finding, for example, that cost decreased (Espling 2004, Espling 2007). More work on railway efficiency and productivity can be found in: (Oum et al. 1994, Gathon et al. 1995, Cantos et al. 1999, Cowie 1999, Jorge-Moreno et al. 1999, Oum et al. 1999, Couto et al. 2008, Jain et al. 2008, Couto et al. 2009, Lim et al. 2009, Asmild et al. 2009, Friebel et al. 2010, Merkert et al. 2010, Cantos et al. 2010, Li et al. 2011).

Keeping the main or core activities of an organisation in-house is often recommended to ensure competitiveness, growth and innovation, i.e. business safety. Activities with the best potential to be successful are routine and easily managed, measured and supplied (Campbell 1995a, McIvor 2000). Whether maintenance is a suitable candidate is debatable and depends on the business, e.g. industry, facilities, railways, etc. (Levery 2002). A commonly held view is that any contracts have to be managed tightly by the client to ensure performance. In the end, it may be more important to know what one's core business is. TRV's core business is the planning of transportation, see Swedish code of statutes SFS 2010:185 (Näringsdepartementet 2010b).

A number of studies have considered whether one receives more maintenance for the money by outsourcing. Several aspects makes the analysis complicated, e.g. confidential contracts, change of contract types, indirect costs, change in different processes etc. Looking into these studies is beyond the scope of this report.

3.3 Maintenance contract description

The activities in the maintenance contracts used at TRV can be found in the contract description, Handling 6.4.1 (BV 2010b). TRV practices the European standard EN 13306 for terminology and dividing of maintenance activities (BV 2007b, CEN 2011, BV 2003a). See Appendix A for terminology. Maintenance is divided into preventive and corrective maintenance; see Figure 11 for the respective subcategories. As noted previously, TRV is in favour of preventive maintenance and, as much as possible, condition based maintenance (CBM). See Section 2.3.1 for TRV's maintenance policy.

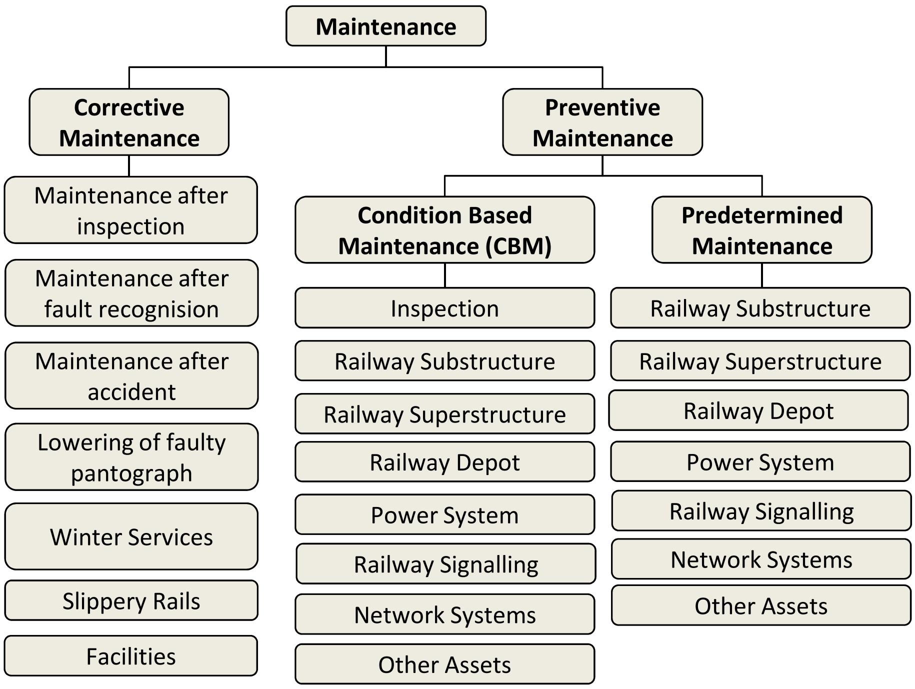


Figure 11: Structure of the maintenance activities. According to contract description (EB) (BV 2010b).

3.3.1 Maintenance inspection planning systems of Trafikverket

This section presents some of the enterprise resource planning (ERP) systems used by maintenance contractors for planning and follow-up of inspections.

BIS is TRV's asset register for all railway engineering assets. Every time an asset is changed in some way, e.g. component replacements, it has to be registered in BIS. A weakness of BIS is that it does not keep the history; therefore, analysis is limited (WSP 2011).

The asset structure can also be found in document (BV 2009d), showing that it is extensive. For example, there are 113 different kinds of switches. Due to this reason, some projects are working with module based systems, e.g. (AUTOMAIN 2010).

Another computer program, BESSY, is used for registration of safety and maintenance inspection remarks in the network. Corrections due to inspection remarks are registered in the computer program Rufus.

Documentation in the form of text and interactive video clips online on TRV's Internet homepage provides instructions on how to use these programs and their related regulations. It is also possible to access some of TRV's enterprise resource planning (ERP) systems, e.g. BIS, through Internet with a user account.

3.3.2 Measures in track

TRV has a number of handbooks and regulations on measures in track, e.g. work and inspections (BV 2005 and 2007, BV 2009b, TRV 2011e). BVF 923 and 924 are the main documents on safety regulations for measures in tracks. Document BVF 807.2 gives details on safety inspections for tracks, switches, embankments, culverts, bridges, tunnels, light systems, yards, track locks, heating systems, overhead contact system, power lines, stations, level crossings, signalling systems, detectors, boards and facilities. To perform an inspection, one must meet the requirements in BVF 807.21, and be approved by TRV (BV 2005 and 2007). In addition, a number of safety regulations by Elsäkerhetsverket (Swedish National Electrical Safety Board) and Arbetsmiljöverket (Swedish Work Environment Authority) must be followed.

Besides safety measures for trains, electrical safety and mechanical stresses are main concerns. Some relevant references are (BV 1995, BV 1995-2011, BV 2002a, BV 2009c).

3.3.3 Winter maintenance and slippery rails

Winter maintenance at TRV is done in accordance with the winter readiness plan for the specific region in question (BV 2010b). Per Unckel notes that the readiness plans differ in their description, scope and definitions over the near 40 agreements and calls for standardisation (Unckel 2010).

An overall picture of the winter activities can be found in the operation and maintenance contract description document (BV 2010b). Special measures for handling switches in a cold climate are described in handbook (TRV 2010c). Videos and instructions are also available through Internet.

Information on slippery rails due to leaves is found in (BV 2006). Contract work on slippery rails can be a separate procurement. Work is commonly done by squirting a water and sand mixture from a rail vehicle on to the rail head.

3.3.4 Condition based maintenance

CBM should be carried out in such a way that the lifetime of the assets is maximised. TRV uses five inspection classes, B1-5; these are a function of train speed and traffic volume. The boundaries of each class are found in Figure 12. For example, class B2 is for speed limits 40 to 80 km/h and traffic of 0 to 8 million of ton per track and year.

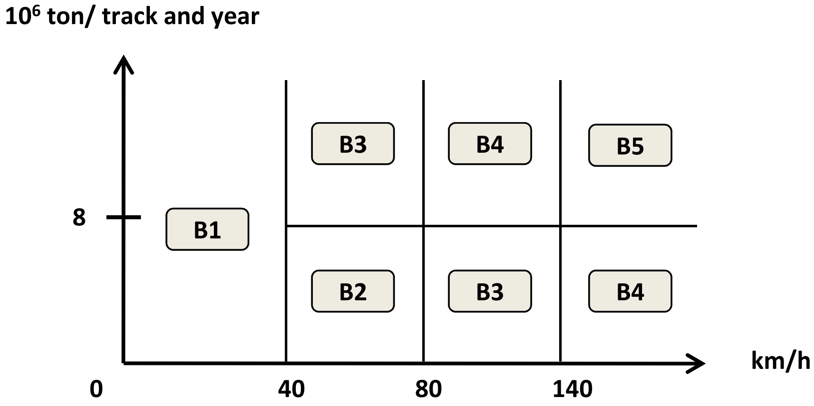


Figure 12: The five inspection classes used by TRV, class = f(speed, traffic). Adapted from (BV 2005 and 2007).

Every asset must be inspected a certain number of times each year depending on the class and the following factors (BV 2005 and 2007):

- Train speed
- Traffic volume
- Type of traffic, e.g. hazardous freight
- Type of surrounding environment
- Geotechnical prerequisite
- Technical structure
- Built in safety systems
- Age and condition of assets

For example, the rail has to be inspected once a year for class B1, twice for B2, and three times for the other classes. However, the number of inspections can also be lower than once yearly, e.g. once every four years.

The safety inspections are more comprehensive than the maintenance inspections. These inspections consider the factors that may cause risk or harm to humans and/or the environment, such as traffic, power, work, third person, operation and environmental accidents and incidents.

TRV's inspection instructions apply to regional primary maintenance contracts and national maintenance contracts. Thus, they include instructions for track geometry and ultrasonic testing cars.

Inspection results are classed differently for the two kinds of inspections. For safety inspections, the classifications are: urgent, week, month and before next inspection. For maintenance inspections, these are: month, year and when time is found (BV 2005 and 2007, BV 2010b).

Track geometry measurement is a part of the national maintenance contracts. The regional contractors do the track adjustments but the client must make the track measurement diagrams. The regional contractor makes assessments from the diagrams in accordance with BVF 541.60 and BVH 825.20 and gives suggestions to the client, i.e. TRV (BV 1992, BV

2004). The geometry measurements are contracted out to Infranord in an open procurement process for five years with an option of four additional years.

Another part of the national maintenance is testing with the ultrasonic testing car (UT-car). The automated ultrasonic testing is outsourced to Sperry Rail, an American company specialised in rail inspections, for three years with an option for two more years (TRV 2010j). All marks registered by the UT-car are manually checked by Infranord and registered in BESSY (TRV 2010d). Technical performance specifications can be found in (BV 1996).

Optram is used to access and analyse data from the measuring cars. Optram is an online Java based computer program owned by Bentley Systems, an American company. Using the asset structure of BIS, it combines data from track geometry cars and UT-cars. There are two types of track geometry cars: there are three older IMV100s (100 km/h) and a newer STRIX (160 km/h) (BV 1992, BV 1997).

The following, with their respective annual frequency according to inspection class, are measured by the track geometry cars (BV 2005 and 2007):

- Geometric position of rail, 1 - 6 times per year
- Rail profile, ≤ 2 times per year
- Long- and short-pitch corrugation, ≤ 1 times per year
- Video recording of track and surroundings, 1 - 2 times per year
- Ballast profile, ¼ - 1 times per year
- Overhead contact wire, ≤ 3 times per year

An updated laser system for contact wire measurements has recently been implemented. The system measures the contact wires' position and texture, i.e. wear and damage. The owner of the contact wire measurement system is Latronix AB, a Swedish company.

TRV has an extensive network of detectors in Sweden for condition based maintenance (CBM); about 160 detectors in total (BV 2009a, TRV 2010f). The detectors give automatic alarms or data for manual analysis. Preventive maintenance of the detectors is regularly carried by contractors (BV 2003a, BV 2009a). See work by Lagnebäck for an extensive review of detectors (Lagnebäck 2007). Work on wheel-rail forces detectors can be found in (Palo 2012). Table 3 shows the various types of wayside detectors used in Sweden.

Indicators extracted from are related to the rolling stock and therefore out of the scope of this report. Nevertheless, the rolling stock is as important as the infrastructure since it will be in alike condition (Lardner 1850).

Table 3: Railway wayside detectors and their function in the Swedish railway network.

Wayside detector	Function
Hot box	Measures the temperature of wheel bearings
Hot/cold wheel	Measures the temperature of the wheel to detect too high or too low breaking force
Damaged wheel	Measures the mechanical stresses in the wheel-rail interface
Overloading	Measures the axle load. This detection is built into the damage wheel detector system
Unbalanced load	Measures the load in lateral and longitudinal direction. This detection is built into the damage wheel detector system
Contact wire lift	Measures the position of the contact wire when it is raised by the pantograph. Lift cannot be too high or too low
Pantograph	Detects damage and wear of the pantograph contact runner
Wheel-rail forces	Collects wheel-rail interface mechanical forces data

3.3.5 Predetermined maintenance

TRV's BVF 817 regulates how the predetermined maintenance actions are to be performed. Examples are lamp bulb replacements, battery replacements, traffic information boards maintenance, relay tests, insulated joints, tightening screws, lubricating switches etc., controlling rail lubrication machines, cleaning, calibration, visual inspections. For facilities, it includes the control of redundant power plants. The periodicity of predetermined maintenance can follow the inspection classes according to Figure 12, the recommendations from manufacturers or empirical knowledge. Periodicity varies from 26 times a year to once every ten years.

3.3.6 Corrective maintenance

All failures identified outside the safety and maintenance inspections fall into the corrective maintenance. Such failures include the following (BV 2010b):

- Accidents with animals
- Inspections after wheel impact
- Actions after failure in railway safety equipment
- Actions after alarms
- Actions after report from operators or other people
- Actions after suspecting failure
- Lowering failed pantographs

Safety inspection marks are labelled according to their severity. Those labelled urgent or week are also going as corrective maintenance. Rail failures identified by ultrasonic testing and classified as group one failures, as well as severe track geometry deviations, constitute corrective work and must be corrected according to the regulations for each type of failure.

3.3.7 Failure identification and follow-up

All persons who find a fault in the railway or suspect a fault are asked to report it to TRV's operation central in the region in question (TRV 2010b). Often the person reporting a failure is the train driver. The central operation registers the fault in the computer program Basun as a work order. Basun is used to handle traffic information within TRV. Faults are registered in Basun but the data are transferred to another computer program, Ofelia, for follow-up. The operation centrals contact the maintenance contractor for restoration of the faulty system. When a work order is completed, it is registered in Ofelia by the contractor. Follow-up can be done in Ofelia by contacting the operation central and reporting the measure taken. The completion and closing of work orders must be carried out within 24 hours. Compulsory fields to fill out in Ofelia are:

- Position
- System type
- Actual failure
- Cause of failure
- Action taken
- Time at work start
- Time at work completion

Immediate correction must be taken if the fault has any symptoms that can:

- Influence safety
- Cause delayed trains
- Create environmental risks in the workplace
- Disturb a third party
- Involve environmental hazards

Actions taken as a result of safety and maintenance inspections are not registered in Ofelia; since 2010, Rufus has been used.

The repair process of an urgent fault is shown in Figure 13.

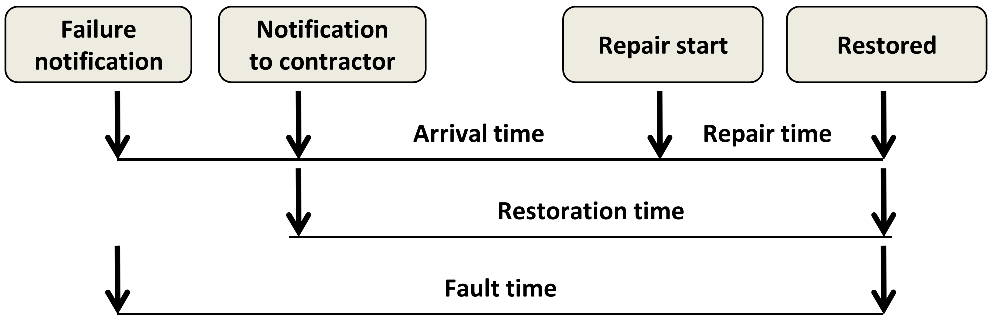


Figure 13: Definition of the urgent fault correction process. Adapted from (BV 2010b).

3.3.8 Additional standards

CEN standards (European Committee for Standardisation) also apply to TRV and railway contractors in the inspection and maintenance of railways, e.g. (CEN 2005, EN 13231 2006 and 2012, CEN 2006, -08, -09, -10, -11).

4 Maintenance performance indicators of railway infrastructure

This chapter starts with a general introduction to performance measurements, followed by performance measurement indicators specific to railway infrastructure used by TRV, some other infrastructure managers and researchers.

4.1 Introduction to performance measurement

What gets measured gets managed

Phrases like "what gets measured gets managed" are often used to justify indicators. What gets measured gets managed is not a promise (Emiliani 2000). Rather, measuring is a management tool which facilitates and supports effective decision making. In and of itself, it does not determine performance, but it can facilitate good management.

All organisations use indicators to measure their performance. The most common ones are financial; many of these are mandatory by law. Other indicators are technical, organisational, HSE (health safety and environment), etc. There are few agreements on how to categorise indicators. It is up to each organisation to decide which standards or frameworks to use. The best known standards for maintenance KPIs are the European standard EN 15341 and SMRP Best Practice Metrics (CEN 2007, SMRP 2011). Use of standardised indicators or metrics, such as the indicators from the standard EN 15341 or the SMRP metrics (Kahn et al. 2011) has the following advantages:

- Maintenance managers can rely on a single set of predefined indicators supported by a glossary of terms and definitions
- The use of predefined indicators makes it easier to compare maintenance and reliability performance across borders
- When a company wants to construct a set of company indicators or scorecard, the development process based on predefined indicators is simplified
- The predefined indicators can be incorporated in various CMMS software and reports
- The predefined metrics can be adopted and/or modified to fit the company's or the branch's special specific requirements
- The need for discussion and debate on indicator definitions is ended and uncertainties are eliminated

Organisations' maintenance performance measurement (MPM) system, e.g. databases and indicators, can grow from the need to measure different processes. Indicators can come in an ad-hoc manner, where some of them will stay, while others go obsolete. It can then be needed to organise or reorganise the MPM system. Databases and indicators must be documented, regulations set, problems must be identified and indicators be aligned to business goals. See Figures 14 and 15 where high level requirements (HLRs) and necessary steps for organising, or reorganising a measurement system have been deduced from previous discussion. Supportive guidelines for asset management in railways can be found in a work by UIC, as a seven-step procedure based on British Standards Institute's PAS 55, the International Infrastructure Management Manual (IIMM) from New Zealand and the Asset Management Overview by the U.S. Federal Highway Administration (INGENIUM et al. 2006, FHWA 2007, PAS 55-1 2008, PAS 55-2 2008, UIC 2010a).

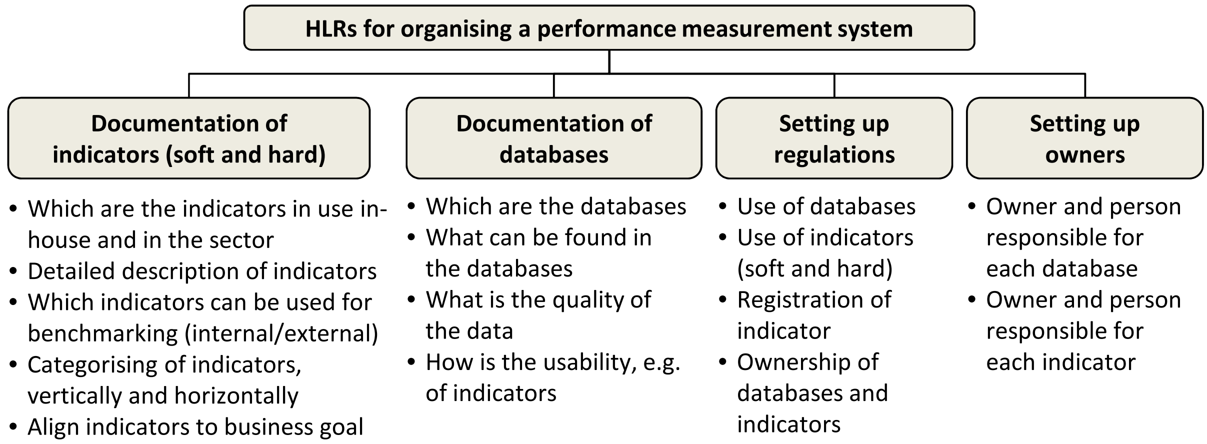


Figure 14: High level requirements (HLRs) for organising or reorganising a performance measurement system.

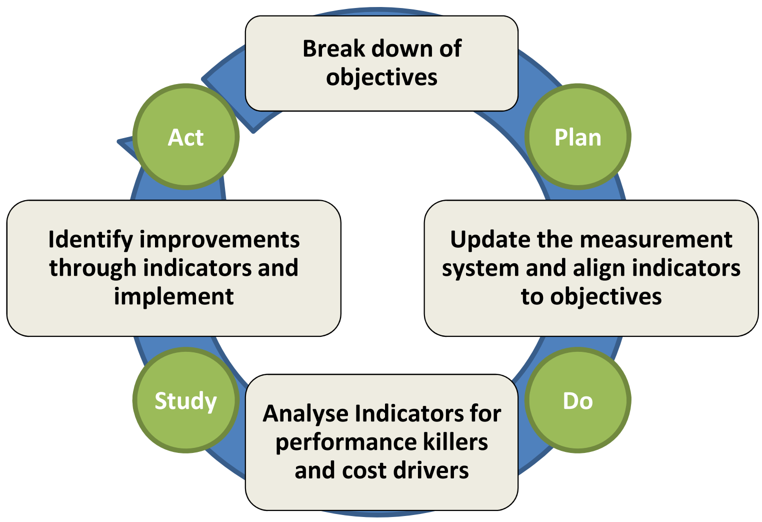


Figure 15: Steps in organising or reorganising a performance measurement system.

According to Gillet (2001), Woodhouse found that a human cannot control and monitor more than four to eight indicators at the same time. Data aggregation is therefore necessary; see Figure 16.

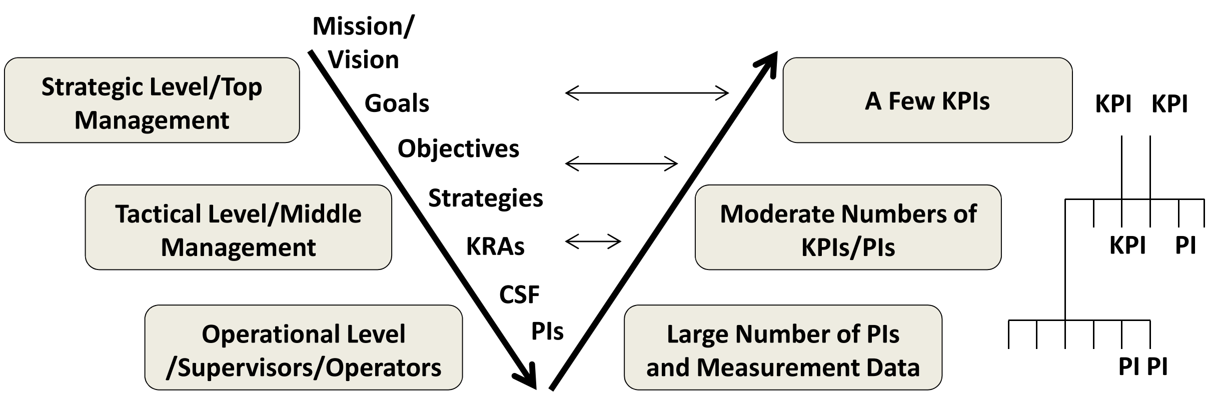


Figure 16: Breakdown of goals and objectives and aggregation of data.

It is not possible to measure everything with only quantitative or only qualitative methods. Rather, both methods must be used to create a measurement system that is as complete as possible. Qualitative measurement methods are good for measuring soft values like employee satisfaction and for checking conformity with quantitative indicators; see Figure 17. Galar et al. (2010, 2011) have merged qualitative measures with quantitative ones and developed an audit that shows the relation between trends in questionnaires and indicators, validating the correlation or highlighting the divergence.

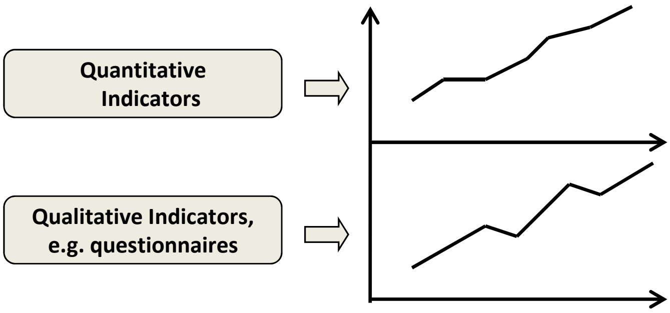


Figure 17: Illustration of how the conformity of quantitative and qualitative measurement methods can be studied. Arbitrary unit at the y-axis and time at the x-axis.

A common qualitative measurement method is to use questionnaires. Many critical factors come into play in the design of a questionnaire, especially if it is repeated at intervals to monitor trends over time. Besides having the same appearance and design, repeated measurements using questionnaires must ensure that the respondents' groups are similar as well as circumstances like the time and day of the year. A classic maintenance audit standard is the COVENIM 2500-93 from Venezuela, where surveys are used to gather data (Comisión Venezolana de Normas Industriales 1993).

See work by Kumar et al. (2011) for a state of the art review of maintenance performance metrics. For work on the need of PIs in maintenance investments, see work by (Stenström et al. 2011).

As this report focuses on quantitative indicators, there are few qualitative indicators given.

4.2 Mapping of railway infrastructure indicators

The indicators used for managing railway infrastructure are somewhat comprehensive, and have therefore been grouped into two overall groups with a number of sub-groups. The two overall groups are: managerial and infrastructure condition indicators. The managerial indicators are extracted from different computer systems, e.g. enterprise resource planning (ERP), computerised maintenance management software (CMMS), etc., excluding condition monitoring (CdM) data. The infrastructure condition indicators group is then all the indicators extracted by sensors and various inspection methods in the railway network. Managerial indicators are more at a high-level compared to CdM indicators that are closer to the operational or low level. Se Figure 18.

Increased interoperability and building of a trans-European railway network requires harmonisation and standardisation of the management, which have led to increased use of European standards. The identified managerial PIs have therefore been grouped according to European standard EN 15341, i.e. economical, technical and organisational. In the standard, the health, safety and environmental PIs are in the technical group, but these indicators have been considered to have such importance for railways that they have been put into a separate group. The managerial indicators consists therefore of four groups, or key result areas (KRAs); see Figure 18.

CdM indicators have been grouped according to the common engineering sub-systems of railways, namely: substructure, superstructure, rail yards, electrification, signalling and information communication technologies (ICT). This structure is applied in Sweden (BV 2009d).

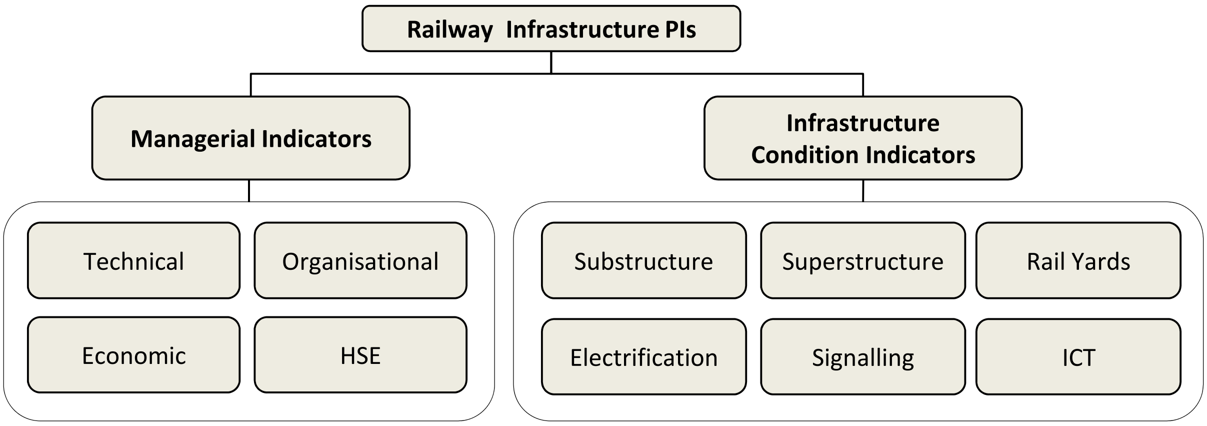


Figure 18: Structure of railway infrastructure PIs. ICT stands for information and communication technologies.

The following sections are structured according to Figure 18 as: technical, organisational, economic, HSE and infrastructure condition indicators.

4.3 Technical indicators

Technical indicators are mainly related to reliability, availability and maintainability (RAM). The research is extensive, for some work, see: (Nyström et al. 2003, Olsson et al. 2004, Granström et al. 2005, Granström 2008, VTI 2011) for work on failure frequency and delay, (Nyström et al. 2003, INNOTRACK 2009) for maintainability, (Åhrén et al. 2004) for mapping of maintenance PIs, (Krueger 1999, UIC 2004, Abril et al. 2008) for capacity, (George et al. 2008, Åhrén et al. 2009b, Malhotra et al. 2009) for overall equipment effectiveness (OEE) and data envelopment analysis (DEA).

4.3.1 RAMS

RAMS is an acronym for reliability, availability, maintainability and safety. These factors have in general the following interrelationships:

- $\text{Reliability} = \text{f(Inherent design)}$, if the manufacturing, transportation, installation, environmental condition, operation, maintenance, etc., are within the design limits
- $\text{Availability} = \text{f(Reliability, Maintainability, Maintenance supportability)}$ (CEN 2011)
- $\text{Maintainability} = \text{f(Inherent design)}$
- $\text{Safety} = \text{f(Inherent design (maintainability), Environmental conditions, Safety barriers, Policies, etc.)}$
- $\text{Maintenance supportability} = \text{f(Maintenance mangement, Organisation, Environmental conditions)}$

The European RAMS standard for railway applications, EN 50126, provides a process for the management of RAMS requirements throughout all phases of the lifecycle of railway applications (CEN 1999). The life cycle is divided into 14 phases, and phase 12 is dedicated to performance measurement. The standard gives an overview of RAMS over an item's life cycle and examples on relevant indicators.

The INNOTRACK project studied the key values for LCC and RAMS by reviewing literature and carry out a questionnaire (INNOTRACK 2009). The project was a collaboration by major stakeholders in the rail sector working to develop a cost-effective high performance railway infrastructure involving 36 partners. Identified indicators were the following:

- Failure Rate
- MTBF (Mean time between failure)
- MTTF (Mean time to failure)
- MTTR (Mean time to repair)
- Train delay caused by infrastructure failures
- Hazard rate
- No. of derailment
- No. of accidents
- MART (Mean active repair time)
- MMH (Mean maintenance hour)
- MTTM (Mean time to maintain)
- Time for maintenance
- MTBCF (Mean time between critical failures)
- MTBSAF (Mean time between service affecting failure)
- MWT (Mean waiting time)
- PPM (Passenger performance metric)

The fundamental indicators for RAMS are presented in this section. Safety related indicators are given in Section 4.6.

4.3.2 Reliability

Reliability is the ability of an item to perform a required function under given conditions for a given time interval (IEC 1990a). Reliability is also used as a measure of reliability performance, measure of probability (CEN 2011), which gives the following alternative definition: reliability is the probability that an item will perform a required function under given conditions for a given time interval. Measured as a probability, it is not possible to ask what the reliability of an item is without specifying at what time, since the answer is given as a percentage that an item is still running. In general, the reliability of an item depends on its inherent design. The reliability of an item will not change if the manufacturing, transportation, installation, environmental condition, operation, maintenance, etc., are within the design limits. Reliability cannot be measured directly, but a reliable item has a positive effect on the availability. Reliability can be calculated as a probability for specific times by using failure data.

4.3.3 Down time

The time from a fault's recognition to its rectification is called down time (DT). Time to recovery and time to restoration are also used, but since the acronym for these is the same as time to repair, they are not used here, even if down time can be due to other factors than failure. Down time is the time interval during which an item is in a down state. In the down state, the item is characterised either by a fault or by an inability to perform a required function during preventive maintenance (CEN 2011). Down time consists of the waiting time and the time to repair in the context of a failure; expressed as the following:

$$
\begin{aligned}
Downtime\ (DT) &= Waiting\ Time + Time\ to\ Repair \\
&= WT + TTR \\
&= Maintenance\ Supportability \\
&+ Maintainability
\end{aligned}
\tag{4.1}
$$

As both organisational and item-specific aspects are mixed in down time, it provides little information on its own. Down time should therefore always be presented together with waiting time and time to repair, i.e. maintenance supportability and maintainability.

Other related indicators that can be considered are uptime (UT) and time between failures (TBF). The mean is commonly calculated for these indicators, e.g. MWT, MTTR, etc., or the total over a time period. See Figure 19 for the morphology of a system under operation.

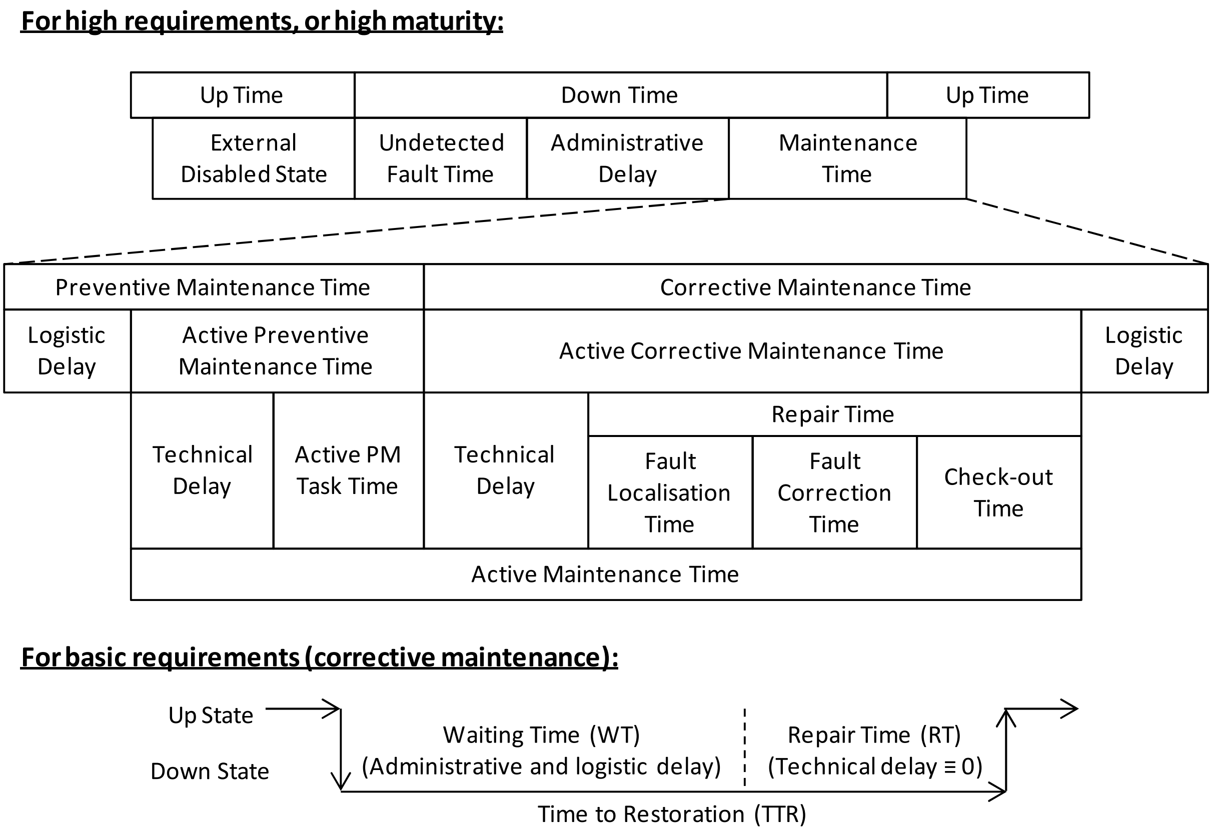


Figure 19: Morphology of an item under operation. High requirements, or high maturity, are in agreement with IEV and EN 13306 (IEC 1990a, CEN 2007).

Down time is used by TRV in its QoS scorecard; see Section 5.1.1 (BV et al. 2009c).

4.3.4 Availability

Availability is the ability of an item to be in a state to perform a required function under given conditions at a given instant of time, or over a given time interval, assuming that the required external resources are provided (IEC 1990a, CEN 2011, IEC 1990b). Availability is commonly given as, e.g. (CEN 2007):

$$A = \frac{Mean\ Uptime}{Mean\ Uptime + Mean\ Downtime} = \frac{MUT}{MUT + MDT} \quad (4.2)$$

A definition in the railway context has been given by (Nyström 2009):

$$A = \frac{Obtained\ Capacity}{Planned\ Capacity} \quad (4.3)$$

Availability is used in TRV's QoS scorecard, measuring the availability of traffic information and of services that make travelling possible; see Section 5.1.1 (BV et al. 2009c).

SBB and ProRail both have an indicator of availability of railways, called network availability and track availability, respectively. See the Asset Management Club Project in Section 5.1.3.

4.3.4.1 Punctuality

TRV uses different time margins to evaluate punctuality, frequently, on time plus five minutes are used, i.e. no later than six minutes (Söderholm et al. 2011). Punctuality is often presented over a couple of years as the percentage of trains that are punctual for different traffic types and line classes. Traffic types of TRV include passenger, freight, long distance, express, regional, commuter and Arlanda line trains. The line classes are city, major, other important, minor and lines with little or no traffic (BV 2010a). See Figure 20 for an example. Punctuality over a 12 years period can be found for passengers and freight in TRV's annual report of 2011 (TRV 2012a).

The indicator used by TRV, punctuality, is one of the underlying indicators of the six QoSs of TRV, with quantitative objectives for the different railway lines. Punctuality is presented in the latest strategic plan for 2010-2021 with objectives to 2021 (BV et al. 2009c). A similar presentation for a five-year period is found in the 2009 annual report (BV 2010a).

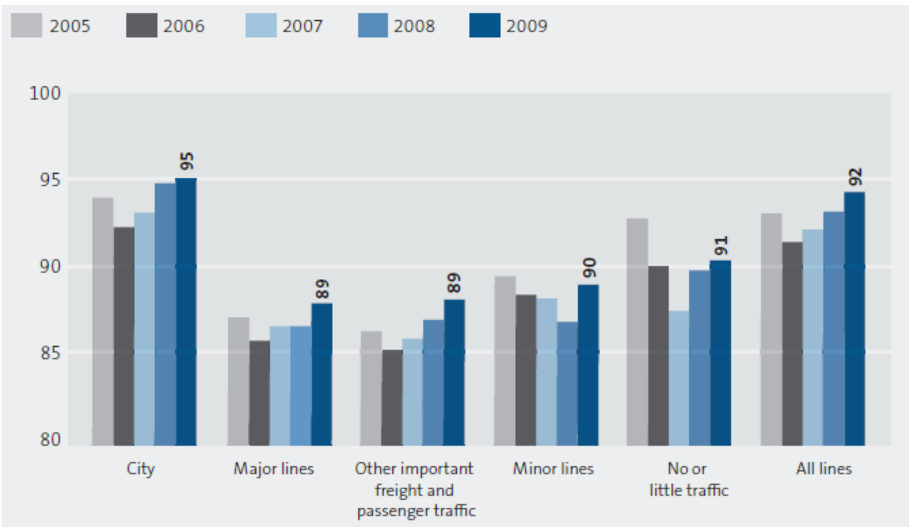


Figure 20: Arrival punctuality per type of line in percentage (BV 2010a).

Generic benchmarks for punctuality of high-speed rails, upgraded and new tracks, can be found in UIC statistics (UIC 2009); see Figure 21.

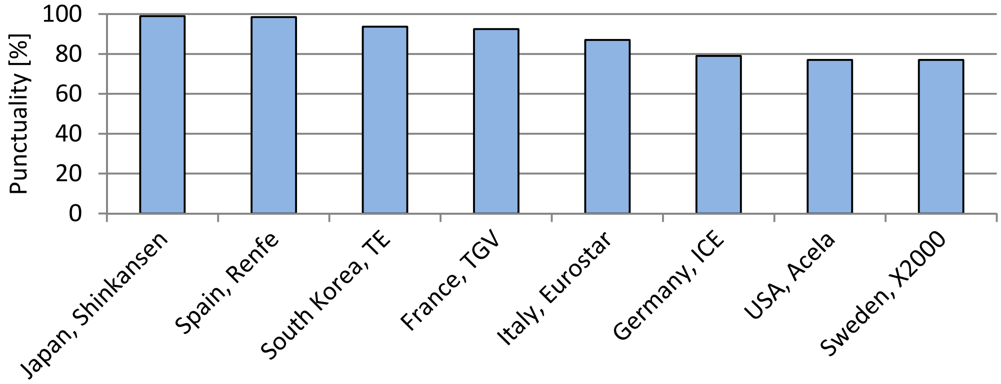
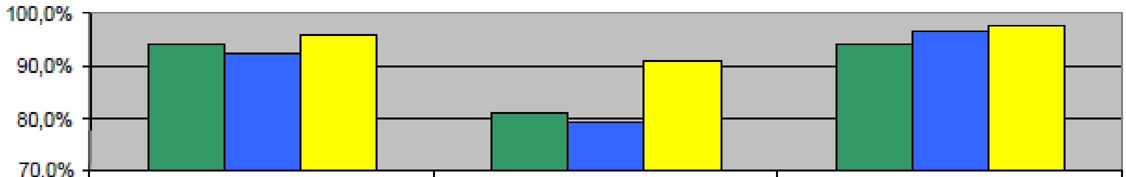


Figure 21: Punctuality of high-speed rails, upgraded and new tracks. Adapted from (TRV 2011g). Data are from (UIC 2009).

4.3.4.1 Regularity

Regularity can be represented as the number of trains that travel the whole planned distance or as the number of cancelled train departures. The regularity of the Swedish network was presented in TRV's December 2010 report for passenger and freight over three years, shown in Figure 22 (TRV 2010h). Also TRV's 2009 annual report provides cancelled train departures for passenger and freight trains over three years (BV 2010a).



	Totalt	Godstrafik	Persontrafik
Ack dec 2010	94,1%	81,2%	94,2%
Tot År 2009	92,3%	79,5%	96,7%
Tot År 2008	96,0%	90,9%	97,7%

Figure 22: Percentage of trains that have travelled the whole planned distance. Bars to the left: total, middle bars: freight and right bars: passenger traffic (TRV 2010h).

4.3.4.2 Train delay

TRV usually present train delays according to the owner of the cause to the delay. The owners of the cause to failure are operation centrals, secondary delays, infrastructure, train operators and accidents and incidents (five in total). Secondary delay occurs when a delayed train affects the next coming trains (TRV 2010h, TRV 2011g). In Sweden, train delays in hours due to infrastructure, besides passenger and freight delays can for example be found in the annual report of 2009 (BV 2010a). In TRV's December 2010 report, delay is presented over a one year period, in hours, specifying the owner of the cause to failure. A trend cannot be followed but the distribution can clearly be seen in Figure 23.

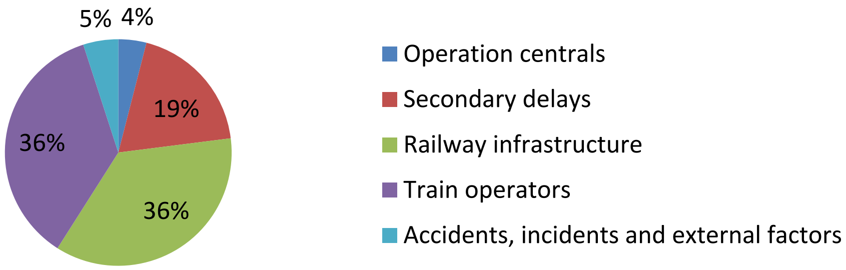


Figure 23: TRV data showing passenger train delays minutes share for Apr — Mar 2011 for operation centrals, secondary delays, railway infrastructure, train operators and accidents, incidents and external factors. Adapted from (TRV 2011g).

In a similar study, Nyström and Kumar (2003) examined the owners of train delays. The owners of the delays were divided into eight categories, as shown in Figure 24.

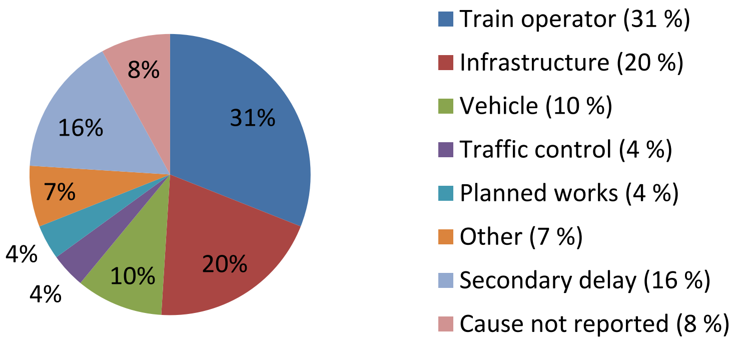


Figure 24: Train delay hours for 2002 distribution between different owners. Adapted from (Nyström et al. 2003).

Riksrevisionen (Swedish National Audit Office) (2010) has examined delay data for passenger and freight traffic over a ten-year period; Figure 25 shows the trends. Data were extracted from Banverket's annual reports and TRV's monthly report for December 2009.

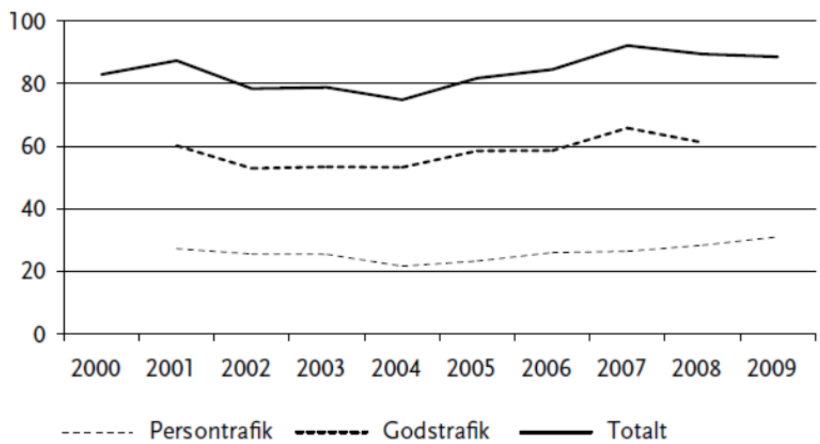


Figure 25: Delay trends in thousands of hours in passenger (thin dashed), freight traffic (thick dashed) and in total (Riksrevisionen 2010).

Delay hours due to failures in infrastructure for different geographical regions for 2002-2005 can be found in TRV's maintenance handbook and are shown in Figure 26 (BV 2007b). TRV stresses that because this indicator does not take into account the time of the delay, it does not show the effect on passengers on their way to work. Nor does the indicator consider cancelled trains. Indicators of regularity measure this issue.

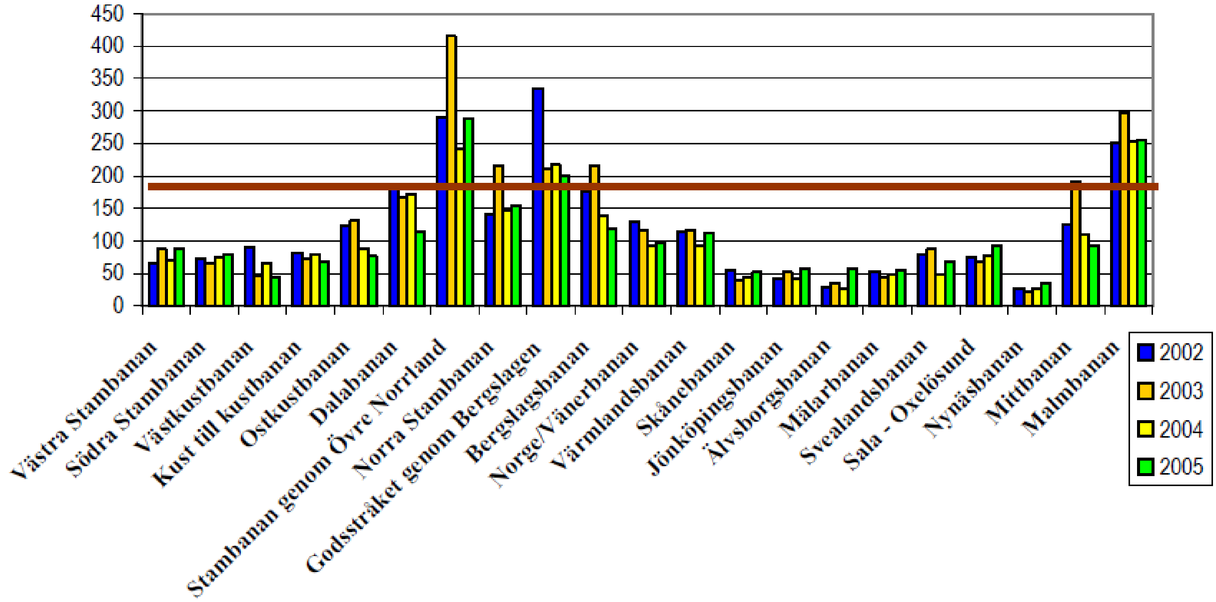


Figure 26: Delay presented with both time trend (2002-2005) and geographical distribution (BV 2007b).

Olsson and Espling (2004) emphasise that maintenance activities must be measured; two indicators of this are delay due to maintenance overdue and time spent on maintenance activities.

Delays caused by infrastructure and delays caused by safety installations are indicators used by SBB (Schweizerische Bundesbahnen, Switzerland) in the defined scorecard agreement with the Swiss Traffic Ministry (BSL 2009). Similarly, DB's (Deutsche Bahn, Germany) scorecard agreement with the German Traffic Ministry contains two indicators related to delay: infrastructure related delay and temporary speed restrictions (TSRs) due to infrastructure and due to regulations. Infrastructure related delay is equivalent to delays caused by infrastructure. See the Asset Management Club Project in Section 5.1.3.

Timetables are constructed with some buffer time (or slack) so trains can recover from small delays during travelling (UIC 2004). This slack affects the delay and the robustness of timetables depending on how large it is and should therefore be compared with the delay. It should also be kept in mind that the delay is a function of the travelled distance; a longer distance gives higher probability of occurrences causing delays.

4.3.4.3 Frequency of failures

Pareto charts, or such, are often used to study frequency of occurrence, and are considered as one of the seven basic quality tools in the book "The Quality Toolbox" (Tague 1994). Granström and Söderholm (2005, 2008) studied data from TRV's failure database Ofelia to determine the main causes to failure and delay at system and component levels; see Figures 27 and 28. A similar study has been carried out by the Swedish National Road and Transport Research Institute (VTI 2011). Moreover, Nyström and Kumar (2003) have studied the top ten items in terms of number of failures and delay. However, neither outliers nor missing data were presented in these studies; the quality of the data is therefore unknown.

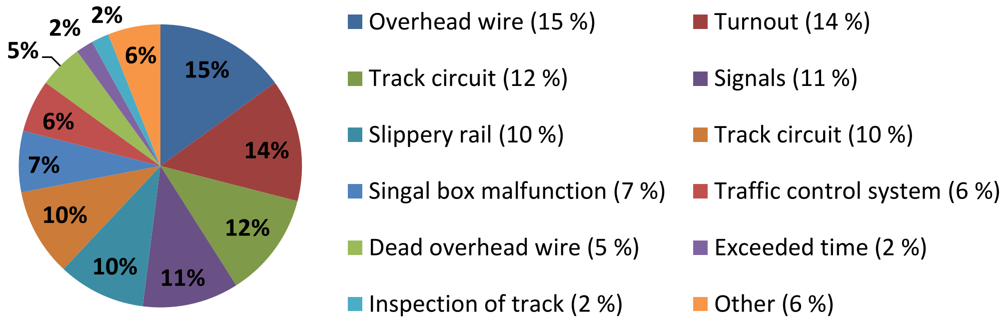


Figure 27: Reported causes of infrastructure related delays at TRV 2001-2003. The chart shows the percentage of work orders for each system. Adapted from (Granström et al. 2005).

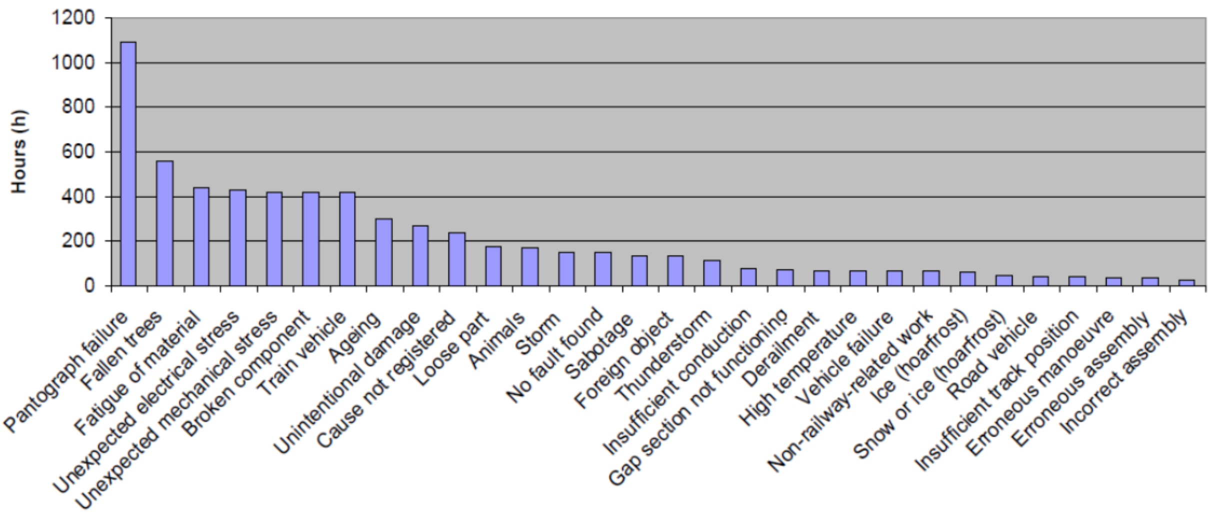


Figure 28: The top 30 causes of train delay related to the overhead contact wire in the Swedish network. Data collected from failure database Ofelia (Granström 2008).

TRV presented failure data and train delay hours for different assets for 2001 in their strategic plan for 2004-2015, and similar data for 2002-2006 in the planning of today's strategic plan (BV 2003b, BV 2007c). The assets include: superstructure, substructure, signalling, power supply and telecommunications and one group called other. In the strategic plan for 2010-2021 one can find the total delay hours for different railway lines due to infrastructure failure (BV et al. 2009c). TRV has also presented failures per track-km for the different line classes and their underlying lines in the Asset Management Club Project by BSL Management Consultants (Section 5.1.3) (BSL 2009).

4.3.4.4 Traffic interfering faults

Riksrevisionen has studied the total number of faults and the faults that interfere with train traffic from 2000-2009 of the Swedish railway system, as a whole and for specific line classes (Riksrevisionen 2010). Table 4 shows the number of faults, while in Figures 29 and 30, the data are presented in graphs so the trends can be studied. TRV has done similar studies for geographical regions, to determine the percentage of faults interfering with traffic (BV 2007b).

In Figure 29, one can see that the trend lines converge, i.e. the share of faults interfering with traffic is increasing. This is more visible when the percentage is presented as well; see Figure 30.

Table 4: Total faults and train interfering faults (Riksrevisionen 2010).

Year	00	01	02	03	04	05	06	07	08	09
Faults in infrastructure (10^3)	41	46	46	45	44	42	44	42	43	44
Faults interfering with traffic (10^3)	4	7	7	7	7	8	11	11	11	10
Percentage of faults interfering with traffic [%]	11	16	16	16	16	18	26	26	25	22

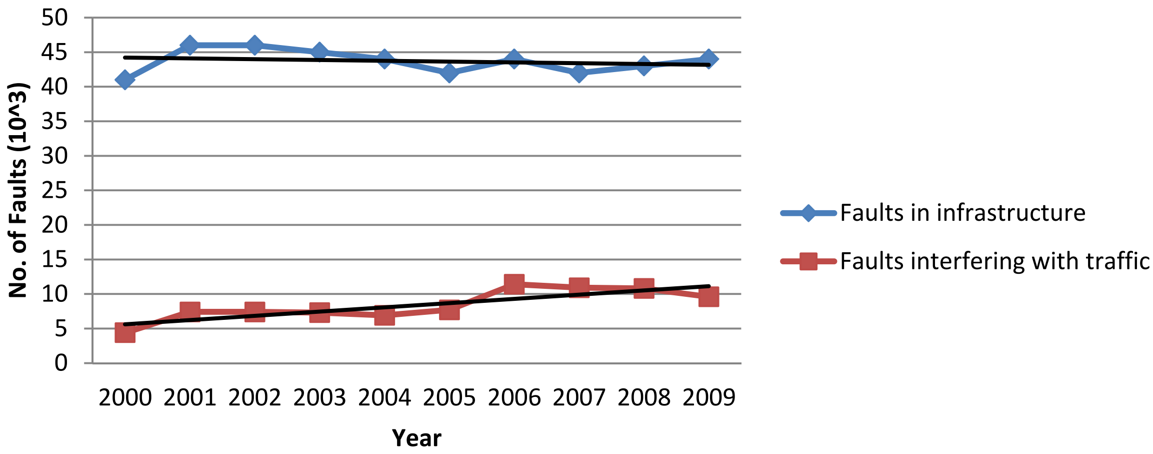


Figure 29: Faults in infrastructure and faults interfering with traffic presented with trend line. Faults in infrastructure are the total number of faults, and faults interfering with traffic are therefore part of it. The data are from Table 4.

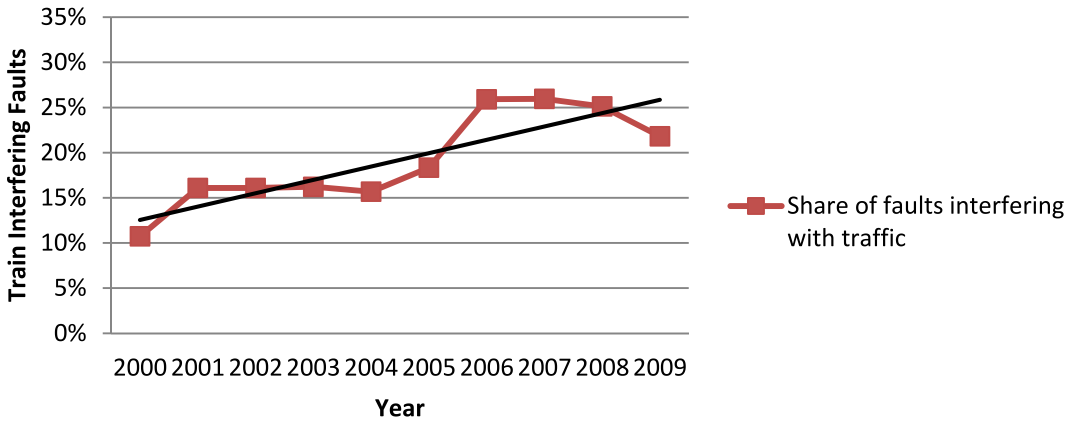


Figure 30: Share of faults interfering with traffic. The data are from Table 4.

4.3.5 Maintainability

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. Note: maintainability is also an indicator that measures maintainability performance (IEC 1990a, CEN 2011). As an indicator, maintainability is the time it takes to restore an item from that maintenance has started, i.e. time to repair (TTR). Maintainability can be studied for different items in order to find out which items are hard to do maintenance on, to determine why it is hard, e.g. poor design, type of failure and position of item.

Nyström and Kumar have looked into the maintainability of switches and crossings, and presented it as a histogram; see Figure 31 (Nyström et al. 2003).

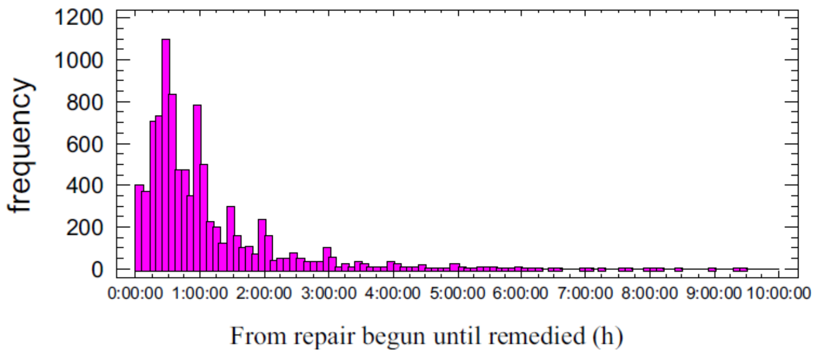


Figure 31: Distribution of TTR of switches and crossings (Nyström et al. 2003).

TRV has presented the maintainability of different line classes in its maintenance handbook (BV 2007b), similar to the graphs found in Section 4.4.1.3 on maintenance supportability.

4.3.6 Capacity consumption

The capacity of any railway infrastructure is the total number of possible paths in a defined time window, considering the actual path mix or known developments and the IM's own assumptions in nodes, individual lines or part of the network and with market-oriented quality (UIC 2004). Another description is given by (Krueger 1999): capacity is a measure of the ability to move a specific amount of traffic over a defined rail line with a given set of resources under a specific service plan.

Capacity interdependencies exist between the number of trains, average speed, stability and the heterogeneity of traffic (Figure 32) (UIC 2004). See leaflet 406 by UIC (2004) or review by (Abril et al. 2008) for guidelines and details.

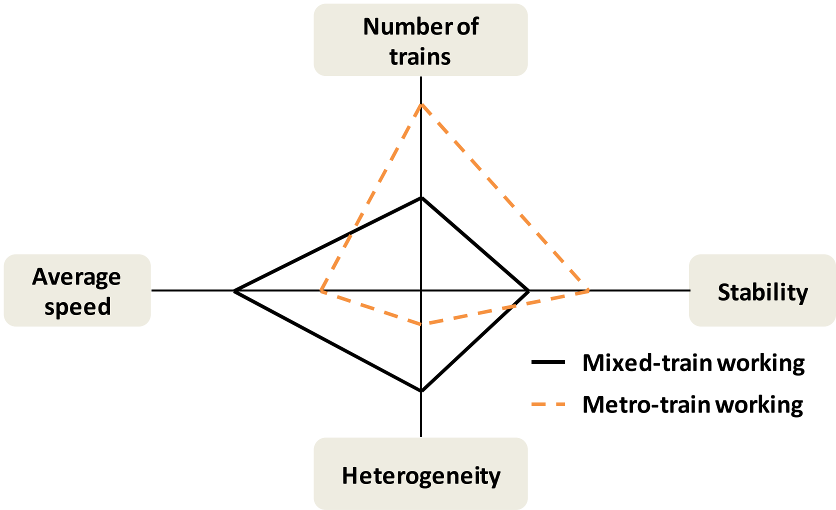


Figure 32: Capacity balance. Adapted from (UIC 2004).

Several indicators of how the capacity is utilised can be found in TRV's 2009 annual report (BV 2010a). Traffic volume in million train-km is presented over a five-year period for the different line classes. Train-km per track-metre and gross-tonne-km per track-metre is presented for 2009 for the different line classes, as well. These two indicators are also included in the preplanning report of TRV's strategic plan for 2006 (BV 2007c). Moreover, TRV's 2009 annual report also has an indicator named capacity utilisation, measured in terms of the proportion of the time the track is used by trains (BV 2010a). Capacity utilisation is calculated for the day as a whole and for the two hours of the day that the track is used to the greatest extent and is presented as a percentage. If the utilisation exceeds 80 % the sensitivity to disruptions is high, average speed is low and it will be hard to find time for maintenance. Utilisation in the range of 60-80 % means that maintenance time should be carefully weighed and sensitivity to disruptions is relatively high. If the utilisation is below 60 %, there is room for more traffic and time for maintenance. Data are presented as the number of line sections in each utilisation range. Lines in the range of 80-100 % can be considered congested; this will affect delays, punctuality and regularity, i.e. quality and dependability. The capacity utilisation is calculated according to UIC Leaflet 406 (Trafikanalys 2011, UIC 2004). The indicator is called capacity consumption in the leaflet and is calculated as follows:

$$K = \frac{k}{U}100, \qquad k = A + B + C + D \tag{4.4}$$

Where:

K = Capacity consumption [%]
U = Chosen time window [min]
k = Total consumption time [min]
A = Infrastructure occupation [min]
B = Buffer time (i.e. slack) [min]
C = Supplement for single-track lines [min]
D = Supplements for maintenance [min]

TRV has presented a harmonised indicator for measuring the capacity utilisation, here called harmonised capacity utilisation. It is calculated by taking the produced train-km over the une-track length. In the une-track length, the length of double tracks is counted twice. This is a simple indicator, however, and more analysis is required to better understand capacity utilisation. Harmonised capacity utilisation for different geographical regions for 2002-2005 is presented in TRV's maintenance handbook (BV 2007b). See Figure 33.

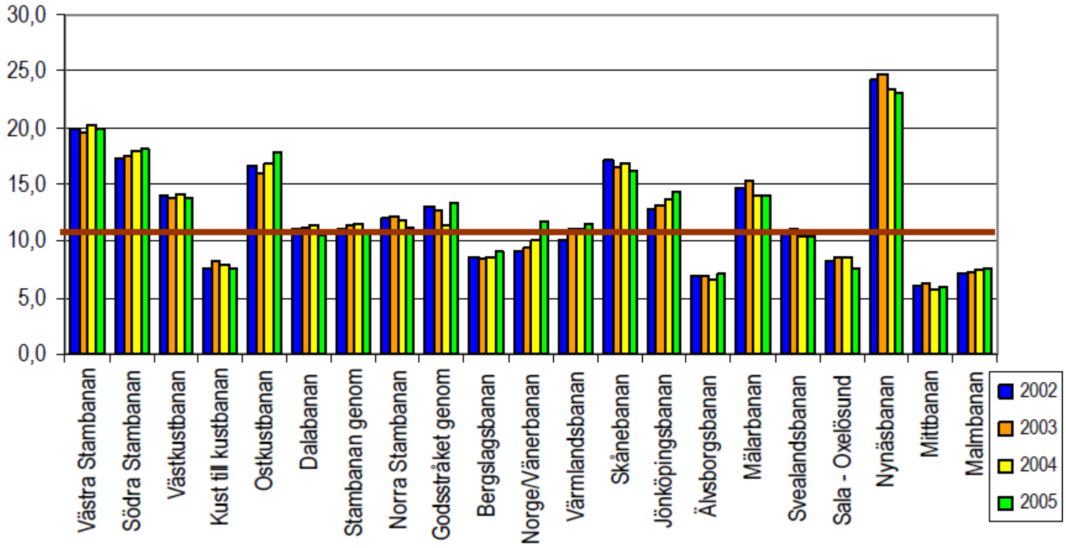


Figure 33: Harmonised capacity utilisation [Train-km/Une-track-metre] for different geographical regions (BV 2007b).

In the future TRV would like to be able to measure the number of axles passing (BV 2007b).

Åhrén and Kumar identified three capacity related indicators by studying appropriation letters and annual reports of TRV and by interviewing TRV personnel: capacity utilisation, capacity restrictions and traffic volume. Details are not given for capacity restrictions (Åhrén et al. 2004).

SBB uses track-km sold to measure the utilisation of the network, see the Asset Management Club project in Section 5.1.3 (BSL 2009).

4.3.7 Riding comfort

Track quality indices (TQI) are measure of the track geometry based on geometrical standard deviations. These indicators are important for the riding comfort and track deterioration.

The analysis is carried out for short and long wavelengths, 0-25 m and 25-75 m, respectively. Short wavelengths are used to determine if tamping is necessary, and long wavelengths serve to determine if lining is necessary (Esveld 2001).

A common TQI is the Q- and K-value used by the Swedish, Norwegian and Danish IMs; TRV, JB and BJ, respectively (BSL 2009). The K-value measures longer track sections, usually 1000 m, and the Q-value shorter sections, usually 200 m. Both indicators are mean-based over a distance; therefore, point defects cannot be seen in these indicators.

The K- and Q-values are based on the following geometrical standard deviations (mean over 25 m):

- Longitudinal level (σ H) [mm]
- Variation of cant (σ R) [mm]
- Alignment (σ V) [mm]
- Cooperative parameter (σ S) [mm]

Each of the four standard deviations has thresholds defined for good riding comfort.

The K- and Q-values are defined as:

$$Q = 150 - 100\frac{\frac{\sigma_H}{\sigma_{H,Threshold}} + \frac{\sigma_S}{\sigma_{S,Threshold}}}{3} \tag{4.5}$$

$$K = \frac{\sum l}{L} 100\ \% \tag{4.6}$$

Where the standard deviations are the mean over the chosen track length L. The summation $\sum l$ is the length of the track with standard deviations lower than the thresholds. Equation 4.14 shows that the highest possible Q-value is 150; occuring when the standard deviations are zero. In other words, higher Q value means higher quality. The same is true for the K-value; higher is better. A K-value of 100 % means that the whole track length is below the thresholds. For details, see BVF 541.60 (BV 1992).

K- and Q-values for the Swedish railway system for 2003-2006 are presented in the preplanning documentation for the latest strategic plan (BV 2007c). K-values for different geographical regions for 2002-2005 can be found in TRV's maintenance handbook (BV 2007b). See Figure 34.

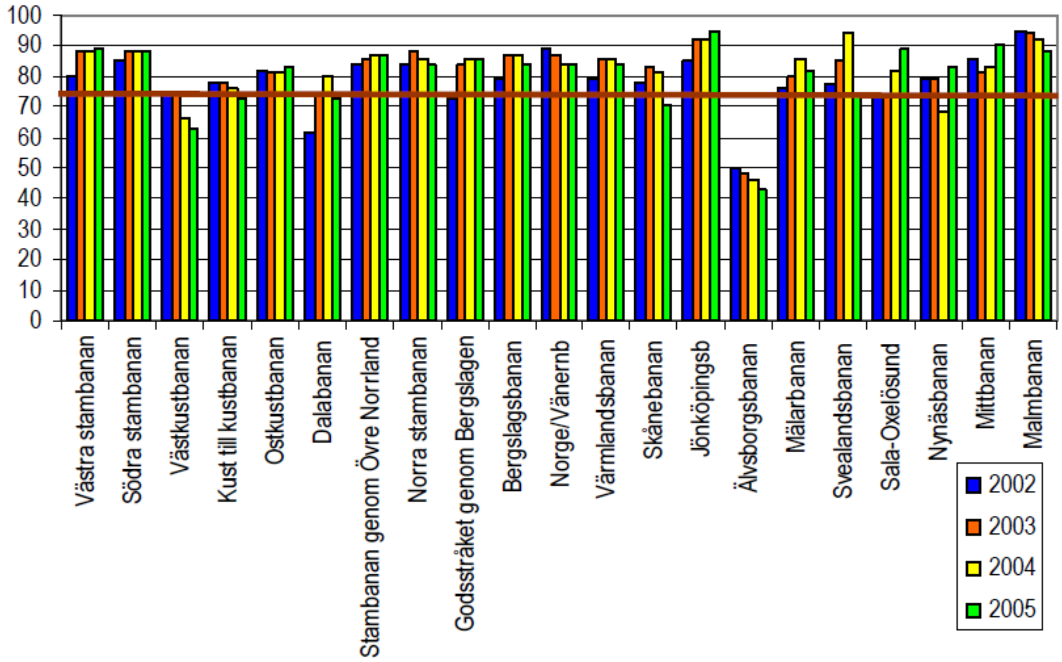


Figure 34: K-value of different lines (BV 2007b).

Another way to calculate the TQI is Nederlandse Spoorwegen's (NS) method (Esveld 2001):

$$QI = 10\left[\frac{QI_{80}}{10}\right]^{\sigma/\sigma_{80}} \quad 0 \le \sigma \le 10 \tag{4.7}$$

Where:

QI = Quality index
σ = Standard deviation
QI_{80} = 6 (by definition)
σ_{80} = Standard deviation at 80 %

The QI has been constructed considering that 20 % of NS's lines are recommended for tamping per annum. Three QIs are calculated, that is: cant, cross level, and alignment (0-25 m). For each 200 m track, the lowest value of the three resulting QIs in the waveband of 0-25 m is considered as the overall QI for the section. Also alignment 25-75 m is used to determine need of lining. For description of some types of track irregularities, see (Iwnicki 2006).

Esveld has proposed another way to calculate the TQI based on normalised standard deviations and peak values (Esveld 2001):

$$\bar{\sigma} = \frac{\sigma}{\sigma_t} \tag{4.8}$$

$$\bar{p} = \frac{p}{p_t} \tag{4.9}$$

Where:

σ_t = Standard deviation standard value (e.g. = σ_{80})
p_t = Peak standard value
$\bar{\sigma}$ = Normalised standard deviation
$\bar{p}$ = Normalised peak value
σ = Standard deviation
p = Peak value

Furthermore, another method to use for the TQI is weighting according to vehicle response (Sato et al. 1987).

Riding comfort can also be measured by qualitative methods. TRV uses questionnaires to measure riding comfort, called customer satisfaction index (CSI) (BV et al. 2009c).

4.3.8 Overall equipment effectiveness and data envelopment analysis

Overall equipment effectiveness (OEE) and data envelopment analysis (DEA) are two common and powerful methods for benchmarking the overall performance of an organisation, internally and externally.

4.3.8.1 Overall railway infrastructure effectiveness

Åhrén and Parida (2009) have proposed a model to calculate the OEE for the maintenance of railway infrastructure, called overall railway infrastructure effectiveness (ORIE). They note: "The ORIE model focuses on the moving time-slots used for traffic operation by the traffic operating company, i.e. the reserved train paths in the timetable". The underlying indicators of the ORIE model are the same as for the ordinary OEE and multiplied in the same way, but their definitions differ. Recalling the formulation of OEE, one defines the ORIE as:

$$ORIE = Availability \times Performance \times Quality = APQ \quad (4.10)$$

Where the factors are defined as:

$$A = \frac{UT - (TDIF + TDOM)}{UT} \quad (4.11)$$

$$P = \frac{TTOT}{TTOT + TDNMR + TDSR} \quad (4.12)$$

$$\begin{cases} Q = \frac{Q_{val}}{Q_{lim}} & \forall \quad Q_{val} < Q_{lim} \\ Q = 1 & \forall \quad Q_{val} \geq Q_{lim} \end{cases} \quad (4.13)$$

Where:

UT = Allocated uptime
TDIF = Down time due to infrastructure failures
TDOM = Down time due to overdue maintenance
TTOT = Scheduled total train operating time
TDNMR = Train delays due to no maintenance required
TDSR = Train delays due to speed reductions
Q_{val} = Measured Q-value
Q_{lim} = Stated Q-value limit

Each underlying indicator ranges from zero to one; thus, the product ORIE ranges from zero to one. The results are given as percentages.

Data for TDOM and TDSR were missing and therefore not taken into account. Åhrén and Parida calculated ORIE for three different railway lines on a monthly basis. They concluded that the ORIE indicator can provide important inputs to IMs after adjustment to meet specific needs (Åhrén et al. 2009b).

4.3.8.2 Data envelopment analysis (DEA)

Data envelopment analysis (DEA) is a non-parametric statistical method for evaluating the efficiency of a set of peer entities called decision-making units (DMUs), or just units, which convert multiple inputs into multiple outputs (Seiford 1990, Cooper et al. 2011).

A measure of efficiency can be given by dividing production output by input. DMUs, e.g. railway sections, can be benchmarked by giving weights to the inputs and outputs. However, finding common weights are normally not possible due to different operational circumstances for each unit. With DEA, relative weights are used by calculating the most favourable weights for each unit subject to the others, making benchmarking possible. Moreover, since DEA is a non-parametric statistical method, it requires fewer assumptions, thus it is more robust.

George et al. (2008) applied DEA on Indian railway zones to benchmark their performance. The inputs were: operating expenses, tractive effort (total horse powers consumed by locomotives), equated track kilometres (total km of track), number of employees, number of passenger carriages and number of wagons. Passenger kilometres and ton kilometres were used as outputs. See work by George et al. (2008) for the resulting operating ratios of the railway zones. A similar study of North American freight railways has been carried out by Malhotra et al. (2009).

Finding the optimum share of preventive maintenance compared to corrective maintenance can be challenging. Preventive and corrective maintenance for systems, like railway sections or switches and crossings, could be used as inputs, together with other inputs, to DEA for studying this subject.

4.3.9 Mean age, prognostics of mean age and service life

The mean age of assets changes over time depending on the operation and maintenance programs and can therefore be used as a lagging indicator if it is updated on a regular or continuous basis. Knowing the mean age, remaining useful life (RUL) is then the difference between expected life and mean age. Expected lifetime is often a constant coming from a prediction or forecast, e.g. by the original equipment manufacturer (OEM), i.e. it is not an indicator.

TRV estimated the mean age and expected life time for the main engineering assets and made predictions for 2015 in their strategic plan of 2004-2015 (BV 2003b). The basis for the calculations is not given. Estimated mean age, predicted mean age and expected life time were given for the following assets: rail, switches and crossings, bridges, superstructures, substructures, power systems and signalling systems. Similar calculations were done in TRV's strategic plan for 2010-2021, but with new equations (BV 2007c, BV et al. 2009c). Furthermore, mean age and age distribution were presented for rails, sleepers, ballast and switches & crossings in TRV's annual report of 2010; see Figure 35 (TRV 2011b). Details are not given but influencing factors have been presented for a number of engineering assets (Riksrevisionen 2010).

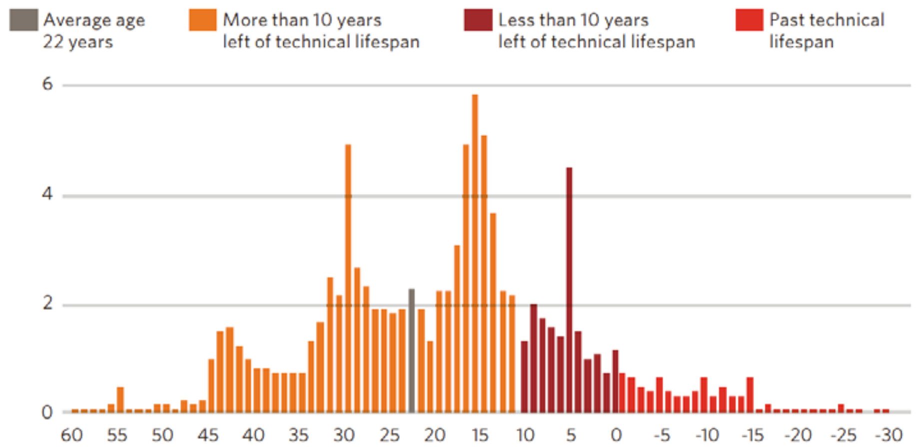


Figure 35: Age distribution for switches and crossings (percentage on the y-axis and years at the x-axis) (TRV 2011b).

According to Riksrevisionen, TRV finds that the mean age of the assets should be kept at half the expected lifetime (Riksrevisionen 2010).

4.4 Organisational indicators

Organisational indicators in this section are mainly considering the maintenance policy and the management of the maintenance. Quantitative indicators should always be complemented with qualitative indicators, like questionnaires. This has special importance in the organisational perspective due to strong human interactions. The quantitative perspective is the main focus in this report, and therefore the other perspective is left out.

4.4.1 Maintenance management

Common indicators of maintenance management are waiting time (Section 4.3.3), maintenance backlog (BSL 2009), schedule compliance (Campbell 1995b) and numbers of workers per manager. Another indicator is, used work time over planned work time for maintenance (Nyström 2009). Besides these indicators, by taking the maintenance or management cost over the total maintenance and management cost, one derives an indicator of organisational efficiency or productivity.

4.4.1.1 Maintenance policy – corrective and preventive maintenance

The number of faults is an essential indicator that is strongly related to corrective maintenance and preventive maintenance. If the number of faults increases, the corrective maintenance work orders will increase at the same time; thus, the corrective maintenance will increase. If the trend of preventive maintenance is negative, it indicates that the number of faults can possibly increase in the near future and vice versa for a positive trend, i.e. indicators of preventive maintenance are leading indicators for the number of faults.

It is preferable to study indicators of corrective maintenance (CM) and preventive maintenance (PM) together since they are correlated and give important inputs to the evaluation of the maintenance policy and strategy. As a general rule, one starts to lose control if the level of corrective maintenance hours is higher than 20 % (Wireman 2003, Espling et al. 2008). Arts et al. (1998) found that appropriate preventive maintenance is about 75-97 %, depending on the assets to maintain. Cooke and Paulsen (1997) described good maintenance practice in terms of two interlinked states: seeing very few corrective maintenance events while performing as little preventive maintenance as possible. Ideally, preventive maintenance should be performed just before the item pass through a functional failure. In addition, indicators related to the maintenance policy and strategy are important for evaluation of the safety, e.g. few corrective maintenance orders increase safety. A calculation of CM versus PM of different lines in Sweden for 2005 are shown in Figure 36 (BV 2007b). The figure gives a good sense of the share of PM and provides a starting point for benchmarking. Comparing this result with costs and failures can give an indication of the appropriate levels of preventive and corrective maintenance.

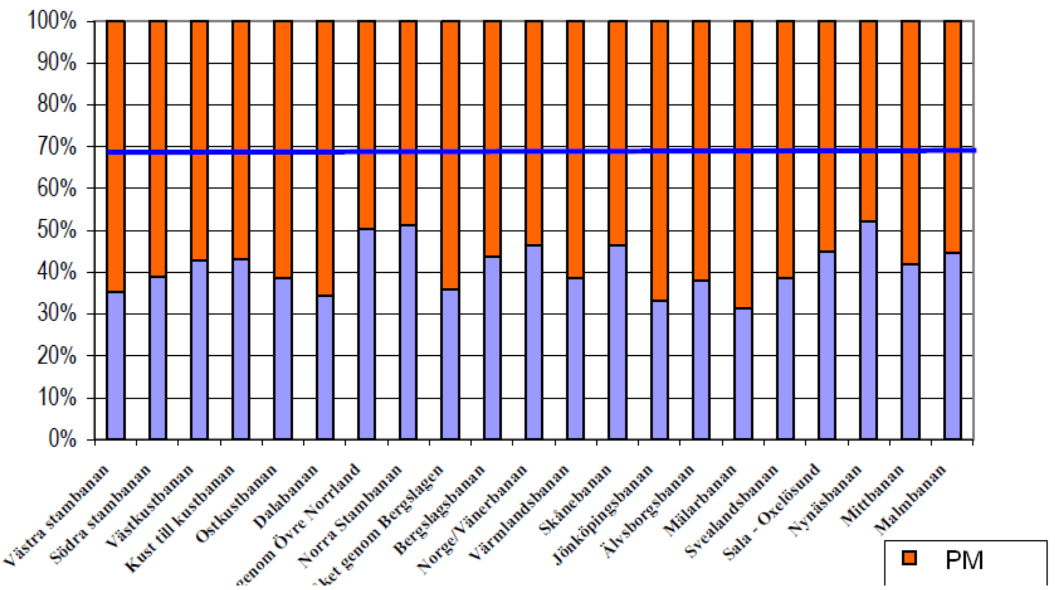


Figure 36: PM (red) and CM (blue) cost of different lines in Sweden for 2005 (BV 2007b).

4.4.1.2 Harmonised corrective maintenance

TRV has developed an indicator for corrective maintenance per harmonised track-km. This is calculated by adding number of failures, urgent inspection remarks and one-week inspection remarks taken over fictitious-track-km (fkm); see Figure 37. A fictitious-track-km is a kilometre of track plus additional track metres for switches and crossings, depending on the type. This indicator is found for 2000-2005 in TRV's maintenance handbook (BV 2007b).

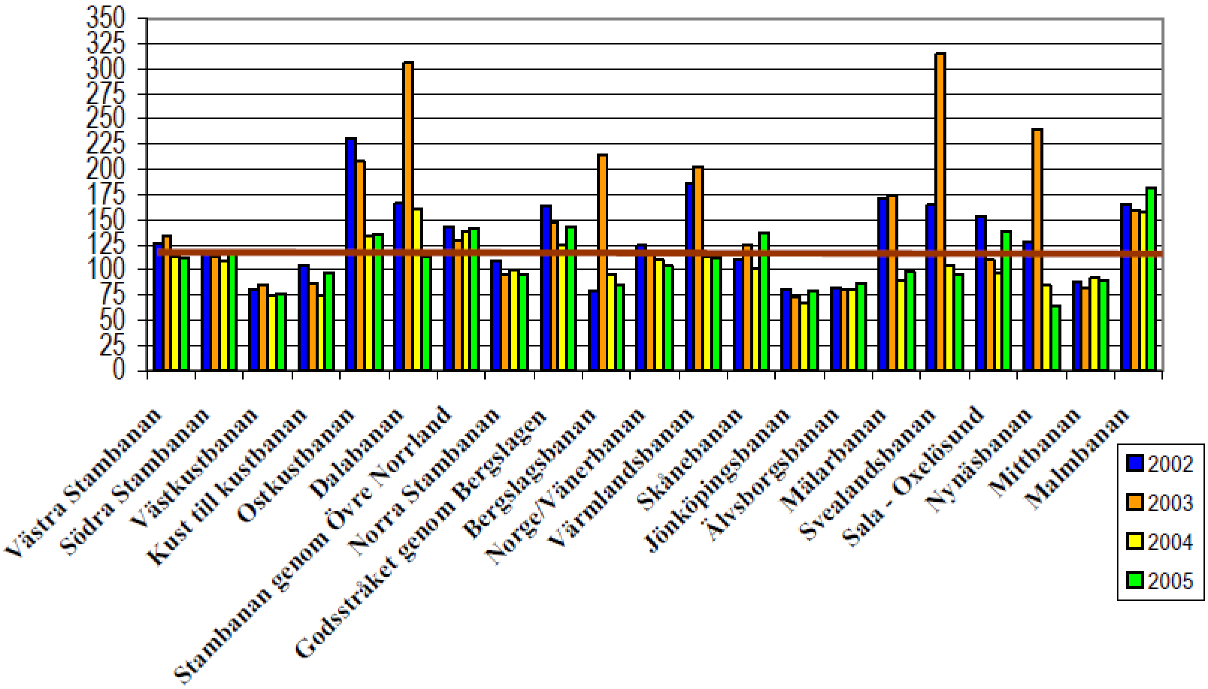


Figure 37: corrective maintenance cost per fictitious-track-km for different lines [Monetary/fkm] (BV 2007b).

4.4.1.3 Maintenance supportability

Maintenance supportability, also known as maintenance support performance, is the ability of a maintenance organisation of having the right maintenance support at the necessary place to perform the required maintenance activity at a given instant of time or during a given time interval (CEN 2011). An important indicator for measuring maintenance supportability is the time from the recognition of a fault until the maintenance work begins; this is called waiting time (WT), organisational readiness, reaction time, arrival time or simply maintenance supportability. Waiting time measures the readiness of the maintenance front line. Waiting times as a result of train disturbing and non-disturbing faults for different geographical regions are given in TRV's maintenance handbook (BV 2007b). See Figures 38-40.

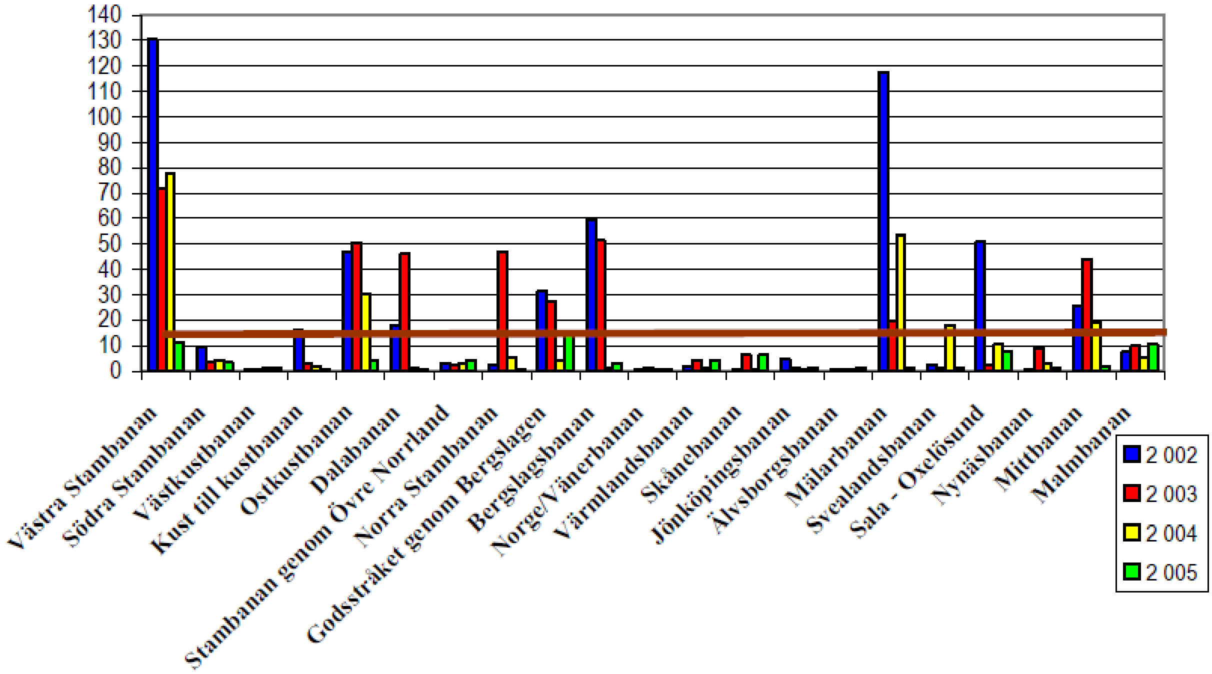


Figure 38: Waiting time for faults interfering with traffic measured in hours (mean) for different lines in Sweden (BV 2007b).

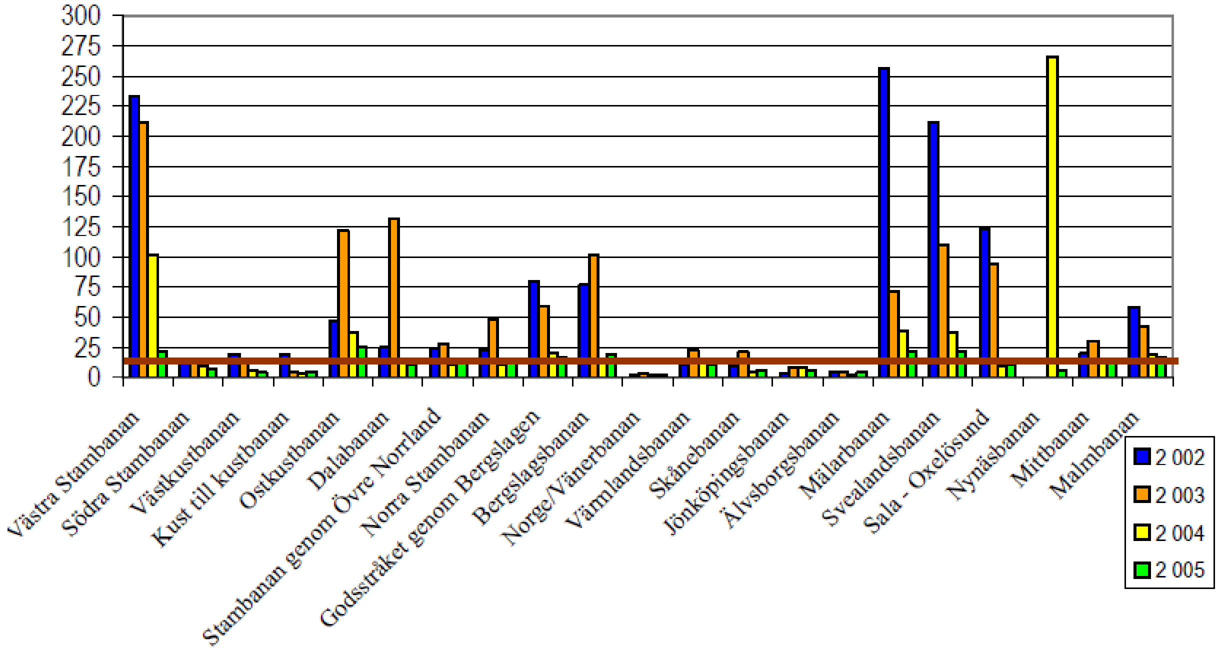


Figure 39: Waiting time for all faults in infrastructure measured in hours (mean) for different lines in Sweden (BV 2007b).

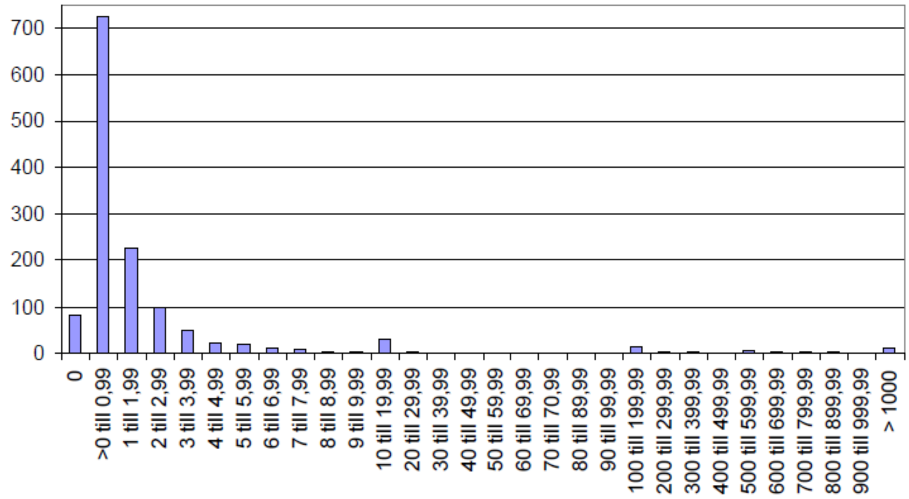


Figure 40: Waiting time for faults in infrastructure put in a histogram (BV 2007b).

A related indicator is waiting time of inspection remarks. Many factors, including safety and cost effectiveness, influence repair requests resulting from inspections. Therefore, it is inaccurate to use the waiting time after inspection to measure maintenance supportability. A better indicator would be the number of inspection remarks that are corrected within the set time, i.e. waiting time within the set time. The set time can be urgent, one week, etc.

4.4.1 Failure reporting process

The failure reporting process should be as efficient as possible to minimise the restoration time of failures, at the same time as the registration of work order data should be complete for future analysis. The reporting process can be analysed by looking into the time from fault notified, contractor notified, repair started, fault rectified and work order closed. Another common measure is to study the quality of the work order data registered in the CMMS.

4.4.1.1 Faults with undetermined cause

A central indicator for the functionality of the reporting system is the number of faults with undetermined cause, related to both CMMS and organisational aspects. See work by Nyström (2008) for details on deviation reporting and delay attribution.

Failures for 2002-2006 with undetermined cause are found in the preplanning of the latest strategic plan of TRV (BV 2007c); see Figure 41. Faults with undetermined cause can also be found in the maintenance handbook of TRV for 2002-2005 for geographical regions (BV 2007b); see Figure 42. To give valuable input, the indicator must be given in relation to all faults and should therefore be expressed in percentage, as in the figure just mentioned.

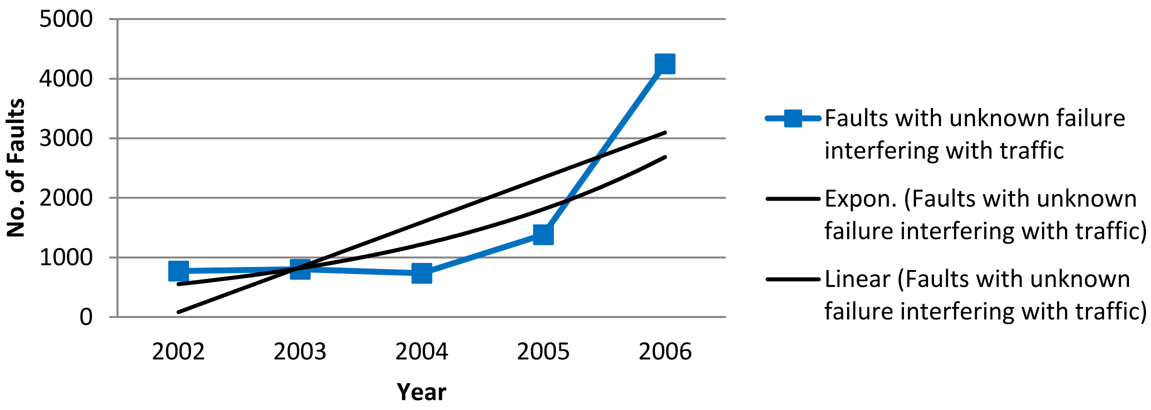


Figure 41: Faults with unknown failure interfering with traffic. The data are from the strategic plan preplanning report of TRV (BV 2007c).

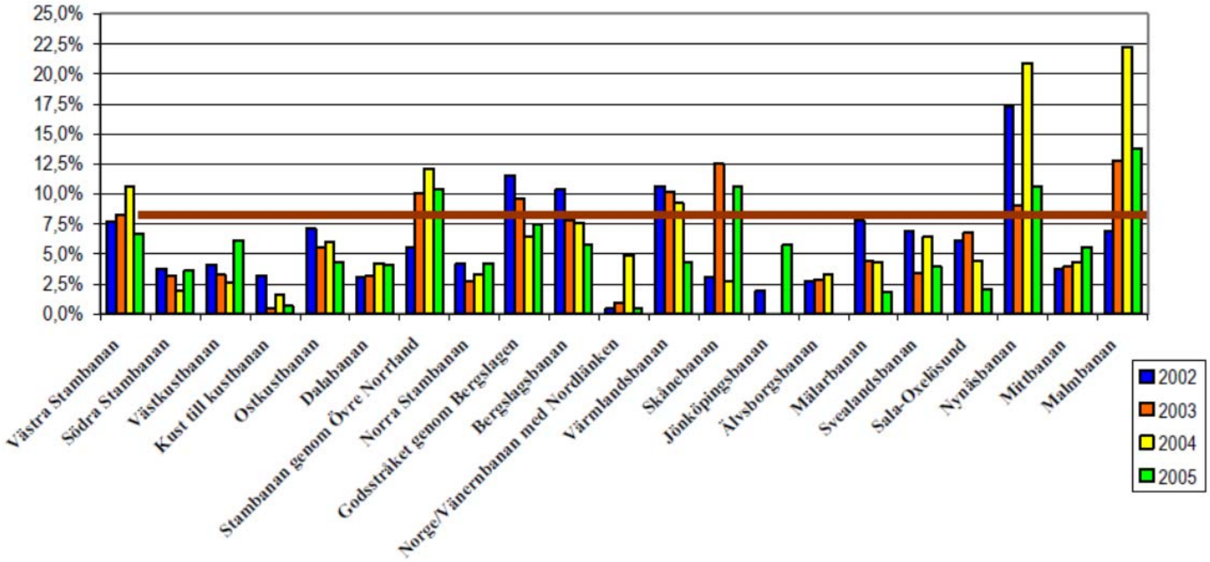


Figure 42: Faults with unknown failure for different lines (BV 2007b).

4.5 Economic indicators

Cost based indicators at an aggregated level are easy to use for benchmarking and to study previous record. Cost indicators found in the annual reports of TRV and its predecessor Banverket include; new investments, reinvestments, maintenance and management. Riksrevisionen has plotted these data for 2002-2009 (Riksrevisionen 2010); the latter three costs are shown in Figure 43. By taking the maintenance or management cost over the total maintenance and management cost, one derives an indicator of organisational efficiency or productivity, similar to the number of workers per manager indicator.

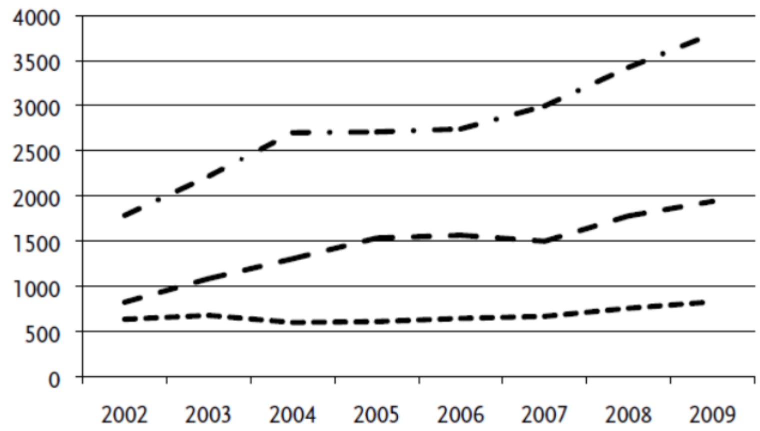


Figure 43: Cost in million SEK for maintenance (upper curve), reinvestments (middle curve) and management (bottom curve) for the Swedish network (Riksrevisionen 2010).

Another set of indicators are maintenance cost per train-km, track-km and fictitious-track-km (fkm). These three indicators are found for 2002-2005 for different regions in TRV's maintenance handbook (BV 2007b). They are similar to the indicator given by Wireman (2003): maintenance cost per square foot maintained. More similar indicators are found in TRV's 2009 annual report: maintenance cost per track-m, reinvestment cost per track-m, maintenance cost per train-km, reinvestment cost per train-km and track access revenues (BV 2010a). Furthermore, several of these indicators are also found in the preplanning report of TRV's current strategic plan, and in addition, maintenance cost per gross-ton-km is presented (BV 2007c).

Track access revenues, traffic management cost per track-km and maintenance cost per gross ton-km are indicators used by SBB in their scorecard agreement with the Swiss Traffic Ministry; see the Asset Management Club Project in Section 5.1.3 (BSL 2009). DB and the Traffic Ministry have agreed upon several indicators presented in the same project: investment-, maintenance- and staff costs.

4.6 Health, safety and environment indicators

Maintenance staff are exposed to hazards and suffer from bad ergonomics due to unstandardized or non-routine work, lowered barriers, leakage, pressure, electricity, etc., thus, HSE has a special importance in the management of maintenance (Galar et al. 2011). General HSE indicators are easy to find and often required by law, but specific ones for maintenance are scarce. Both types are considered in this section.

4.6.1 Health indicators

Common hard indicators for health are absenteeism and employee turnover, measures of employees' psychological and physiological wellbeing. These data for maintenance can easily be obtained from human resources (HR). Another common measure is number of employee talks.

4.6.2 General safety indicators

Urgent and one-week inspection remarks are central leading indicators for assessing the safety of railways. This indicator has been harmonised by TRV by taking the ratio of urgent and one-week inspection remarks over the total track length or a fictitious track length (BV 2007b). This harmonised indicator can be used for benchmarking different geographical regions. Two other indicators used by TRV, deaths and injuries and vehicle damages, are found in the QoS scorecard (BV et al. 2009c). Åhrén and Kumar have identified two further indicators, accidents involving railway vehicles and accidents at level crossings (Åhrén et al. 2004).

One of the best sources for safety statistics is Trafikanalys (Swedish Transport Analysis), as it is responsible for official transport statistics. Overall numbers of deaths, suicides and accidents at railways in Sweden with benchmarks against other types of transportation can be found in Trafikanalys' follow up assessment of national transportation goals (Trafikanalys 2011).

A number of safety indicators have also been presented in the Asset Management Club Project (Section 5.1.3) by SBB; these include collisions with persons involved, derailments with persons involved, unmanned level crossings and casualties.

4.6.3 Specific maintenance safety indicators

The European Standard EN 15341 (Maintenance Key Performance Indicators) gives several safety KPIs specific to maintenance (CEN 2007). Extracted indicators are the following:

$$\mathrm{T5} = \frac{\sum \#_{\mathrm{Maint}}^{\mathrm{Injuries}}}{\sum \mathrm{t}} \quad (4.14) \qquad \mathrm{T5(2)} = \frac{\sum \#_{\mathrm{Maint}}^{\mathrm{Pot\ injuries}}}{\sum \mathrm{t}} \quad (4.15)$$

$$\mathrm{T11} = \frac{\sum \#_{\mathrm{Failure}}^{\mathrm{Injuries}}}{\sum \#_{\mathrm{Failures}}} \quad (4.16) \qquad \mathrm{T12} = \frac{\sum \#_{\mathrm{Failure}}^{\mathrm{Pot\ injuries}}}{\sum \#_{\mathrm{Failures}}} \quad (4.17)$$

The letter T stands for technical indicator. As an example, indicator T5 should be read as: total number of injuries related to maintenance over total time. Indicator T5(2) is a related indicator that have been added here.

Some key safety indicators specific for railways are derailments and bucklings (Office of Rail Regulation 2006, TRV 2010k, Famurewa et al. 2011).

4.6.4 Environment indicators

By examination of annual reports and interviews at TRV, Åhrén and Kumar found three indicators related to the environment: energy consumption per area, use of environmental hazardous materials and use of non-renewable materials (Åhrén et al. 2004). Details were not given.

Environmental indicators mentioned in EN 15341 include (CEN 2007):

$$\mathrm{T13} = \frac{\sum \#_{\mathrm{Failure}}^{\mathrm{Envir\ dmg}}}{\sum \#_{\mathrm{Failures}}} \quad (4.18) \qquad \mathrm{T14} = \frac{\sum \#_{\mathrm{Failure}}^{\mathrm{Pot\ envir\ dmg}}}{\sum \#_{\mathrm{Failures}}} \quad (4.19)$$

Noise and vibration is another environmental issue (Famurewa et al. 2011). While it is not directly related to maintenance, poor track condition can increase the noise and vibration levels from passing trains.

4.7 Railway infrastructure condition indicators

The largest source of technical maintenance indicators are the databases containing railway condition monitoring (CdM) data. Inspection methods, parameters assessed and indicators are brought together in Table 6, in the conclusions (Section 4.9). Deduced indicators are indicators without reference. References used are (BSL 2009, Esveld 2001, INNOTRACK 2008).

The most common technical parameters monitored have been identified by the UIC WG Track Condition Monitoring group. Fifteen European members answered a questionnaire on condition monitoring (UIC 2010b). More than 80 % of the respondents monitored the following parameters:

- Track Geometry
- Rail Profile Side Wear
- Rail Cracks
- Rail Temperature
- Switch Geometry
- Presence of Fasteners
- Catenary/overhead Line Height
- Presence of Obstacles in the Clearance Gauge

Switches and crossings constitute a major part of all failures. Efforts are being made to monitor switches and crossings by using recording cars. Nissen et al. (2010) analysed longitudinal level data from track recording cars and was able to identify the position of switches and crossings, a first step towards switches and crossings condition monitoring.

The bearing capacity of railway substructures can be assessed by measuring the vertical track stiffness (Table 6). See work by Berggren for details regarding methods used by various IMs for measuring the vertical track stiffness (Berggren 2009).

4.8 Traffic information

TRV uses three indicators in its QoS scorecard to measure the performance of traffic information systems: availability of the traffic information system, customer satisfaction index (CSI) and trip-planner (BV et al. 2009c). The first indicator measures availability, as the name implies; the second measures passenger satisfaction through questionnaires; the third measures the number of cities using a trip-planner.

The down time of traffic information systems is found in TRV's 2009 annual report and is presented for each line class (BV 2010a).

These indicators are strongly related to information and communications technology (ICT), not to the function of the railway and operation of trains. For this reason, they are not considered in this work.

4.9 Conclusions

The identified indicators have been brought together in Tables 5 and 6. The grouping follows the structure in Figure 18 (Section 4.2) and the previous sections. In addition, the indicators have been grouped into system, sub-system and component levels. The system level is considered as the whole railway network supervised by an IM. The sub-systems are then the railway lines, classes and specific systems, while the component level is the individual parts of the systems. Some indicators can be found at two levels, while others are only found at one level.

Infrastructure condition indicators (Table 6) come both for mechanical and electrical assets, e.g. track and signalling. This report is focused on the mechanical engineering aspect, thus the electrical systems are out of the scope of this report. Most ocular and measurement instrument inspections have also been left out.

Table 5: Identified managerial indicators related to the maintenance of railway infrastructure.

Category	Indicators (Comments) [Unit]	Reference
Technical indicators		
Availability	**System level**	
	Track availability (or Network availability) [%]	(Nyström 2009, BSL 2009)
	Arrival punctuality [No. or %]	(BV et al. 2009c, Söderholm et al. 2011, BV 2010a)
	Train regularity [No. or %]	(BV 2010a, TRV 2010h)
	Failures in total [No.]	(VTI 2011, Nyström et al. 2003, Granström et al. 2005, Granström 2008, CEN 1999, BV 2003b, BV 2007c)
	Train delay [Time]	
	Delay per owner (Operation centrals, Secondary delays, Infrastructure, Train operators, Accidents and incidents, etc.) [Time/Owner or %/Owner]	
	Faults interfering with traffic [No. or %]	(BV 2007b, Riksrevisionen 2010)
	Temporary speed restrictions (TSRs) [No.]	(BSL 2009)
	Sub-system level	
	Availability per line, line class or area [%/line, class or area]	(BSL 2009)
	Punctuality per line, line class or area [No. or %/line, class or area]	(BV et al. 2009c, BV 2010a)
	Regularity per line, line class or area [No. or %/line, class or area]	(TRV 2010h)
	Failures per Item [No./Item]	(VTI 2011, Nyström et al. 2003, Granström et al. 2005, Granström 2008, BV 2003b, BV 2007c)
	Failures per track-km, line, line class or area [No./track-km, line, class or area]	
	Delay per item [Time/item]	
	Delay per line, line class or area [Time/line, class or area]	
	Temporary speed restrictions (TSRs) per line, line class or area [No./line, class or area]	(BSL 2009)
Maintain-ability	**System level**	
	Mean time to repair (MTTR) (or mean time to maintain (MTTM), or maintainability)	(BV 2007b, INNOTRACK 2009, CEN 1999)
	Sub-system level	
	Mean time to repair (MTTR) per item (or Maintainability)	(BV 2007b, Nyström et al. 2003, INNOTRACK 2009)

Table 5: Continuation.

Category	Indicators (Comments) [Unit]	Reference
Capacity consumption	**System level**	
	Traffic volume [Train-km]	(Åhrén et al. 2004, BV 2010a)
	Sub-system level	
	Traffic volume per line, line class or area [Train-km/line, class or area]	(Åhrén et al. 2004, BV 2010a)
	Train-km per track-m and line class [Train-km/track-m]	(BV 2010a, BV 2007c)
	Tonne-km per track-m and line class [Tonne-km/track-m]	
	Capacity consumption (or Capacity utilisation) (24h and 2h) [%]	(Åhrén et al. 2004, UIC 2004, BV 2010a)
	Harmonised capacity consumption (double track counted twice) [Train-km/track-metre]	(BV 2007b)
Riding comfort	**Sub-system Level**	
	Track quality index (TQI) (e.g. K-/Q-value) [Index]	(BV 2007b, BV 1992, BSL 2009, BV 2007c)
OEE and DEA	**Sub-system level**	
	OEE per line, line class or area [%/line, class or area]	(Åhrén et al. 2009b)
	Data envelopment analysis (DEA) [-]	(George et al. 2008, Malhotra et al. 2009)
Age	**Sub-system level**	
	Mean age of assets (rail, switches and crossings, overhead contact system, ballast, etc.) [Time]	(BV et al. 2009c, BV 2003b, BV 2007c, TRV 2011b)
Organisational indicators		
Maintenance management	**System level**	
	Preventive maint. share (or Corrective maint. share) [%]	(BV 2007b, Unckel 2010)
	Mean waiting time (MWT) (or Maint. supportability, or Org. readiness, or Reaction time, or Arrival time) [Time]	(BV 2007b, INNOTRACK 2009)
	Maintenance backlog [No. or time]	(BSL 2009)
	Maintenance possession overruns [Time or No.]	(Olsson et al. 2004)
	Sub-system level	
	Preventive maint. share (or corrective maint. share) per line, line class, area or item [%/line, class, area or item]	(BV 2007b)
	Mean waiting time (MWT) per line, line class, area or item [Time/line, class, area or item]	
Failure reporting process	**System level**	
	Faults in infrastructure with unknown cause [No. or %]	(BV 2007b, BV 2007c)
	Sub-system level	
	Faults in infrastructure with unknown cause per line, line class, area or item [No. or %/line, class, area or item]	(BV 2007b)

Table 5: Continuation.

Category	Indicators (Comments) [Unit]	Reference
Economic indicators		
Allocation of cost	**System level**	
	Maintenance cost (incl. or excl. management cost) [Monetary]	(BV 2010a, Riksrevisionen 2010, BSL 2009, TRV 2011b)
	Maintenance management cost (or indirect maintenance cost) [Monetary]	(BV 2010a, TRV 2011b)
	Maintenance cost per train-km, track-km, fkm or gross-ton-km [Monetary/train-km, track-km or fkm]	(BV 2007b, BV 2010a, BSL 2009, BV 2007c, Wireman 2003, UIC - LICB 2008)
	Maintenance contractor cost	(TRV 2011b)
	Corrective maintenance cost [Monetary]	(BV 2007a)
	Preventive maintenance cost [Monetary]	
	Sub-system level	
	Maintenance cost per line, line class, area or per item [Monetary/line, class, area or item]	(Nissen 2009a, Nissen 2009b, REMAIN 1998)
HSE indicators		
Health	Maintenance personnel absenteeism [Time or No.]	General
	Maintenance employee turnover [No.]	
	Maintenance employee talks [No.]	
Safety – General	Urgent and one-week inspection remarks [No.]	(BV 2007b)
	Harmonised inspection remarks	
	Deaths and injuries (or Casualties and accidents) [No.]	(BV et al. 2009c, Trafikanalys 2011, BSL 2009, TRV 2011b, Holmgren 2005)
	Vehicle damages [No.]	(BV et al. 2009c)
	Accidents at level crossings [No.]	(Åhrén et al. 2004, BSL 2009)
	Accidents involving railway vehicles [No.]	(Åhrén et al. 2004)
	Incidents (or Mishaps, or Potential injuries) [No.]	(TRV 2011b)
Safety – Maintenance	Maint. accidents and incidents (occurred and potential) [No.]	(Holmgren 2005)
	Failure accidents and incidents (occurred and potential) [No.]	
	Derailments [No.]	(Famurewa et al. 2011, BSL 2009, TRV 2011b)
	Bucklings (or Sun kinks) [No.]	(BSL 2009, TRV 2010k)
Environment	Environmental accidents and incidents due to failure [No.]	General
	Energy consumption per area [J/Area]	(Åhrén et al. 2004)
	Use of environmental hazardous materials [-]	
	Use of non-renewable materials [-]	

Table 6: Railway infrastructure condition indicators assessed. Deduced indicators are indicators without reference.

Features	**Method**	**Parameters (Component level)**	**PIs (Sub-system level)**
Substructure			
Embankment			
Ballast composition	- GPR (automatic)	- Ballast composition (layered structure)	-
Track Stiffness (related to bearing capacity)	- Hydraulic loading (automatic with stops)	- Track deflection/stiffness/ strength	Deduced: Stiffness loss inspection remarks [No. or No./length]
	- Deflectographs (continuous)	- Track deflection/stiffness/ strength and deflection speed	
Ballast contamination	- Thermographic imaging	- Contamination	Deduced: contaminated ballast and bad drainage inspection remarks [no. or no./length]
Moisture content	- Resistivity tomography	- Moisture content (related to drainage)	
Track geometry			
Geometry	- Contact axles - Optical system - Gyroscope sys. - Inertial system	- Gauge - Cross level - Cant - Long. level - Twist - Geometry of rails (spatial pos.) - Alignment - Wheel rail contact profile	- TQI (Track quality index), based on std. dev., commonly for each 200 m. Deduced: - Track geometry inspection remarks [No. or No./km]
	- Failure reporting	- Bucklings (or Sun kinks)	Bucklings [No.]
Track surroundings			
Clearance and signal visibility	- Video sys.	- Vegetation clearance - Signal visibility	- Track surroundings inspection remarks [No. or No./km]
Superstructure			
Rail			
Integrity	- Continuous monitoring using sensors	- Temperature - Longitudinal and lateral disp.	-
	- Ultrasonic inspection	- Discontinuities in central part of head, web, foot and running side	Deduced: Ultrasonic and eddy current inspection remarks [No. or No./km]
	- Eddy current inspection	- Discontinuities in the running surface	
Rail profile, rail surface and fasteners	- Optical profile and surface sys. - LVDT corrugation sys. - Axle box Accelerometers	- Profile - Gauge wear - Running surface wear - Rail inclination - Rail type - Corrugation (amp. and λ)	Deduced: - Inspection remarks requiring grinding [No. or No./km] - Inspection remarks requiring rail replacement [No.] - Inspection remarks requiring component replacement - Rail breaks [No.]
	- Video System	- Rail breaks - Rail joints - Burns/patches - Corrugation - Fastenings	

Table 6: Continuation.

Features	Method	Parameters (Component level)	PIs (Sub-system level)
Switches and crossings			
Geometry and integrity	- Geometry car	- Track deflection at switches and crossings	Deduced: Switches and crossings deflection inspection remarks [No. or No./switches]
	- Continuous monitoring using sensors	Switch blade position; - Contact area between blade and rail - Switch flangeway (open distance) - Operational force - Power and current usage - Residual stress (retaining force) - Detector rods pos.	Deduced: Malfunctions per switch and crossing type [No. or %] (in open, in closed, residual stress, detector rods, power or current consumption)
		- Impacts on frog (wear)	Deduced: Axis passing [No.]
		- Frog fastening force	-
		- Rail temp. and long. forces	
	- Mechatronic system	- Gauge	Switch and crossing total deviation
		- Switch blades groove width	
		- Cross level	
		- Twist	
	- Measuring Instruments	- Switch close clearance - Frog tip geometry	Deduced: Switches and crossings manual inspection remarks [No. or No./switches]
	- Ultrasonic Testing	- Discontinuities at critical spots	
Signalling			
Overhead contact system (OCS)			
Position and condition	- Optical sys. (Laser)	- Vertical and lateral (stagger) position of contact wire - Contact wire thickness - Abrasion patches at contact wire	Deduced: Inspection remarks requiring adjustment or replacements of components [No. or No./km]
	- Video sys.	- Condition of catenary wire, droppers, clamps and contact wire	

4.9.1 Constructing a railway maintenance scorecard

A scorecard, scorebook or scoresheet in business is a statistical record used to measure achievement or progress towards a particular goal (Oxford Dictionary 2011). For a successful MPM-system, it needs to be able to provide the right information at the right time, to the right people, in the right quantity and format (Parida et al. 2004). According to Gillet (2001), Woodhouse found that a human cannot control and monitor more than four to eight indicators at the same time. For these reasons, it is essential to find the right indicators for the different organisational levels, indicators that match the objectives and strategy of the business. With use of a scorecard the top management can oversee the indicators for each responsibility, e.g. operations, maintenance, finance, human resources, etc. The indicators in Tables 5 and 6 have been brought together into a scorecard; see Table 7.

Table 7: Railway infrastructure maintenance scorecard. Dash means that indicators are not applicable or it has not been considered in the report.

Perspective	Aspect	Indicators	
Managerial		**System**	**Sub-system**
Technical	Availability	8	8
	Maintainability	1	1
	Capacity consumption	1	5
	Riding comfort	-	1
	OEE and DEA	-	2
	Age	-	1
Organisational	Maintenance management	4	2
	Failure reporting process	1	1
Economic	Allocation of cost	6	1
HSE	Health	3	-
	Safety – General	7	-
	Safety – Maintenance	4	-
	Environment	4	-
Condition monitoring		**Sub-system**	**Component**
Technical	Substructure	6	16
	Superstructure	10	32
	Rail yards	-	-
	Electrification	-	-
	Signalling	1	4
	Information communication technologies	-	-

4.9.2 Concluding remarks on the indicators

Generally, many indicators are strongly linked to each other and should therefore always be presented together with their previous record. One example is failures and their corresponding delays; another is punctuality and regularity which are negatively correlated to each other.

Increased interoperability and building of a trans-European railway network is a goal of the European Union. The required harmonisation and standardisation of the management of railways have led to increased use of European standards. Standardised railway PIs can make it possible to compare and carry out international benchmarking of European infrastructure managers. See work by Stenström et al. (2012) for comparison of railway infrastructure PIs with the European standard; Maintenance Key Performance Indicators, EN 15341.

Further concluding remarks are put into headings accordingly to previous sections of indicators in this chapter.

4.9.2.1 Availability

A limitation of the train delay indicator is that it does not take into account the specific time during the day when the delay occurs, and therefore, it does not show the effect on passengers on their way to work (BV 2007b).

Delay, punctuality and regularity are closely related to the capacity utilisation of tracks and should therefore be presented together. Additionally, punctuality and regularity can both be presented as a percentage, and can therefore be multiplied to an aggregated measure of effectiveness. The motivation is that cancelling trains can increase the punctuality and vice versa; few cancelled trains can decrease the punctuality. Furthermore, if a track quality index (TQI), e.g. Q-value, is taken into account as a third factor, a measure of overall railway effectiveness (ORE) is received. The formulas are as follows:

$$Railway\ Effectiveness = Regularity^{\ a} \times\ Puctuality^{b} \in [0,1] \tag{4.20}$$

$$ORE = Availability^{\ a} \times\ Performance^{\ b} \times\ Quality^{c} = Regularity^{\ a} \times Punctuality^{b} \times TQI^{\ c} \in [0,1] \tag{4.21}$$

Equations 4.20 and .21 can be calculated as an overall measure of a network, class or line, as well as for specific owners of train cancellations and causes to unpunctuality. The letters a, b and c are constants that can be chosen for giving different weights to the parameters, to satisfy specific needs. See Figure 44 for an example of the principle. The data is the overall punctuality and regularity of the network managed by TRV for Jan 2011 to Jan 2012, coming from TRV's public homepage (TRV 2012b). Comparison with other IMs is not possible since the data is for all different traffic and railway types, which differ from country to country. In this case, it can be seen that the punctuality increases while the regularity decreases, resulting in a quite flat railway effectiveness.

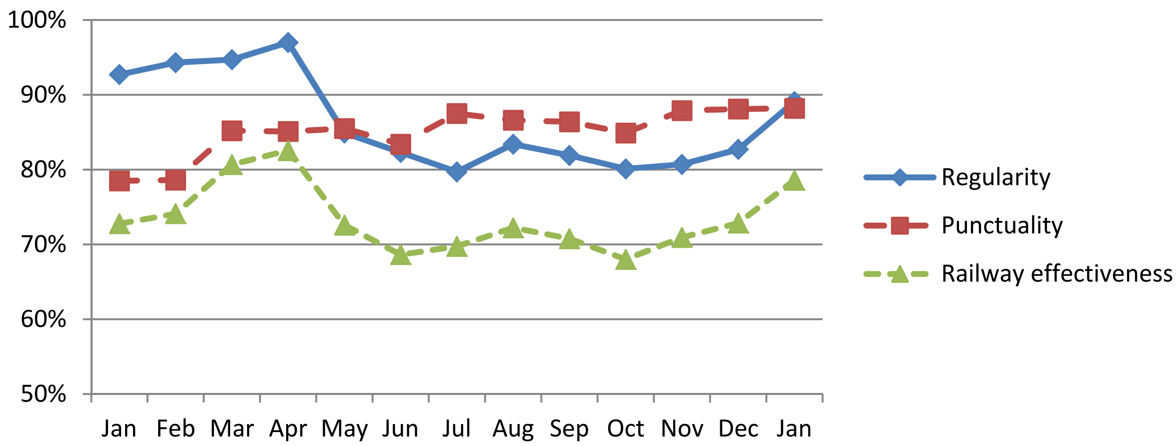


Figure 44: Railway effectiveness of the network managed by TRV from Jan 2011 to Jan 2012.The constants a and b equals one.

4.9.2.2 Capacity consumption

In the future, TRV would like to be able to measure the number of axles passing (BV 2007b). By placing sensors in switches and crossings, this information can be collected at the same time as it gives a measure of the degradation of switches and crossings, e.g. frog wear.

4.9.2.1 Maintenance management

Creating a timetable requires that maintenance work is planned well in advance. Planning after the deadline for requesting time in track is an undesirable ad-hoc process which consumes extra resources. This process can possibly be assessed by measuring the ad-hoc maintenance work in terms of numbers and cost, to complement the other management indicators.

4.9.2.1 Maintenance supportability

Waiting time is used to measure the maintenance supportability when a fault has been identified and issued as immediate corrective maintenance. At TRV, these are faults outside the safety and maintenance inspections. Safety and maintenance inspection remarks are labelled as week, month, etc., referring to the time span when the remarks are going to be rectified. Waiting time cannot be used for these work orders to measure the maintenance supportability. A possible indicator would be to measure the remarks that are corrected within the set time presented as a percentage.

4.9.2.2 Health, safety and environment

Besides the HSE indicators identified above, several other indicators measure safety. The following are some indicators found in other sections:

- Mean Age of Assets
- Faults in Infrastructure
- Faults Interfering with Traffic
- Corrective Maintenance Tasks
- Preventive Maintenance Tasks
- Faults with Undetermined Cause
- Down time (DT)

Some indicators are of a more reactive nature while others are leading indicators. An example is incidents, which can be a leading indicator for accidents.

There are many tools that can be used in risk management: see ISO/IEC 31010 (2009) for comparison of 31 tools and techniques.

5 Scorecards and benchmarking

Benchmarking is often used when comparing something, but to be more strict, benchmarking is to evaluate something by comparison with a benchmark (reference point, or best practice). See EU projects EQUIP (2000), IMPROVERAIL (2001), UTBI (2004) and SuperGreen (2010) for reviews on benchmarking in the railway sector. The benchmarks are focused on the transportation but some maintenance management is also considered.

5.1 Scorecards and aggregation of performance indicators

As discussed in Section 4.9.1, it is essential to find the right indicators for the different organisational levels, indicators that match the objectives and strategy of the business. This is commonly done by starting from the business goal in a top-down and bottom-up manner; see Figure 16 in Chapter 4. The next step is to evaluate the available data and the indicators that can be defined out of it. The data and the operational level indicators have to be aggregated up through the organisation. Hundreds of indicators can be spread throughout the various organisational units on the operational level, but the top management level may have only a few indicators, depending on the structure of the organisation, e.g. number of senior managers and organisational flatness.

The output of the development of a MPM-system is a framework, or scorecard, where indicators are grouped into categories. Some categories of indicators are given here:

- Technical
- Functional
- Strategical level/Top management
- Tactical/middle management
- Functional/supervisors and operators
- BSC perspectives (customer, processes, financial and innovation)
- Business areas
- Key result areas
- Quality
- Productivity
- Health
- Safety
- Environment
- Risk management
- Quantitative
- Qualitative
- Equipment performance
- Process performance
- Cost performance
- etc.

Campbell (1995b) classifies performance indicators into three categories: equipment-, process- and cost performance. Indicators of equipment performance can be availability, reliability and OEE; indicators of process performance can be ratio of planned work and schedule compliance; and examples of cost performance indicators include maintenance labour cost and material cost.

Another way of grouping is into leading and lagging indicators which measure future events and events that already have occurred, respectively. Leading indicators are also known as operational indicators, monitoring the inputs to a process, and lagging indicators are known as financial measures, monitoring the outputs (Kaplan et al. 1996, Kaplan et al. 1992).

5.1.1 The operation and maintenance scorecard of Trafikverket

One of TRV's tools for monitoring the function of the railway is the maintenance scorecard quality of service (QoS) (BV et al. 2009c, TRV 2011i, Söderholm et al. 2011). The scorecard consists of six QoS, each of which has a number of underlying PIs with objectives for 2021; see Table 8.

Table 8: Quality of service (QoS) scorecard and their underlying indicators used by TRV.

Quality of service (QoS)	Performance indicator (PI)	Objectives for line classes		
		Basic	+	++
Punctuality	Punctuality [%]	82	87	93
	Train delay due to infrastructure [h/million-train-km]	120	100	50
Robustness	Down time (or Restoration time) after major disturbance (e.g. storm or landslide) [Days]	8	4	2
Traffic information	Customer satisfaction index (CSI) [Index]	70	80	85
	Trip-planner [No.]	-	-	Available in three large cities in 2012
Riding comfort	Q-value (Track quality index) [Index]	65	85	90
	Customer satisfaction index (CSI) [Index]	50	75	85
Safety	Accidents due to deficiencies in operation or maintenance (deaths or severely injured while travelling or transporting) [No.]	-	-	0
	Vehicle damages due to deficiencies in operation or maintenance [No.]	-	-	Shall decrease
Usability	Availability of services that make travelling possible for all (e.g. escalators, elevators etc.) [%]	99	-	-

5.1.2 Indicators of Trafikverket in relation to balanced scorecards

Åhrén and Kumar (2004) have identified 15 maintenance indicators, out of almost 70 indicators at Banverket, by studying appropriation letters and annual reports. At the time of their work, Banverket had six sub-goals, compared to today's two sub-goals and six QoS (Näringsdepartementet 2008, BV 2009f). Åhrén and Kumar noticed that these six sub-goals were further broken down into 17 goals. Åhrén and Kumar put the 15 recognised maintenance indicators into Banverket's goal structure and related them to Kaplan and Norton's balanced scorecard, as shown in Table 9. Four of the six sub-goals are related to maintenance. The other two are therefore not found in the table.

When Åhrén and Kumar carried out interviews, they identified two more indicators used by Banverket:

- Functional disruptions
- Urgent inspection remarks

Table 9: Maintenance indicators identified by Åhrén et al. (Åhrén et al. 2004).

1st level sub-goals	2nd level sub-goals	Maintenance performance indicators (MPIs)	Relationship to BSC perspectives
An accessible transport system	Improve the use of state infrastructure	Capacity utilisation	Customers
		Capacity restrictions	Customers
A high quality of transport	Decreased train delays	Train delays due to infrastructure	Processes
	Decreased freight traffic disruptions	Hours of freight train delays due to infrastructure	Processes
		Delayed freight trains due to infrastructure	Processes
	Increased rail network maintenance efficiency	Train disruptions due to infrastructure	Processes
		Q-value	Processes
		Markdowns in current standard	Processes
		Maintenance cost per track-km	Processes
		Traffic volume	Financial
Safe traffic	Reduced number of killed and injured persons	Accidents involving railway vehicles	Customers
		Accidents at level crossings	Customers
A sound environment	Reduced energy consumption	Energy consumption per area	Financial
	Effective natural resource consumption	Use of environmental hazardous material	Innovation
		Use of non-renewable materials	Innovation

5.1.3 Scorecards identified through the Asset Management Club Project

In the Asset Management Club Project, the eight European IMs listed below worked together to benchmark their MPM process, condition assessments and LCC (BSL 2009):

- Banedanmark (BD), Denmark
- Trafikverket (TRV), Sweden
- Deutsche Bahn (DB), Germany
- Jernbaneverket (JB), Norway
- Österreichische Bundesbahnen (ÖBB), Austria
- ProRail (PR), Netherlands
- Schweizerische Bundesbahnen (SBB), Switzerland
- Network Rail (NR), United Kingdom

Important aspects of infrastructure performance were identified as:

- Transport Quality
- Safety
- Environment
- Availability
- Asset Reliability
- Activity Volume
- Efficiency
- Staff
- Customer Satisfaction
- Finance

The following sections reflect the chapters of the project report.

5.1.3.1 Scorecard agreements

Three IMs had an agreement with their Traffic Ministry on a defined set of KPIs to use. SBB and the Swiss Traffic Ministry agreed on a defined structure of KPI reporting. The scorecard has 12 KPIs in four categorises; see Table 10. DB's performance and funding agreement with the German Traffic Ministry consists of seven KPIs in two categories (Table 11). KPIs are reported on a monthly basis to the Traffic Ministry. NR's scorecard is called Asset Stewardship Incentive Index (ASII). The ASII weights seven PIs together and NR receives a monetary reward if a certain performance threshold is reached. The PIs and the assets they measure are found in Table 12.

Table 10: SBB's defined scorecard agreement with the Swiss Traffic Ministry (BSL 2009).

Safety	Utilisation
• Collisions with persons involved • Derailments with persons involved • Unmanned Level Crossings • Casualties	• Track-km-sold • Track access revenues
Efficiency	**Productivity**
• Network Availability • Delay minutes caused by infrastructure • Delay minutes caused by safety installations	• Traffic management cots per track-km • Maintenance per gross ton-km • Efficiency of subsidies

Table 11: DB's defined scorecard agreement with the German Traffic Ministry (BSL 2009).

Cost	Quality
• Investment • Maintenance • Staff	• Temporary speed restrictions • Due to infrastructure • Due to regulations • Infrastructure related delay

Table 12: The ASII scorecard of NR and the British Traffic Ministry (BSL 2009).

Track	Signalling
• Track geometry index • No. of broken rails • Level 2 accidences	• No. of signalling failures causing delay of 10 min or more • Switches/track circuit failures
Structures and earthworks	**Electrification**
• Structures & earthworks TSRs (Temporary speed restriction)	• Traction power supply failures on overhead lines & conductor rails causing delay over 500 min

5.1.3.2 Internal scorecards

Scorecards have been provided by TRV, BD, NR and PR. TRV's scorecard has been presented in Sections 5.1.1 (Table 8).

BD has adopted a MPM structure whereby KPIs are broken down in a top-down manner, similar to the multi-criteria hierarchical framework for MPM proposed by Parida and Chattopadhyay (2007). KPIs are split into three levels with different set of KPIs for each asset group, i.e. separate pyramids, as shown in Figure 45. The KPIs of the track are given as an example in Table 13. The number of critical track geometry failures decreased significantly after the introduction of the new KPI system, but details are omitted.

NR and PR's scorecards are found in Tables 14 and 15.

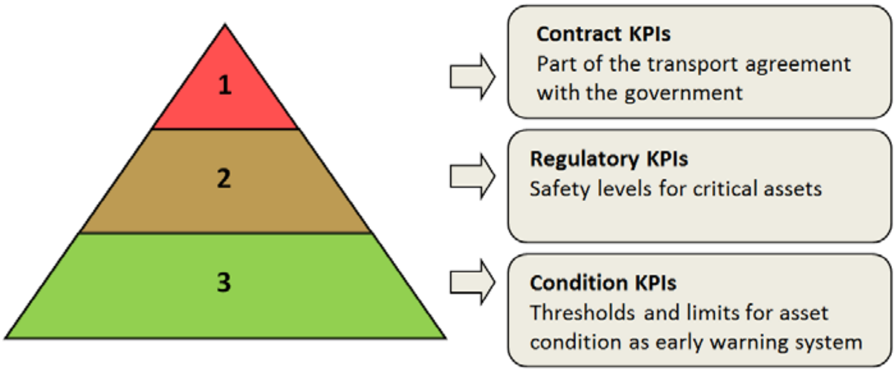


Figure 45: The three KPI levels adopted by BD. Adapted from (BSL 2009).

Table 13: KPI levels of the track used by BD (BSL 2009).

Level	Indicator	Unit
1st level	• Train delay • Number of TSR	[No.] [No.]
2nd level	• Track geometry resulting in TSR • Rail condition critical • Ballast profile deviation • Switches and crossings condition	[No./100 km] [No./100 km] [No./100 km] [% failing]
3rd level	• Track geometry abnormal • Track geometry class-4 fail • Rail condition abnormal • Critical 2-block sleeper • Condition of level crossings	[% of failing 250 m sections] [No./100km] [No./100 km] [No./100 km] [% crossings >2.5]

Table 14: NR's scorecard (BSL 2009).

Group	Indicator	Unit
Train performance	• Public performance measure • Train delay minutes • Reliability	[%] [Minutes in millions] [Index]
Asset failure	• Asset failures	[No.]
Asset quality	• Asset stewardship incentive index (ASII)	[%]
Activity volumes	• % of Activity compared with plan	[%]
Finance and efficiency	• Debt to RAB ratio • Financial efficiency index (FEI) • RAB adjustment for passenger volume incentive • RAB adjustment for freight volume incentive • Expenditure variance	[%] [Index] [Monetary] [Monetary] [Monetary]
Customer satisfaction	• Customer satisfaction – Train operators • Customer satisfaction – Freight operators	[Index] [Index]

Table 15: PR's 10 KPI scorecard used on regional level (BSL 2009).

Group	Indicator	Unit
Availability	• Track availability • Train affecting failures • Planned maintenance	[%] [%] [%]
Customer satisfaction	• Cleanliness station • Social security stations – Day • Social security stations – Night • Rating by local councils	[Index] [Index] [Index] [Under development]
Safety	• Electrocutions • Train-train collisions • Number of derailment	[No.] [No.] [No.]

5.1.3.3 KPIs for tracks

The working group of the Asset Management Club Project have put together the railway infrastructure related KPIs used by the different IMs.

Indicators used by JB to measure the track condition are the following (units not given):

- Q-value
- K-factor
- Buckling
- Excess width of track gauge
- Rail breaks
- Lateral track displacement
- Ballast fines
- Catenary failures
- Signalling failures
- Avalanches

JB uses a number of indicators and thresholds for the different line classes, all based on the standard deviation of track parameters. The indicators, or parameters, are the following:

- Longitudinal level (σ H) [mm]
- Variation of cant (σ R) [mm]
- Alignment (σ V) [mm]
- Cooperative parameter (σ S) [mm]

SBB uses the following three indicators for tracks:

- Track geometry (T)
- Delay minutes [Min]
- Renewal rate [%] (Annual renewed track over total track length)

5.1.3.4 Key findings

Some key findings used by IMs to monitor the tracks are the following (BSL 2009):

- All IMs use line classes according to traffic and utilisation to differentiate inspection frequencies and to prioritise activities
- Linking performance related KPIs on different levels and using them as a controlling instrument for governmental funding is still in the early stages
- Internally, KPIs create a link between targets and activities
- KPI-systems covering different aspects on each organisational level have much to offer, e.g. improved performance and simplified and transparent reporting
- Systematic data recording and evaluations have a huge cost saving potential if it is used for asset degradation behaviour
- There is a large gap between status quo and realising the full potential of available condition information

5.1.3.5 Line classification

Most railways use line classes to differentiate between sections. In the Asset Management Club Project, the eight IMs categorised their network into classes based on different criteria. The number of line classes varied from three to twelve among the IMs. ÖBB presented quantitative indicators for its line classification, which are:

- Tons per day [tons/day] (used by ÖBB)
- Train speed [km/h] (used by ÖBB)
- Tilting trains [boolean] (used by ÖBB)

5.2 PIs used for benchmarking

The railway infrastructure is different for lines, regions and countries, and it changes over time as a result of reinvestments. This affects the maintenance cost, number of failures, delays, etc. This call for the use of harmonised indicators which are constructed by taking into account factors like: number of switches and crossings, bridges, tunnels, etc.; percentage of single track; and percentage of high-speed rail (HSR). A maintenance policy that stresses on use of standardised indicators and methods facilitates internal and external benchmarking.

5.2.1 UIC project – Lasting Infrastructure Cost Benchmarking

Lasting Infrastructure Cost Benchmarking (LICB) is a benchmarking project carried out by UIC with 14 European IMs participating (UIC - LICB 2008). Maintenance and renewal costs per track-km were harmonised for single track/double tracks, switches and crossings, etc., but details are not given due to confidentiality. See Figure 46. The letters corresponds to the IMs.

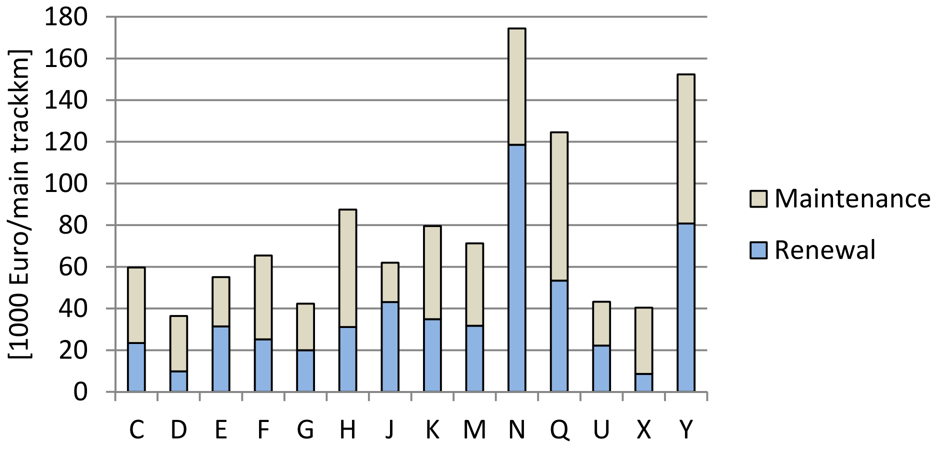


Figure 46: Harmonised LCC per main track-km for European IMs. The letters corresponds to the IMs. Adapted from (UIC - LICB 2008).

5.2.2 Benchmarking for Narvik – Kiruna railway track line

Åhrén and Parida have done benchmarking for Narvik – Kiruna railway line that crosses the Norwegian – Swedish boarder, using the following six indicators (Åhrén et al. 2009a):

- Snow removal cost / total maintenance cost (%)
- Preventive maintenance (%)
- Corrective maintenance, including stand-by organisation for immediate emergency maintenance (%)
- Maintenance cost / track meter (currency/m)
- Reinvestment cost / total track budget (%)
- Employees for maintenance of railway line

Details of the indicators are not given.

6 Discussion and conclusions

This report starts with a look at Trafikverket's (TRV's) maintenance management of the railway infrastructure in Sweden, including its mission, vision, policies, goals, objectives, business strategy, etc., with consideration to the European Union transport policies (Chapters 2 and 3). A more detailed look has been carried by review of maintenance performance indicators used by researchers in the field of railway maintenance, as well as reviewing European railway project reports and also documentations of TRV, like policy documents, handbooks, etc. (Chapter 4). TRV are also using a number of enterprise resource planning systems, with integrated analysis tools, to manage the railways; this have been lightly described in Section 2.5 and Chapter 3. Here follows the results, conclusions and future research of the report:

Results:

- High level mapping, or description, of the maintenance processes at TRV has been carried out in Chapter 3.
- Reasons of having a well defined and organised maintenance performance measurement system are discussed in Chapter 4. As outputs from the discussion, high level requirements and steps to organise, or reorganise, such systems are presented in Figures 14 and 15, as well as an illustration of a top-down – bottom-up Figure 16.
- Railway infrastructure maintenance performance indicators used by IMs and researchers have been identified through exploratory and qualitative review of literature. Concluded in Tables 5 and 6 (Section 4.9), and brought together into a scorecard in Table 7 (Section 4.9.1). How the indicators have been grouped and the reasons behind can be found in Section 4.1 and Figure 18. Concluding comments on railway infrastructure maintenance performance indicators are found in Section 4.9.2.
- Scorecards and benchmarking considering railway infrastructure maintenance performance measurement of other research projects have been exploratory and qualitative reviewed in Chapter 5.

Conclusions:

- Punctuality and regularity are preferably studied together, with the owners of the train cancellations and causes to unpunctuality. The motivation is that cancelling trains can increase the punctuality and vice versa; few cancelled trains can decrease the punctuality (Section 4.9.2.1). Negatively correlated indicators should therefore be presented together, e.g. punctuality and regularity. Suboptimising could be hindered in this way.
- Throughout the literature review (Chapter 4) of quantitative research projects with statistical results, it has been observed that the raw data cleaning process is sometimes left out, making the quality of the output by some means unknown.
- A benefit of regularly updating indicators is that current performance can be compared with previous performance, and also that trends can be studied. As a result of new better ways of measuring, changed objectives, or due to organisational changes, the way that indicators are calculated can be changed. The benefits of measuring can then

be lost, and therefore the old ways of calculating should be kept and presented with the new ways of calculating for a period of time, i.e. overlapping. Some indicators can give a good record for trend studies quite fast, while others need several years to be trustworthy.

Future work:

- Indicators for maintenance of railway infrastructure have been identified in Chapter 4, but none of them have been studied in detail, thus the indicators need to be studied closer, e.g. for purpose, importance, advantages, disadvantages, target levels, formula, frequency, etc.

- Standardised maintenance performance indicators and corresponding limits, or benchmarks, are lacking for railway infrastructure. Work on standardisation, similar to the European standard EN 15341 and the Harmonisation project, could increase the maintenance performance, and thus the capacity of railway networks where it is applied (CEN 2007, Kahn et al. 2011). A starting point could be to compare railway infrastructure indicators with the indicators of EN 15341, see Stenström et al. (2012).

- An indicator for the overall railway infrastructure effectiveness (ORIE) has been presented by Åhrén et al. (2009b). Once adjusted for specific needs, the indicator can provide important inputs to IMs. As discussed in Section 4.9.2.1, another way to calculate effectiveness is by taking the product of regularity and punctuality, giving a measure of railway effectiveness. If a track quality index, e.g. Q-value, is also taken into consideration, a measure of overall railway effectiveness is received. These methods can be further evaluated to see if they can support railway operations. See Figure 44 for an example.

- Knowing and finding the optimum share of preventive maintenance compared to corrective maintenance for different systems, such as railway sections or systems like switches and crossings, can be challenging. Benchmarking is a method that can be used to study this subject, where one method is to use production efficiency, given as production output divided by input. Benchmarking of different systems is then possible by comparing the efficiencies. However, finding common weights for the inputs and outputs are normally not possible due to different operational circumstances for each unit. With data envelopment analysis (DEA), relative weights are used by calculating the most favourable weights for each unit subject to the others, making benchmarking possible. DEA is a non-parametric statistical method that can be studied for its possibility to be used in this topic.

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A Terminology

This appendix explains some technical terms in maintenance management. Some terms are fundamental while others are less common but important in their respective engineering or managerial field. Sometimes a term that seems self-explanatory has a more complex meaning.

Basic definitions related to maintenance performance measurement (MPM) and management are given in Table A.1. Terminology related to railways are given in Table A.2

Table A.1: Terminology of maintenance, repair and operations.

Term	Description	Reference
Asset management	Systematic and coordinated activities and practices through which an organisation optimally manages its assets and their associated performance, risks and expenditures over their lifecycle for the purpose of delivering the organisation's business objectives.	(PAS 55-1 2008)
	Note: Five more descriptions can be found in (Kivits 2008).	
Audit	A systematic and independent examination to determine whether the procedures specific to the requirements of a product comply with the planned arrangements, are implemented effectively and are suitable to achieve the specified objectives.	(CEN 1999)
Availability	The ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided.	(IEC 1990a, CEN 2011, IEC 1990b)
Best practice	Best operating practices that, when implemented, produce superior performance. Also known as dantotsu from the Japanese.	(Bogan et al. 1994)
Benchmark	A standard or point of reference against which things may be compared.	(Oxford Dictionary 2011)
Benchmarking	The continuous process of measuring products, services, and practices against the toughest competitors or those companies recognised as industry leaders.	(Camp 1989)
	The process of seeking out and studying the best internal and external practices that produce superior performance.	(Bogan et al. 1994)
Computerised maintenance management system (CMMS)	Computer program used for planning of maintenance works, work orders handling and analysis.	-

Table A.1: Continuation.

Critical success factor (CSF)	CSFs thus are, for any business, the limited number of areas in which results, if they are satisfactory, will insure successful competitive performance for the organisation. They are the few areas where things must go right for the business to flourish.	(Rockart 1979)
	Key success factors are those variables which management can influence through its decisions that can affect significantly the overall competitive positions of the various firms in an industry.	(Hofer et al. 1978)
	Also known as key variables, key result areas (KRAs), strategic factors and pulse points (Anthony et al. 1972, Leidecker et al. 1984). KRAs are commonly few areas where most of the results are visualised, whereas the CSFs are the factors to achieve the objectives of the KRAs.	
Dependability	Collective term used to describe the availability and its influencing factors: reliability, maintainability and maintenance supportability. Note: Dependability is used only for general descriptions in non-quantitative terms.	(CEN 2011)
Down time (DT)	The time interval during which an item is in a down state.	(IEC 1990a, CEN 2011)
Failure	Termination of the ability of an item to perform a required function. Note: Failure is an event, as distinguished from "fault", which is a state.	(CEN 2011)
Fault	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.	(CEN 2011)
Inspection	Check for conformity by measuring, observing, testing or gauging the relevant characteristics of an item. NOTE: Generally inspection can be carried out on before, during or after other maintenance activity.	(CEN 2011)
Item	Any part, component, device, subsystem, functional unit, equipment or system that can be individually considered. Note: A number of items, e.g. a population of items or a sample, may itself be considered as an item.	(IEC 1990a, CEN 2011)
Key result area (KRA)	See critical success factor (CSF).	-
Maintainability	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. Note: The maintainability is also used as a measure of maintainability performance.	(IEC 1990a, CEN 2011)

Table A.1: Continuation.

Maintenance	The combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function.	(IEC 1990a)
Maintenance management	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 economic aspects.	(CEN 2011)
Maintenance supportability	Ability of a maintenance organisation of having the right maintenance support at the necessary place to perform the required maintenance activity at a given instant of time or during a given time interval. Also known as maintenance support performance.	(CEN 2011)
Performance driver	A supporting input element to a process, driving the process or business performance	(Stenström et al. 2011)
Performance killer	An input element to a process that performs poorly or hinders performance. Note: Similar to cost driver but more intangible since it does not directly affect costs.	(Stenström et al. 2011)
Policy	A policy is a course or principle of action adopted or proposed by an organisation or individual.	(Oxford Dictionary 2011)
	A policy answers what an organisation's desired outcomes are, forming a basis for the objectives and strategies that answer the how, where and when.	-
Prognostics	Engineering discipline of predicting the time at which an item will no longer perform its required function.	-
Process	A set of interrelated tasks that, together, transform inputs into outputs.	(EIA 1999)
RAMS	An acronym meaning a combination of Reliability, Availability, Maintainability and Safety.	(CEN 1999)
Rate of occurrence of failure	Number of failures of an item in a given time interval divided by the time interval.	(CEN 2011)
Reliability	The ability of an item to perform a required function under given conditions for a given time interval.	(IEC 1990a)
Safety	Freedom from unacceptable risk of harm.	(CEN 1999)
Service	Actions that prevents an accelerated degradation by removing dirt, water, snow and other debris without restoring the actual function of the asset.	(INNOTRACK 2009)

Table A.2: Terminology related to railway operation and maintenance.

Term	Description	Reference
Capacity	The total number of possible paths in a defined time window, considering the actual path mix or known developments respectively and the IM's own assumptions; in nodes, individual lines or part of the network; with market-oriented quality.	(UIC 2004)
	Capacity is a measure of the ability to move a specific amount of traffic over a defined rail line with a given set of resources under a specific service plan.	(Krueger 1999)
Fictitious-track-km (fkm)	A fictitious-track-km (fkm) is a kilometre of track plus additional track meters for switches and crossings depending on the type.	(BV 2007b)
Infrastructure manager (IM)	Any public body or undertaking responsible in particular for establishing and maintaining railway infrastructure, as well as for operating the control and safety systems. The functions of the infrastructure manager on a network or a part of a network may be allocated to different bodies or undertakings.	(European Commission 1991)
Inspection class	TRV uses five different inspection classes, B1-5, which are a function of train speed and traffic volume.	(BV 2005 and 2007)
Junctions	Point of a network in which at least two lines converge and neither overtaking, neither crossing nor direction reversals are possible.	(UIC 2004)
Line	A link between two large nodes and usually the sum of more than one line section.	(UIC 2004)
Line class, or Line type	Most railways use line classes, or categories, to differentiate and prioritise their network.	(BSL 2009)
Network statement (JNB)	According to the Council Directive 2001/14/EC, each rail IM is obligated to publish a description of the railway network, or Network Statement (JNB) as it is called, in collaboration with concerned stakeholders. These are primarily those who require railway capacity.	(Europeiska kommissionen 2001, European Commission 2001, Näringsdepartementet 2004)
Nodes	Points of a network in which at least two lines converge. Nodes can be stations or junctions. They can be differently-sized, depending on the number of converging lines and their tasks.	(UIC 2004)
Stations	Points of a network where overtaking, crossing or direction reversals are possible, including marshalling yards.	(UIC 2004)
Une-track-length	In the une-track length, the length of double tracks is counted twice and single tracks are counted one time.	(BV 2007b)
UBA	Maintenance Need Analysis. The UBA is an input to the BAP.	(TRV 2010l)

Table A.2: Continuation.

BAP	Planning of Engineering Works. Consists of the PSB and Ad hoc engineering works.	(TRV 2010l)
PSB	Planning of Major Engineering Works. The PSB is a part of BAP.	(TRV 2010l)
BUP	Track Use Plan. BUP shows the planned engineering works.	(TRV 2010l)