

Maintenance performance indicators  
(MPIs) for railway infrastructure:  
identification and analysis for improvement

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DOCTORAL THESIS

**MAINTENANCE PERFORMANCE INDICATORS (MPIs)  
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## PREFACE

The research work presented in this thesis has been carried out at Luleå Railway Research Center (JVTC) and the Division of Operation and Maintenance Engineering, Luleå University of Technology. The research has been sponsored by Banverket (the Swedish National Rail Administration), which is gratefully acknowledged.

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Thomas Åhrén  
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## ABSTRACT

With the increasing awareness that maintenance not only ensures safety and track performance, but also creates additional value in the business process, many infrastructure managers and owners are treating maintenance as an integral part of the business process. This is also true of Banverket (the Swedish National Rail Administration). One key issue for Banverket is to verify that the undertaken maintenance activities provide the expected results, measured through maintenance performance indicators (MPI) related to technical, economical, and organizational issues. It is also necessary to classify the degree of effect for every single MPI, i.e. to create a logical cause-and-effect structure.

The main purpose of this research work is to identify and study the existing operation and maintenance performance indicators related to railway infrastructure, and their application in the short-term and long-term perspective, to analyze their usefulness for the operation and maintenance planning of the railway infrastructure. Furthermore, the study is to find a structured, reliable, and cost-effective method using maintenance performance indicators (MPI) such as OEE-values to facilitate the operation and maintenance decision-making process, both in the short-term and long-term perspective, for the railway infrastructure management.

A study at Banverket shows that, out of the 17 MPIs identified, 10 MPIs are in use, eight of which match the MPIs identified through the documents and two of which were identified through interviews. Two case studies conducted at Banverket and Jernbaneverket, the Norwegian rail administration, show that it is possible to quantify and benchmark MPIs between different countries. The comparison from the Iron Ore Line (Malmbanan) between Kiruna and Narvik indicated more or less the same rail- and track-related maintenance costs per track kilometre in Norway as in Sweden. The overhead cost per track kilometre results in 12 times higher costs for Jernbaneverket due to the different track length in Norway and Sweden, although the number of employees in the work force of the infrastructure manager organization was almost the same in both countries.

A case study evaluating technical and financial aspects of grinding campaigns on the track section between Kiruna and Riksgränsen shows that the grinding campaign postpones major rail replacement activities into the future. The yearly cost for grinding and renewal is an example of an aggregated MPI that can be used for future follow-ups and benchmarking. The grinding campaign itself seems not to affect the total system in a negative way.

One important issue for the infrastructure manager is to focus on the overall railway infrastructure effectiveness. A model for calculating the overall railway infrastructure effectiveness (ORIE) is presented in this thesis. Case studies performed on three track sections show similar ORIE figures that are significantly higher than the industrial OEE, and such high values are required for a punctual railway transportation system. The study indicates that ORIE must be calculated on a monthly basis. The findings of the ORIE study and calculation are ORIE values of 89.7 - 100%. The findings indicate that ORIE can be used as a key performance indicator by the railway infrastructure

manager. It is also visualized that ORIE can provide important input and support in decision making for the infrastructure managers.

A link and effect model (LinkEM) is proposed for railway infrastructure maintenance, which supports the overall objectives and focuses on critical strategic areas determined by the nature of the railway industry and public requirements and regulations.

To conclude, in this research study relevant MPIS for the effective management of the operation and maintenance of the railway infrastructure are identified and analyzed. Further, models like LinkEM and ORIE are proposed for the railway infrastructure managers to facilitate the decision-making.

*Keywords:* Maintenance, railway infrastructure, KPI, performance indicators, link and effect, LinkEM, ORIE, OEE



## SAMMANFATTNING

Infrastrukturförvaltare av järnväg ser idag underhåll som en värdeskapande och integrerad del av hela förvaltningsverksamheten för att uppfylla kundernas krav och förväntningar. En central uppgift för Banverket är att verifiera att genomförda underhållsåtgärder ger önskat resultat ur tekniska, ekonomiska och organisatoriska perspektiv. Ett sätt att mäta detta är att använda underhållsrelaterade indikatorer (MPIs, maintenance performance indicators). Det är därför viktigt att dessa indikatorer förmår koppla och visa effekter av genomförda underhållsaktiviteter, dvs. förmår visa underhållsrelaterade orsak-verkansamband.

En studie genomförd på Banverket visar att utav 17 identifierade MPIs så används 10 stycken. Åtta av dessa är identifierade i Banverkets egna dokument medan de två övriga är identifierade genom intervjuer. Två genomförda studier på Banverket och Jernbaneverket visar att det är möjligt att kvantifiera och jämföra MPIs mellan olika länder med hjälp utav benchmarking. Jämförelsen visar att underhållskostnaderna per spårmeter är ungefärligen lika stora på svensk och norsk sida för Malmbanan. En liknande jämförelse av overheadkostnaderna visar att kostnaderna på den norska sidan är ungefär 12 gånger högre per spårmeter räknat. En jämförelse av organisationernas storlek till antalet anställda visar dock att de är ungefärligen jämstora.

En teknisk och ekonomisk utvärdering av genomförda rälsslipningskampanjer på sträckan mellan Kiruna och Riksgränsen visar att rälsslipning kan fördröja behovet av utbyte av räl. Den årliga kostnaden för rälsbyte är ett exempel på MPIs som kan användas för uppföljning och benchmarking. Genomförda rälsslipningskampanjer ser inte ut att påverka järnvägssystemet som helhet på något negativt sätt.

En viktig fråga för infrastrukturförvaltare av järnväg är att kunna mäta järnvägssystemets effektivitet. En modell för att kunna mäta just detta presenteras i denna avhandling, dvs en så kallad ORIE-modell (overall railway infrastructure effectiveness eller infrastruktureffektivitet för järnväg). Genomförda studier och simulering på bandelnivå visar på höga och jämförbara ORIE-värden för de olika bandelarna, vilka för övrigt är påtagligt högre än för motsvarande OEE-värden för exempelvis tillverkande industri. Studien påvisar att ORIE-värdena bör beräknas per månad och att de kan användas som MPIs. Resultaten visar på ORIE-värden mellan 89,7 – 100 %. ORIE-värden kan därmed utgöra ett bra beslutsstöd för järnvägens infrastrukturförvaltare.

Ett förslag på en länk- och effektmodell för järnvägsinfrastruktur vilken stödjer övergripande mål för verksamheten och som fokuserar på strategiska områden utifrån järnvägens förutsättningar presenteras i denna avhandling.

Sammanfattningsvis så har denna studie identifierat ett antal MPIs som används av infrastrukturförvaltare av järnväg. Koncept och modeller såsom LinkEM, ORIE och benchmarking har applicerats på och genererat resultat användbara för infrastrukturförvaltare av järnväg.



## LIST OF APPENDED PAPERS

### **Paper I:**

Åhrén, T., Waara, P. and Larsson, P.-O. (2003) Technical and economic evaluation of maintenance for rail and wheels on Malmbanan. *Conference proceedings of International Heavy Haul Association Specialist Technical Session (IHHA STS 2003)*, Dallas, USA, 5-7 May, pp. 5.81-5.86.

Thomas Åhrén performed the economic evaluation, Patric Waara carried out the technical evaluation, and P-O Larsson provided support and feedback.

### **Paper II:**

Åhrén, T. and Kumar, U. (2004) Use of maintenance performance indicators: a case study at Banverket. *Conference proceedings of the 5th Asia-Pacific Industrial Engineering and Management Systems Conference (APIEMS2004)*, Gold Coast, Australia, 12-15 Dec., pp. 30.8.1-30.8.9.

Thomas Åhrén performed the case study and Uday Kumar provided supporting discussions and feedback.

### **Paper III:**

Åhrén, T. and Parida, A. (2008a) Maintenance performance indicators (MPI) for benchmarking the railway infrastructure – a case study. *Accepted for publication in Benchmarking: an International Journal*.

Thomas Åhrén performed the case study and Aditya Parida provided supporting discussions and feedback.

### **Paper IV:**

Åhrén, T. and Parida, A. (2008b) Overall railway infrastructure effectiveness (ORIE): a case study on the Swedish rail network. *Revised as per referees comments and re-submitted to Journal of Quality in Maintenance Engineering*

Thomas Åhrén conducted the case study and Aditya Parida provided support and feedback.

### **Paper V:**

Åhren, T. and Larsson-Kråik, P.-O. (2007) Railway maintenance link and effect model: a conceptual framework. *Accepted for publication in Journal of Quality in Maintenance Engineering*.

Thomas Åhrén described the basic concept and Per-Olof Larsson-Kråik provided supporting discussions and feedback.



## LIST OF RELATED PAPERS AND REPORTS NOT APPENDED

Espling, U. and Åhrén, T. (2007) Outsourcing as a strategic tool to fulfil maintenance objectives - a case study for railway, Submitted for publication in a Journal.

Kumar, U. and Åhrén, T. (2006) Maintenance performance measurement system. *Conference proceedings of the 18th Euromaintenance 2006*, Basel, Switzerland, June 20-22, pp. 531-536.

Parida, A., Åhren, T. and Kumar, U. (2003) Integrating maintenance performance with corporate balanced scorecard. *Conference proceedings of the 16th International Congress of COMADEM*, Växjö, Sweden, 27-29 Aug., pp. 53-59.

Åhrén, T. (2005) *A study of maintenance performance indicators for the Swedish railroad system*, Licentiate thesis, Luleå, Luleå University of Technology.

Åhrén, T. (2004) *Indicators: an overview within Banverket*, Research report, Luleå, Luleå University of Technology (in Swedish).

Åhrén, T. (2003) *Cost drivers for the Ofotenbanen Iron Ore Line*, Technical report, Luleå, Luleå University of Technology (in Swedish).

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Åhrén, T., Espling, U. and Kumar, U. (2005) Benchmarking of maintenance process: two case studies from Banverket, Sweden. *Conference proceedings of Railway Engineering 2005*, London, UK, 29-30 June.

Åhrén, T., Liyanage, J. P. and Kumar, U. (2006) Maintenance performance measurement study at Banverket. *Conference proceedings of 19th International Congress COMADEM 2006*, Luleå, Sweden, June 12-15, pp. 643-649.



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# 1 INTRODUCTION AND BACKGROUND

The history of the Swedish railway network goes back more than 150 years (Banverket, 2005c). From the beginning, both private and government initiatives were undertaken to build the rail network. In 1939, the entire network was nationalized, and the Swedish State Railways (SJ) was established. Banverket (the Swedish National Rail Administration) was formed in 1988 when the infrastructure ownership was separated from SJ, which now became a pure traffic operator. In 1998, Banverket was divided into an infrastructure owner organization and result units such as operation, maintenance, and consultancy units, i.e. one purchasing organization and several contractor organizations. Banverket follows and conducts development in the railway sector, assisting Parliament and the Government on issues related to the railway, besides the operation and management of state track installations, the co-ordination of local, regional and inter-regional railway services, and the provision of support for research and development. Banverket's operations are therefore divided into sectoral duties, track provision and production. Since 2001, maintenance has been outsourced to different in-house or external contractors.

The Swedish national railroad system is a complex system, which is used for freight and passenger transportation and where political and social considerations have to be taken into account; e.g. safety and environmental impact, as well as public demands for safe, reliable and cost-effective transportations. The railroad is therefore strictly governed by regulations and government legislation (Ministry of Industry Employment and Communication, 2006). The Swedish railway authorities have a long tradition of working with and using performance indicators to follow up their performance. As early as 1915, when they started to operate the electrified Iron Ore Line between Kiruna and Riksgränsen, they introduced some indicators to measure and follow up the calculated benefits of upgrading the transportation system (Wiklund, 2005). Two of the introduced indicators reflected the transportation process, e.g. the costs per transported iron ore tonnage and the total amount of transported iron ore tonnage. In addition, some indicators related to health, safety and the environment (HSE) were used, such as employee safety training and accidents or near-accidents related to the new power source of electricity.

The evolution and use of performance measurements in a wider perspective started in the 1880s in the USA (Segovia and Thornton, 1990). The evolution of management accounting and management accounting systems (MAS) provided the management with relevant, accurate, and timely information regarding an organization's internal activities. From the beginning, the use of MAS could be looked upon as an engineer's approach to ensuring good resource allocation and utilization; i.e. the focus was placed on management decisions rather than on reported profit. From the 1920s, the use of MAS declined due to the ever-increasing costs needed just to keep the MAS in function when the firm grew; i.e. more and more diverse product lines were added due to the market forces as well as manufacturing and technical developments. At the same time, the influence of accountants was increasing, with a greater focus on reported profit than on management decisions, i.e. the auditor's approach. During the late 1960s, once again

the need for complementary engineering management decision-making parameters increased (Husband, 1976). Today, there are a great number of Computerized Maintenance Management Systems (CMMS) available on the market. Some of them are stand-alone applications, while others are parts of total business solutions. Independent of the chosen system, one important issue is to bridge the gap between the overall objectives, the strategies, and the performance measurement system (Espling, 2007). One way of accomplishing that is the use of different balanced scorecards and link and effect models (Kaplan and Norton, 1996, Liyanage, 2003, Liyanage and Kumar, 2003).

### **1.1 Problem discussion**

The Swedish national railroad system is a complex system, which is used for freight and passenger transportation and where political and social considerations have to be taken into account; e.g. safety and environmental impact, as well as public demands for safe, reliable and cost-effective transportations. When Banverket was established, it took over a railway infrastructure in need of scale renewals. Therefore, during the 1990s Banverket made large investments and re-investments to upgrade and meet increased requirements for the railroad system, e.g. increased axle loads, higher speed, and increased transportation volumes (Banverket, 2002b).

In the future plan for the Swedish rail network, some important statements are made (Banverket, 2004). First, there has been a positive growth in the traffic volume, especially for passenger traffic, where the growth has been 28% during the past five years. This has led to a high infrastructure capacity utilization, at the same time as the punctuality has decreased (Banverket, 2007). The future plan contains large new investments in order to increase the infrastructure capacity. Secondly, when looking at the railway network as a whole, it is important to maintain the existing infrastructure through effective and efficient maintenance in order to keep high capacity utilization with the highest possible safety levels, as well as increased punctuality. Although there is an increase in the total transportation volumes on the railway network, the estimated need for resources will not fully be covered in terms of government funding; there is a need for continuous improvements in the area of maintaining the railway infrastructure. The work of maintaining the infrastructure in a good shape is therefore being undertaken from five perspectives; i.e. safety, customers' needs, cost-effectiveness, environmental aspects, and continuous development.

With the increasing awareness that maintenance not only ensures safety and track performance, but also creates additional value in the business process, Banverket is treating maintenance as an integral part of the business process, i.e. applying a holistic view of the infrastructure maintenance process in order to fulfil customer requirements (Karlsson, 2005). For their infrastructure maintenance process, Banverket is visualizing both front- and back-end processes regarding track maintenance (Banverket, 2005b). One front-end process is *Determine track maintenance demands*, supported by external measures such as the track capacity and track quality (Banverket, 2005a). The sub-process denoted *Control and monitor production* is a back-end process, supported by internal measures such as the track maintenance costs and the use of environmental hazardous materials.

The requirement from the infrastructure management perspective, in order to achieve cost-effective maintenance activities and a punctual and cost-effective railroad transportation system, is an ongoing development process in the area of railway maintenance engineering. Cost-effective maintenance processes are necessary to achieve budget targets, while a punctual railroad system is required by different stakeholders. By meeting the requirements of stakeholders in a punctual and cost-effective manner, Banverket will be able to keep the existing infrastructure and rolling stock in good shape. Thereby, it will be possible to prolong the expected life of such assets.

Today, all the maintenance activities are outsourced and contracted out on the open market to different contractors. Depending on the chosen strategy for maintenance outsourcing and how the purchased maintenance contracts are written, how much of the maintenance process Banverket can manage by themselves, without needing to negotiate with the maintenance contractor, can vary a great deal (Esplling and Kumar, 2004). However, since Banverket is the infrastructure owner, it is their responsibility to define the overall maintenance objectives and strategies, as well as to carry out the final assessment of the maintenance outcomes and compare it with their own overall objectives and strategies. The strategic part of the maintenance process is therefore managed by Banverket, while the day-to-day maintenance activities are managed and executed by the different contractors.

An unexpected event or disruption will affect different stakeholders, e.g. passengers, operators and contractors. An obvious example of this was all the extensive train delays due to bad weather conditions with heavy snowfalls during the winter of 2001/2002 (Banverket, 2002). It is therefore necessary to identify, classify, and analyze all the disruptions in the railroad transportation process, so that they can be minimized through effective and efficient maintenance activities. Maintenance decisions should be taken on rational foundations, based on a carefully prepared and well-defined maintenance strategy developed by the infrastructure owner, considering different stakeholder requirements. Maintenance decisions must be based on reliable data reflecting the status and condition of the railway infrastructure system, as well as the asset degradation patterns; i.e. knowing the asset's condition degradation trends, it is possible to predict the future. The decision-making process can be supported by different decision-support systems, if these systems are supported by the necessary data and measures. The measurement of maintenance performance has become an essential element of the strategic thinking of assets owners and managers (Liyanage and Kumar, 2000). Without any formal measures of performance, it is difficult to plan, control, and improve the maintenance process.

One key issue for Banverket is therefore to verify that the undertaken maintenance activities produce the expected results. One way of doing that is to compare the railway asset condition before and after the maintenance activities have been carried out in terms of technical, economical, and organizational indicators. Efficient and effective maintenance is also expected to give environmental benefits, a reduced number of train disruptions, increased safety, etc. Together this results in competitive and cost-effective transportation solutions for both passengers and industry.

## **1.2 Purpose**

The main purpose of this research work is to identify and study the existing operation and maintenance performance indicators (MPI) related to railway infrastructure, and their application in the short-term and long-term perspective, to analyze their usefulness for the operation and maintenance planning of the railway infrastructure. Furthermore, the study is to find a structured, reliable, and cost-effective method using MPI like OEE-values to facilitate the operation and maintenance decision-making process, both in the short-term and long-term perspective, for the railway infrastructure managers.

The main aim is to identify and analyze the MPIs, and provide recommendations for implementing MPIs and necessary frameworks for infrastructure managers, to support and link the maintenance decision-making process with respect to punctuality, safety, environmental impact and profit. The aim is also to propose some additional indicators for infrastructure managers for measuring the infrastructure effectiveness.

## **1.3 Research questions**

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

1. What are the MPIs being used and how can one identify and benchmark the additionally required MPIs for the railway infrastructure with specific reference to Banverket, Sweden?
2. How can one measure the Overall Railway Infrastructure Effectiveness (ORIE) as a Key Performance Indicator (KPI) for the railway infrastructure?
3. How can one develop a link and effect model framework for the railway infrastructure's maintenance management?

## **1.4 Scope and limitations**

The study considers only maintenance and maintenance-related activities from an infrastructure owner's perspective, and is limited to the area of maintenance performance measurement and MPIs. While considering the MPIs and ORIE together with the link and effect model framework, the present situation for the Swedish rail network and Banverket is taken into consideration. The concept of a railway maintenance link and effect model is applied on Banverket. The ORIE concept is also applied on Banverket in a case study.

## **1.5 Structure of the thesis**

The thesis structure is as follows.

The first chapter (Introduction and Background) introduces the reader to the background and research problem area. It also describes the purpose, research questions, and scope and limitations.

In the second chapter, the theoretical frame of reference is discussed, i.e. maintenance, performance indicators, performance measurement, and MPIs. Besides, the concepts of the balanced scorecard, the link and effect model, and overall equipment effectiveness are briefly presented.

The third chapter (Research Methodology) presents and discusses the selected research methodology and approach for this thesis.

In the fourth chapter (Summary of Appended Papers), a summary of the five appended papers in this thesis is presented. The relationship between the research questions and the appended papers is outlined in Table 1.1.

*Table 1.1. The relationship between the stated research questions (RQ) and the appended papers.*

	Paper I	Paper II	Paper III	Paper IV	Paper V
RQ 1	x	x	x		
RQ 2				x	
RQ 3					x

Finally, in the fifth chapter (Conclusions and Discussion), the general conclusions with respect to the research questions are presented and discussed. The research contributions of the thesis and proposals for further research are also outlined in this chapter.



## 2 THEORETICAL FRAME OF REFERENCE

### 2.1 *Maintenance*

The purpose of maintenance and maintenance management is to maximize the production system availability at minimum costs, by reducing the probability of equipment or system breakdowns (Husband, 1976). The management of the maintenance process can from a holistic view be described as the management of the available maintenance resources, i.e. competence, capital, material, and information, to ensure a desired output in terms of high physical asset integrity (Liyanage and Kumar, 2002a). It also includes the management of unexpected inputs, as well as undesirable outputs, in terms of equipment or plant anomalies or unwanted events.

The evolution of maintenance and maintenance management started in the time period up until the Second World War, when the dominating maintenance policy was “run to failure” (Kelly, 1989). This period is called the First Generation of Maintenance (Moubray, 1991). During the time period until the 1960s, safety matters became more important, as well as improvement in labour efficiency, and a more preventive maintenance strategy emerged; this is called the Second Generation of Maintenance (Moubray, 1991). This change of strategy also made it possible to start controlling maintenance performance, costs and production assets availability (White, 1973). The Third Generation of Maintenance (Moubray, 1991), emerged during the 1970s, and the preventive maintenance strategy was developed further due to technological advances and requirements from maintenance managers to predict the future amount of maintenance; a condition-based maintenance strategy evolved (Kelly, 1989). The evolution of maintenance has today reached the Fourth Generation of Maintenance, in which maintenance is looked upon from a more holistic point of view (Dunn, 2003), and there is an integration of production asset management and maintenance management (Peterson, 1999, Woodhouse, 1997). Maintenance is not longer viewed as a cost-profit centre, and it creates value for the business process (Liyanage and Kumar, 2003, Liyanage and Kumar, 2002b).

Maintenance is needed due to a lack of reliability and quality losses. According to standards, maintenance is a “combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function” (SIS, 2001). Maintenance is often looked upon as a process, i.e. the establishment of a goal and strategy, programme establishment, planning, execution, and analysis and continuous improvement. The maintenance activities themselves are performed either as corrective maintenance after a disturbing equipment failure has occurred, or preventive maintenance to reduce the probability of future breakdowns (Swanson, 2001). Traditionally, preventive maintenance is performed on a distance or time basis. Today, a predictive maintenance approach is often used when it is possible to monitor the equipment condition, giving the opportunity to perform maintenance only when there is a need for it. The benefits of this strategy are prolonged maintenance intervals and reduced maintenance costs (Swanson, 2001). Sometimes, however, it is more cost-effective to adopt a run-to-

failure strategy for cheap equipment whose failure is easy to detect and which has no effect on the production process, i.e. no health, safety or environmental impacts.

In order to follow up and evaluate the short- and long-term effectiveness and efficiency of the maintenance management and the undertaken maintenance activities, as well as to assess whether the maintenance process is supporting the overall corporate business objectives, the use of maintenance performance measurement systems generating useful performance indicators is a requisite; i.e. performance cannot be managed if it cannot be measured (Wireman, 1998). Back in the 1960s, the main focus was directed at economy, equipment, and organizational issues (Husband, 1976), but today health, safety, and environmental issues are equally important (Kumar and Ellingsen, 2000).

## **2.2 Performance indicators (PIs)**

Broadly, PIs are classified as leading or lagging indicators (Stricoff, 2000). A leading, lead, or prospective indicator is a performance driver, i.e. a measure that drives the performance of the outcome measure. The outcome measure itself is simply the lagging, lag, or retrospective indicator, e.g. different financial measurements. Leading and lagging indicators can also relate to strategy or goals, and therefore it is important not to mix means and ends (Failing and Gregory, 2003). When developing and implementing PIs, other important contradictory PI characteristics are:

- Off-the-shelf or tailor-made indicators: an important distinction if the indicators are supposed to be used in benchmarks (Wireman, 2004)
- Long- or short-term indicators: an important distinction when deciding how long a time the indicator measures have to be stored (IAEA, 2000)
- Slow or fast changing rate indicators: an important distinction when performing trend calculations or deciding if slower/faster redundant indicators must be used or developed, often the case for environmental issues (Miljövärdsberedningen, 1998, Kimberling *et al.*, 2001).

When designing PIs it is important that they should act as a signal or indicator that something is happening and give a hint of the characteristics of necessary decisions (Mossberg, 1977). The relation between different PIs can be studied from three different perspectives, namely relationships through signal characteristics, decision characteristics, or signal and decision characteristics. The chosen PIs must also be scalable; i.e. it must be possible to use them locally at the same time as they can be aggregated and used globally or vice versa (Failing and Gregory, 2003). Since the development process for PIs follows a top-down approach where the overall business objectives are cascaded down to specific PIs to be measured in the organization (Tsang *et al.*, 1999), the reporting and aggregation of PIs follow a bottom-up perspective (Andersen and Fagerhaug, 2002, Engelkemeyer and Voss, 2000). This approach also makes it possible to integrate fully the PI system into other performance management systems in use, for instance balanced score cards (Ahlmann, 2002, Parida and Kumar, 2006).

Three basic models or systems are used when developing and implementing PIs. In a horizontally grouped PI system, the PIs are arranged in independent logical groups,



covering perspectives related to the maintenance process such as reliability/maintainability, preventive/predictive maintenance, planning and scheduling, materials management, skills training, maintenance supervision, and work process productivity. For detailed examples, see (Smith, 2003, Cummings, 1993, Allander, 1997). In a vertically aggregated indicator system, the indicators are arranged in a pyramid structure, where a large number of indicators on a bottom level are aggregated upwards in the pyramid structure and often reduced to one or a few indicators at the strategic level, such as ROI etc. For detailed examples, see (IAEA, 2000, Lyons et al., 2000, Kimberling et al., 2001). An indicator system combining horizontally grouped indicators with vertically aggregated ones, gives semi-independent logical PI groups arranged in a horizontal or vertical structure, i.e. no indicator aggregation between the indicator groups, although logical links exist between them. Every separate PI group is a sub-system of PIs reflecting different maintenance perspectives, e.g. economy, equipment, organizational issues, and health, safety, and environmental (HSE) issues. For detailed examples, see (Wireman, 1998).

### **2.3 Performance measurement**

The basic concept of performance is a function of ability, efforts, and opportunity (Salminen, 2005). Performance is the ability of an organization to implement a chosen strategy and achieve organizational objectives (Tsang, 2002). The organizational performance is the result of the performance of individuals and groups. Performance can be examined from different perspectives, such as the customer, financial, process, employee, safety, and environmental perspective, etc. (Feurer and Chaharbaghi, 1995).

Performance measurement (PM) is the process by which a company manages its performance, and the performance measures are the set of metrics used to quantify the efficiency and effectiveness of actions (Neely *et al.*, 1995, Bititci *et al.*, 1997). Reasons for measuring performance are, for example, to provide management and employees with feedback on performed work (Andersen and Fagerhaug, 2002). PM includes hard financial and non-financial metrics, as well as soft metrics like employee attitudes, and covers both processes and results (Salminen, 2005). Measurement provides the basis for an organization to assess how well it is progressing towards its predetermined objectives, and helps the organization to identify areas of strength and weakness, and decide on future initiatives, with the goals of improving organizational performance (Amaratunga and Baldry, 2002, Rouse and Putterill, 2003). The decision-making process must consider multiple criteria, since both economic and non-economic factors are involved (Al-Najjar and Kans, 2006, Blanchard and Fabrycky, 1998).

### **2.4 Maintenance performance indicators (MPIs)**

Maintenance performance indicators (MPIs) are utilized to evaluate the effectiveness of the maintenance carried out (Wireman, 1998). MPIs compare the actual conditions with a specific set of reference conditions (requirements/targets) (EEA, 1999). An MPI is a product of several measures (metrics) used for the measurement of maintenance performance (Wireman, 1998), and is equipped with baselines and realistic targets to facilitate prognostic and/or diagnostic processes and justify associated decisions and

subsequent actions at appropriate levels in the organization, to create value in the business process (Liyanage and Kumar, 2003).

MPIs are linked to the reduction of downtime, costs and wastes, and the enhancement of capacity utilization, productivity, quality, health and safety. MPIs also need to be different for different industries and the difference causes a need for other PIs (Arts *et al.*, 1998). MPIs can be used for different purposes, such as measuring financial performance, employee performance, customer satisfaction, the health, safety and environmental (HSE) rating, and the overall equipment effectiveness (OEE) etc. Examples of MPIs are the maintenance budget, availability targets, the meantime between failures and repair (MTBF and MTTR), maintenance reliability, and downtime. The establishment of a link between the lagging and the leading indicators helps to monitor and control the performance of the process, and the indicators to be linked are selected in line with the chosen maintenance strategy (Kumar and Ellingsen, 2000).

Maintenance performance measurement (MPM) is not a new concept. Today, the senior management wants to know the value created by the maintenance process, while taking care of the safety and environmental issues (Liyanage and Kumar, 2003). Therefore, MPM has become an important part of the organizational strategy. MPM must consider the issues of stakeholders' requirements and total maintenance effectiveness both from internal and external perspectives to identify the relevant MPIs, and then align the MPIs with the corporate objectives (Ahlmann, 2002).

It is important that the concepts used in defining maintenance metrics should be clear concerning what to measure, how to communicate maintenance performance across the organization, and aligning maintenance performance with objectives and strategies etc. (Murthy *et al.*, 2002). The opportunities to monitor and control all kinds of assets are today's reality, but also a source of data overload for managers, which is often visible in terms of redundant performance reports (Parida *et al.*, 2004, Neely, 1999, Kennerly and Neely, 2003). When it is time for decision making, the manager is still not able to take into consideration more than just 5 to 8 parameters at the same time (Wickens and Hollands, 1999), which emphasizes the importance of choosing the right indicators for decision making; i.e. parameter aggregation is often necessary. The old traditional way of measuring a company's performance, based on financial results alone, was found to be inadequate and inefficient, since all the measures only reflected outcome results. To overcome these shortcomings, Kaplan and Norton (1992) introduced the concept of the Balanced Scorecard.

## **2.5 Balanced Scorecard**

The basic idea behind the introduction of the balanced scorecard was to find a way of managing and measuring the company performance from a more holistic view, not only taking financial performances into account. The balanced scorecard concept introduced three more strategic perspectives in addition to the financial one, and these perspectives were seen as critical to a company's performance, reflecting not only the company's financial history, but also its present and future performance (Kaplan and Norton, 1992, Ahlmann, 2002). The three additional perspectives are the customers' perspective, the internal business perspective reflecting the present performance, and finally the learning

and growth perspective reflecting what the company has to do to prepare itself for the future, i.e. innovations. The advantage of such a scorecard is the possibility of managing and balancing different activities within a company, even if the different activities cannot be directly measured in economical terms. Empirical studies have shown that the use of more holistic performance measurement systems like BSC or the Malcolm Baldrige Criteria to assess organizational performance has a positive impact on business results and performance (Evans, 2004, Alsyouf, 2006).

In order to develop and implement the scorecard in an existing company, one must involve more than the top management, and to make sure that the overall objectives permeate all the scorecard perspectives in the process, a top-down approach is necessary, in combination with the top management support (Kaplan and Norton, 1992). If necessary, the balanced scorecard can be broken down to provide scorecards further down into the organization. One fundamental idea with the balanced scorecard is that important values cannot always be related to financial measures. The balanced scorecard model is therefore suitable for long-term non-business activities where profit is not the main purpose (Olve et al., 1999). This is especially the case in the public sector, where long-term public demands have to be taken into consideration, e.g. public services such as healthcare, education, environmental protection and transportation. The use of the balanced scorecard concept also gives the opportunity to highlight what will happen in the long term with different financial assumptions, i.e. how to act in the long term.

## **2.6 Link and effect model**

The introduction of any performance measurement system which is meant to fulfil the needs of operation and maintenance processes in a company or a business unit requires a strategic focus on critical strategic areas determined by the nature of the specific business, business concerns and public requirements and regulations (Kumar and Ellingsen, 2000, Liyanage and Kumar, 2003, Liyanage, 2003). The critical strategic areas vary from business to business, but normally include areas such as financial issues, health safety and environment issues, internal processes, the technical status of plant, competencies, and, finally, internal and external relationships.

When developing the performance measurement system, it is important that it should support the overall objectives of the company or the business unit, signifying a top-down approach (Liyanage and Kumar, 2003, Liyanage, 2003). The direct link between the overall objectives and the measures for operations and maintenance is in terms of the return on investments (ROI) and health, safety and the environment (HSE). The main performance driver for ROI and HSE is the integrity of the plant. Adequate competencies, functional internal processes, and good internal and external relationships lay the foundation of plant integrity. Therefore, when deriving the different MPIs for each critical strategic area (CSA) to trace the maintenance performance, it is also necessary to classify the degree of effect for every single MPI towards linked CSAs, i.e. create a logical cause-and-effect structure, to pinpoint those measures that are the key performance indicators (KPI). The final output from this is a link and effect model, showing how the operation and maintenance processes contribute to the overall objectives of the company or the business unit. The link and effect model itself can be looked upon as an extended balanced scorecard.

## 2.7 Overall equipment effectiveness

Overall equipment effectiveness (OEE) is a key performance indicator (KPI) frequently used in the manufacturing industry to calculate the overall equipment effectiveness of a production system or parts of it. OEE was presented as an overall metric in the Total Productive Maintenance (TPM) concept (Nakajima, 1988, Al-Najjar, 1996). OEE is an aggregated productivity measure that takes into consideration the six big losses that affect the productivity of equipment in a production system. These losses are divided up into three main groups according to availability, speed, and quality. The availability is related to downtime in terms of equipment failure, setup, and adjustments. The speed or performance rate is related to idling and minor stoppages, together with reduced speed. Finally, the quality rate is related to process defects and reduced yield. To obtain the OEE, one simply multiplies the equipment's availability, performance rate, and quality rate. Normally, OEE figures can be found from 30 – 95% (Ahlmann, 1995, Ljungberg, 1998).

The definition varies between applications by different industries and therefore it is difficult to identify the ideal OEE figures as well as compare the OEE figures between different companies (Jonsson and Lesshammar, 1999). Generally, availability is defined as the ratio of the actual uptime and the intended uptime, the performance rate as the ratio of the actual production time and the intended production time, and finally the quality rate as the ratio of the good items produced and the total amount of produced items. The availability and performance rate normally refer to the loading and operating time (Nakajima, 1988) or the planned time and amount of production (De Groote, 1995). There is an ongoing discussion in the literature regarding the availability metric. Some authors claim that the availability metric is influenced by factors beyond the equipment itself, such as operators, facilities, the input material availability, scheduling requirements, etc; i.e. the OEE metric reflects the integrated equipment system and not the stand-alone equipment itself (De Ron and Rooda, 2005, De Ron and Rooda, 2006). Others argue that the OEE metric does not take into consideration all the factors that reduce the availability, such as the planned downtime and a lack of material and labour (Ljungberg, 1998, Sheu, 2006).

### 3 RESEARCH APPROACH AND METHODOLOGY

All research activities start with a problem that needs to be explained and understood. The aim of this study is to solve practical related problems for the railway infrastructure owner and the results are supposed to be used by the same railway infrastructure owner. Therefore, this research is called applied research (Patel and Davidson, 1994). On the other hand, if the aim is to gain and widen knowledge for future use, the research is called fundamental.

Depending on how much knowledge needs to be acquired about a certain problem or problem area, the research focus varies. Since the aim of this study is to generate new knowledge and understanding about MPIs and MPI models for the railway infrastructure management, the research focus can be described as exploratory (Patel and Davidson, 1994). Descriptive research is used when the knowledge level is moderate and it is possible to categorize existing knowledge into models etc. Hypothesis testing is used when the knowledge level is considered as high and developed theories exist in the area of interest.

The research strategy varies depending on the research questions, the behaviour events, and contemporary events. In this study the majority of the research questions focus on “how” and the behaviour events are out of the researcher’s control, at the same time as contemporary events must be taken into consideration; i.e. implying that the case study is the main research strategy for this study (Yin, 1994). Other research strategies that could have been used as the main research strategy are the experiment, survey, archival analysis, or history study.

The research approach used in this study is the abduction approach (Alvesson and Sköldbberg, 1994); i.e. literature studies and the collection of empirical data are combined in order to develop a general framework and models using an iterative research process (Wigblad, 1997). Abduction is a combination of the deductive approach using theories and general rules, and the inductive approach using empirical data.

The empirical data used in this study were collected over a period of five years. The data type is secondary, except for the interview data. The main data source is Banverket and its documents and databases. However, empirical data were also collected at other railway infrastructure manager organizations in Scandinavia and the UK. The collected data were thereafter processed into useful information; i.e. the data were examined, categorized, arranged, rearranged and recombined (Patel and Davidson, 1994). The main data analysis was performed with a qualitative approach using non-statistical methods (Creswell, 1994).

Whenever research is conducted, it is crucial that the presented findings and conclusions can be evaluated. The reliability requirement, which reflect the research process, is met by using existing methods and models (Carmines and Zeller, 1979). The validity requirement for the empirical data, which reflect the extent to which a measure reflects what it is supposed to measure, is in this study met by comparison with other sources of information whenever it has been possible. Examples of activities carried out

to strengthen both the reliability and the validity are workshops and presentations at Banverket.

### **3.1 Research approach and methodology**

The approaches used for identifying MPIs in use at Banverket are as follows. The overall business objectives and sub-goals are identified through the government appropriation letter for Banverket, as well as through Banverket's annual report. They contain, in addition to the objectives, a number of predefined measures that are supposed to be tracked in order to support the government evaluation of goal fulfilment for Banverket. These predefined measures, i.e. indicators, will in this study be analyzed with the same approach as that used in the Norwegian oil and gas industry to identify its maintenance performance indicators, as used by the Centre for Maintenance and Asset Management at the University of Stavanger (Liyanage, 2003, Liyanage and Kumar, 2003, Kumar and Ellingsen, 2000). Further, interviews are held with regional operations planners at Banverket to identify the use of maintenance-related performance indicators at regional levels, as well as to identify any regional deviations concerning the indicators in use. The identified maintenance performance indicators in use at Banverket are then classified into lead or lag indicators, and examined as to whether they conform to the recommended standards and prevalent regulations. Finally, the impact of the identified indicators on the overall objectives is analyzed with a link and effect model, and an examination is performed of the extent to which the balanced scorecard is used and the way in which it influences the use of maintenance performance indicators.

The approach used for investigating and comparing high administrative and maintenance costs for Norwegian railway infrastructure managers (Jernbaneverket) is benchmarking. The benchmarking data of the railway infrastructure are retrieved, classified and analyzed for best practice improvement. The current cost levels are compared with the costs on the Swedish side for the same main track line. Data from the two case studies carried out at Banverket and Jernbaneverket are compared and analyzed (Åhrén and Espling, 2003, Åhrén and Kumar, 2004). The two case studies are examined and the results are compared with benchmarks at the national and international levels. A comparison of four similar rail networks in Scandinavia and the UK is carried out, by studying annual reports etc.

The approach for technical and economic evaluation of the maintenance of rail and wheels on the Iron Ore Line was to compare track simulations, technical field data and financial data, collected at the infrastructure owner and the traffic operator. The case study was performed in close co-operation with MTAB (Malmtrafik i Kiruna AB, an iron ore transportation company), Banverket, and Duroc Rail AB. Simulations have been performed in order to investigate the wear rate sensitivity as a function of the wheel/rail profiles by using the commercial software GENSYS (DE-solver, 2000). The calculated energy dissipation is used as an indication of the amount of expected relative change of wear for the different profiles. The amount of metal removing due to rail grinding activities is measured by using the MiniProf Rail system shortly before and after the grinding of the rails (Esveld and Gronskov, 1996). Data were collected from a literature search, different databases at MTAB, Duroc Rail, Banverket, and Jernbaneverket and from interviews with personnel at the different companies.

The approach used for the development of the overall railway infrastructure effectiveness (ORIE) model is to transform the standard industrial OEE model and apply the modified model on the railway infrastructure system (Jonsson and Lesshammar, 1999, De Groot, 1995, Nakajima, 1988). Thereafter, Swedish railway track sections are selected for collecting data and their ORIE validation, as a case study. The ORIE model is applied on Banverket and the input is literature studies, simulations, case studies on Banverket, and Banverket documents and data.

The approach used in the LinkEM study is to identify and configure a conceptual framework that explains, either graphically or in narrative form, the main issues to be studied, the key factors, variables and the presumed relationship amongst them (Miles and Huberman, 1994). The approach is based on the concepts of Multi Criteria Decision Making (MCDM) and Multi Criteria Decision Analysis (MCDA) (Dodgson et al., 2000, CIFOR, 1999, Spengler et al., 1998). A total MCDA consists of three process steps, namely the scope and objectives, scoring and weighting, and results and analysis. Since this study focuses on the development of a conceptual LinkEM, only the first MCDA process step will be used. The first stage will verify if the pre-chosen CSAs from the original link and effect model are valid for the railway maintenance LinkEM. The second and third stage will identify the options and criteria, i.e. the key result areas (KRA) and key performance indicators (KPI). Since the LinkEM design uses aggregation of parameter values, it is necessary to include some basic design methods; otherwise, a change of one parameter during operation will result in multiple changes in the LinkEM. The design method used in this study is the Requirement Tree Method (Pahl et al., 1996). The LinkEM has been applied on Banverket and the input to stage 1 – 3 consists of literature studies, benchmarks and case studies on Banverket, and Banverket documents and data.





## 4 SUMMARY OF APPENDED PAPERS

This chapter summarizes the five appended papers. Each paper makes its own contribution to answering the research questions. The first research question is discussed in Paper I, Paper II, and Paper III and is related to the MPI foundation, i.e. how to identify, benchmark, and evaluate the MPIs. The second research question, discussed in Paper IV, is related to specific MPI models like the Overall Railway Infrastructure Effectiveness (ORIE) model. The third research question, discussed in Paper V, is related to the MPI decision-making framework, i.e. the Railway Link and Effect (LinkEM) model. The relations between the papers are illustrated in Figure 4.1. For more information, the readers are referred to the appended papers.

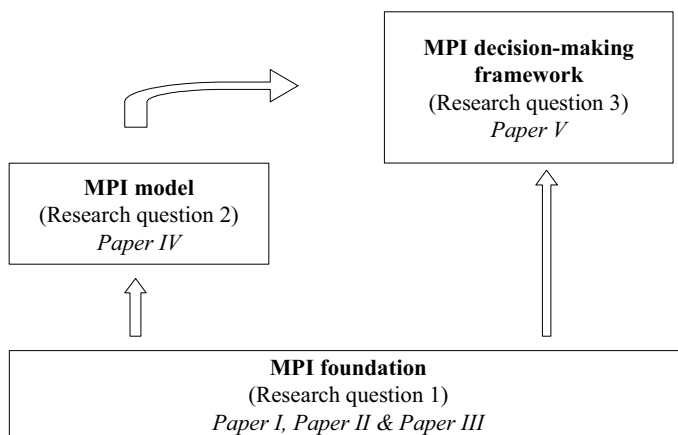


Figure 4.1. Interrelation between appended papers and research questions.

### 4.1 Paper I

Åhrén, T., Waara, P. and Larsson, P.-O. (2003) Technical and economic evaluation of maintenance for rail and wheels on Malmbanan. *Conference proceedings of International Heavy Haul Association Specialist Technical Session (IHHA STS 2003)*, Dallas, USA, 5-7 May, pp. 5.81-5.86.

#### 4.1.1 Purpose

The purpose of this paper is to provide an overview of how the maintenance costs for rails and wheels are distributed between the infrastructure owner and rolling stock owner on the Iron Ore Line running from coast to coast between Luleå in Sweden and Narvik in Norway.

#### 4.1.2 Findings

This paper presents a technical and economic correlation between maintenance activities performed and decisions taken by MTAB, Banverket and Jernbaneverket, the Norwegian railway infrastructure owner. The technical aspects are generated by

controlling rolling contact fatigue (RCF) failures and wear in connection with grinding. Rail profile measurement, which has been carried out since 1997, gives an indication of the parameters that have to be taken into account when choosing a grinding strategy for the Iron Ore Line. The economic aspects are generated from different maintenance activities, such as grinding and re-profiling wheel sets.

The rail-grinding project on the Iron Ore Line between Kiruna and Riksgränsen reduced the requirement for rail replacement from approximately 25,000 metres to 5,000 metres annually, as shown in Figure 4.2. The rail life due to wear and grinding was evaluated based on the material loss rates and the mean renewal level is suggested to be  $12000 \pm 1900$  m over the same distance. The cost level is predicted to be slightly over 13.3 million SEK, which represents a significant reduction when compared with the years '93, '94, '95 and '96. The result in economic terms is a reduction in the rail maintenance costs of approximately 50%.

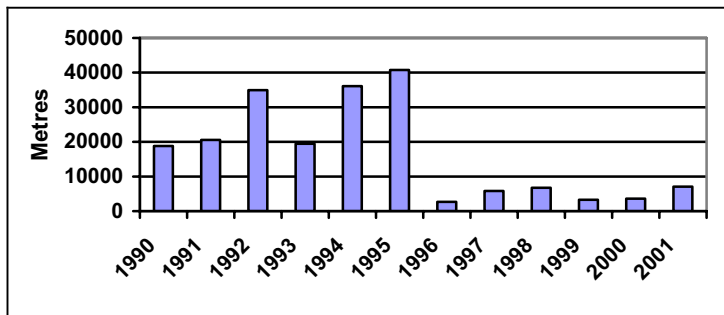


Figure 4.2. Quantity of annual rail renewals on the Iron Ore Line track section between Kiruna and Riksgränsen.

MTAB's maintenance programme is based on experience and relates to the distance driven with the ore car. Each wheel can be re-profiled 4 or 5 times. The type of wear/damage that dominates changes over time, but analyses show that as one wear mode decreases, another mode increases. More important is the fact that the total number of wheel sets replaced per annum decreased, as shown in Figure 4.3. However, at this stage it is too early to link the reduction in wheel set replacements to the ongoing grinding programme. The major problem for MTAB is that the cost of replacing wheels is at least ten times greater than that for re-profiling an old wheel. Different wheel wear modes will require different re-profiling. If one wear mode is very fast for short periods, this can result in high maintenance costs if that particular wear mode results in shifting to new wheels. Therefore, it is possible for MTAB to incur higher overall costs, even if the total number of worked and shifted iron ore wheel sets decreases, which also happened in the year 2001.

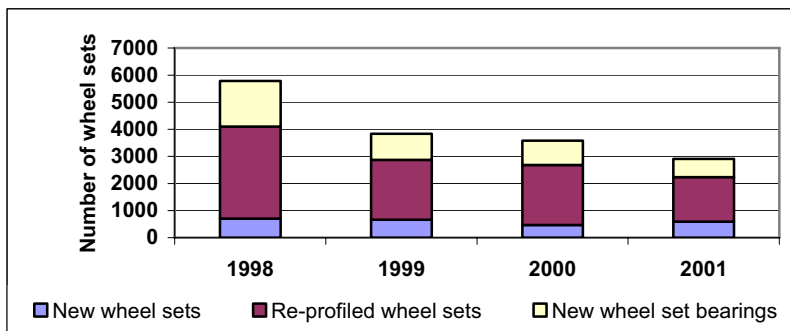


Figure 4.3. Number of worked/shifted wheel sets.

### 4.1.3 Main conclusions

The study shows that the grinding campaign delays major replacement of rail to the future. It is evaluated to give a yearly cost of 13.6 million SEK, with the rail renewal and the grinding campaign included. Train/track simulations can be used as a tool in maintenance planning and they clearly suggest that, by altering the traffic load direction of the cars, it would be possible to obtain a longer wheel life. Neither the grinding campaigns on the Swedish side nor objective measurements to increase the rail life on the Norwegian side seem to affect the total system in a negative way.

## 4.2 Paper II

Åhrén, T. and Kumar, U. (2004) Use of maintenance performance indicators: a case study at Banverket. *Conference proceedings of the 5th Asia-Pacific Industrial Engineering and Management Systems Conference (APIEMS2004)*, Gold Coast, Australia, 12-15 Dec., pp. 30.8.1-30.8.9.

### 4.2.1 Purpose

The purpose of this paper is to identify the use of maintenance performance indicators by the Swedish National Rail Administration (Banverket). The paper will discuss the different types and forms of indicators used; who own them, who use them and for what purpose etc. An attempt is made to analyze the impact of such indicators on the organizational goal and strategy through a link and effect model. An examination is performed as to whether these indicators conform to the recommended standards and prevalent regulations.

### 4.2.2 Findings

When using the same approach at Banverket as that used for the Norwegian oil and gas industry to identify maintenance performance indicators, 17 indicators can be identified as maintenance performance indicators. They are grouped as follows. Two of them support the sub-goal “an accessible transport system”, 10 of them support “a high quality of transport”, 2 of them support “safe traffic” and finally three of them support

“a sound environment”, see Table 4.1. Since Banverket has decided to implement the balanced scorecard, there are indications that some of these indicators are now being set in focus, and will be highlighted in those regions that have started to implement and use Kaplan and Norton’s balanced scorecard in a modified version.

*Table 4.1. Identified maintenance performance indicators within Banverket.*

<b>First level sub-goals</b>	<b>Second level sub-goals</b>	<b>Maintenance performance indicators</b>	<b>Relationship to BSC perspectives</b>	
An accessible transport system	Improve the use of state infrastructure	□ Capacity utilization	□ 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
			□ Number of delayed freight trains due to infrastructure	□ Processes
	Increased rail network maintenance efficiency	□ Number of train disruptions due to infrastructure	□ Processes	
			□ Q-factor (Degree of track standard)	□ Processes
		□ Markdowns in current standard	□ Processes	
			□ Maintenance cost per track-kilometre	□ Financial
	□ Total number of functional disruptions	□ Process		
		□ Total number of urgent inspection remarks	□ Process	
		□ Traffic volume	□ Financial	
Safe traffic	Reduced number of killed and injured persons	□ Number of accidents involving railway vehicles	□ Customers	
		□ Number of 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		

### 4.2.3 Main conclusions

The study at Banverket shows that, out of the 17 MPIs identified, 10 MPIs are in use, eight of which match the MPIs identified through the documents, i.e. lag indicators

supporting the sub-goal “a high level of transport quality”, and two of which were indicators identified through interviews, namely:

- train delays due to infrastructure
- hours of freight train delays due to infrastructure
- number of delayed freight trains due to infrastructure
- number of train disruptions due to infrastructure
- Q-factor (degree of track standard)
- markdowns in current standard
- maintenance cost per track-kilometre
- traffic volume
- total number of functional disruptions
- total number of urgent inspection remarks.

### **4.3 Paper III**

Åhrén, T. and Parida, A. (2008a) Maintenance performance indicators (MPI) for benchmarking the railway infrastructure - a case study. *Accepted for publication in Benchmarking: an International Journal*.

#### **4.3.1 Purpose**

For railway infrastructure, benchmarking is an effective tool that can support the management in their pursuit of continuous improvement by the use of maintenance performance indicators (MPIs). Hence, there is a need to study the MPIs and link them with benchmarking. This paper presents case studies dealing with the application of benchmarking and maintenance performance indicators for the railway infrastructure.

#### **4.3.2 Findings**

MPIs can successfully be used in combination with benchmarking as a tool for improvement by learning from within or from other organizations for continuous improvement. One of the findings was that the amount of corrective maintenance was very high, more than 32%. The track area covered by the Swedish side is ten times larger than that covered by the Norwegian side. The main cost drivers were tracks, switches, and insulated joints. The operation and maintenance cost was approximately the same when compared by track metre, but the overhead costs on the Norwegian side were 12 times higher when comparing the overhead costs per track metre, due to the geographical isolation of the Norwegian track sections, which required their own administration. However, a comparison of the size of the infrastructure manager organization shows approximately the same figures, indicating a similar staff requirement to fulfil the infrastructure management duties. Moreover, the cost of renewals and investments per track metre are higher on the Norwegian side of this track. The benchmarking result for the Narvik – Kiruna track section is given in Table 4.2.

Table 4.2. Benchmarking results for Narvik – Kiruna railway track section.

MPIs/activities	Norway	Sweden
Snow removal as cost percentage	24%	20%
Preventive maintenance (cost %)	19%	48%
Corrective maintenance including stand-by organization for immediate emergency maintenance (cost %)	50%	32%
Maintenance cost / track metre	285	280
Share for renewal/investment of total track budget	81%	77%
Infrastructure manager's organization size (number of staff employed)	9	8

### 4.3.3 Main conclusions

From the results of the two studies conducted at Banverket and Jernbaneverket, it is seen that quantifying the maintenance performance indicators in use is possible and can be used for benchmarking. The comparison from the Iron Ore Line between Kiruna and Narvik indicated more or less the same rail and track related maintenance costs in Norway as in Sweden. The geographical location and other factors have a large impact on the overhead costs, resulting, for example, in a cost per track metre that is 12 times higher in Norway than in Sweden. However, the number of employees in the work force of the infrastructure manager organization was nearly the same in both countries.

The results indicate that costs related to the amount of assets, e.g. track, can be compared to each other. Overhead costs must, on the other hand, be treated and compared using real figures; i.e. a comparison must be performed to identify the best practice regarding the size of the infrastructure manager organization. When comparing equally sized track areas, the benchmarking can be performed in a straightforward way, but a comparison between differently sized track areas needs caution.

## 4.4 Paper IV

Åhrén, T. and Parida, A. (2008b) Overall railway infrastructure effectiveness (ORIE): a case study on the Swedish rail network. *Revised as per referees comments and re-submitted to Journal of Quality in Maintenance Engineering*

### 4.4.1 Purpose

The purpose of this study is to develop an approach for measuring the Overall Railway Infrastructure Effectiveness (ORIE) for the Swedish National Rail Administration (Banverket) and to test this approach as a case study to verify the effectiveness of the approach.

### 4.4.2 Findings

The conceptual ORIE model has been tested and validated as a case study and the results show that the model can be used for other sections of the Swedish railroad, as well as for other railways.

The resulting average ORIE value during 2007 for the Boden – Gällivare track section was 90.6%. The maximum ORIE was 91.0%, which occurred in November, while the minimum ORIE was 89.7%, which occurred in January. The resulting ORIE for Järna – Åby and Bräcke – Östersund varies from 98.0 – 100%. The ORIE results for the track sections are shown in Figure 4.4, together with the ORIE values for the Bräcke – Östersund track section.

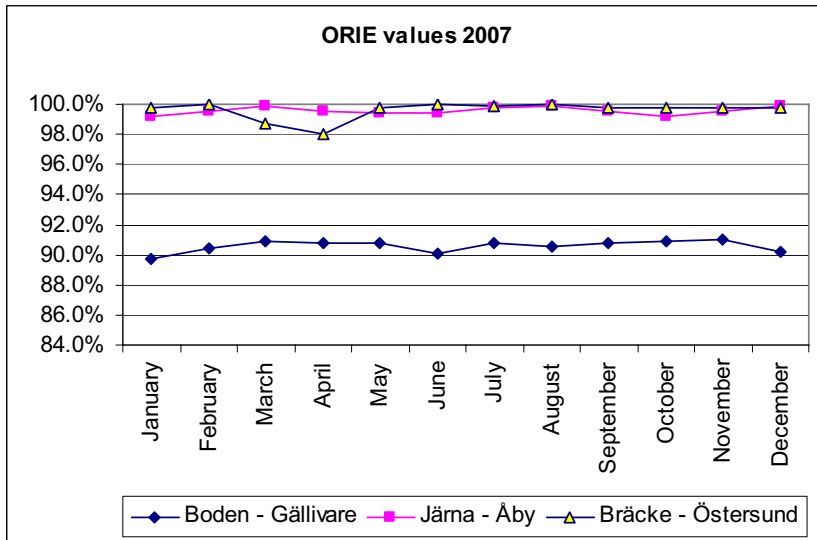


Figure 4.4. ORIE per month for Bräcke – Östersund, Järna – Åby, and Boden - Gällivare track sections during 2007.

#### 4.4.3 Main conclusions

The case studies performed on the three track sections show similar ORIE figures that are significantly higher than the industrial OEE, and such high ORIE figures are required for a punctual railway transportation system. The study indicates that ORIE must be calculated on a monthly basis. The findings of the ORIE calculation are ORIE values of 89.7 – 100%. The findings indicate that ORIE can be used as a key performance indicator by the railway infrastructure manager. It is also visualized that ORIE can provide important input for the infrastructure managers and support in decision making.

#### 4.5 Paper V

Åhren, T. and Larsson-Kräik, P.-O. (2007) Railway maintenance link and effect model: a conceptual framework. *Accepted for publication in Journal of Quality in Maintenance Engineering.*

### 4.5.1 Purpose

The purpose of this study is to present how to develop a link and effect model (LinkEM) framework for the management of railway infrastructure maintenance, taking into consideration the specific needs of the railway infrastructure manager.

### 4.5.2 Findings

The conceptual LinkEM focuses on critical strategic areas determined by the nature of the railway industry and public requirements and regulations. The direct links between the overall objectives and the outcome measures for railway maintenance are in terms of health, safety, and the environment (HSE) and the return on maintenance investments (ROMI). The main performance driver for ROMI and HSE is the railway infrastructure integrity (RII). Adequate competencies, functional internal processes, and good internal and external relationships lay the foundation of RII.

Therefore, when deriving the different PIs for each critical strategic area (CSA) to trace the maintenance performance, it is also necessary to classify the degree of effect for every single PI towards linked CSAs, i.e. create a logical cause-and-effect structure, to pinpoint those measures that are the key performance indicators (KPI). The LinkEM itself is a horizontally arranged indicator system based on semi-independent logical groups see Figure 4.5.

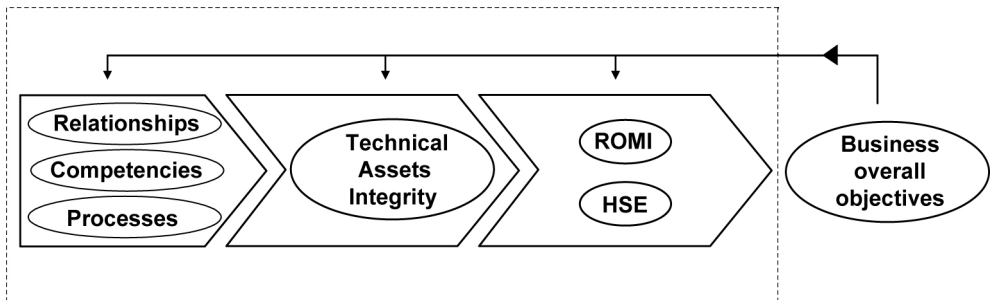


Figure 4.5. General link and effect model (LinkEM) framework.

### 4.5.3 Main conclusions

LinkEM takes into consideration the specific needs of the railway infrastructure manager, focusing on critical strategic areas determined by the nature of the railway industry and public requirements and regulations. The direct links between the overall objectives and the outcome measures for railway maintenance are in terms of health, safety, and the environment (HSE) and the return on maintenance investments (ROMI). The main performance driver for ROMI and HSE is the railway infrastructure integrity (RII). Adequate competencies, functional internal processes, and good internal and external relationships lay the foundation of RII.



## 5 CONCLUSIONS AND DISCUSSION

The main purpose of this research work is to identify and study the existing operation and maintenance performance indicators related to railway infrastructure and their application in the short-term and long-term perspective, to analyze their usefulness for operation and maintenance planning for the railway infrastructure. Furthermore, the study is to find a structured, reliable, and cost-effective method using maintenance performance indicators (MPI) like ORIE values and a link and effect model to facilitate the operation and maintenance decision making process both in the short-term and long-term perspective for the railway infrastructure management. The relationships between research questions, methods, and results are briefly described in Figure 5.1.

The main objective of this research is to identify, analyze, develop, and give recommendations for the implementation of MPIs and necessary frameworks to support and link the maintenance decision-making process with respect to punctuality, safety, environmental impact and profit.

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

1. What are the MPIs being used and how can one identify and benchmark the additionally required MPIs for the railway infrastructure with specific reference to Banverket, Sweden?
2. How can one measure the Overall Railway Infrastructure Effectiveness (ORIE) as a Key Performance Indicator (KPI) for the railway infrastructure?
3. How can one develop a link and effect model framework for the railway infrastructure's maintenance management?

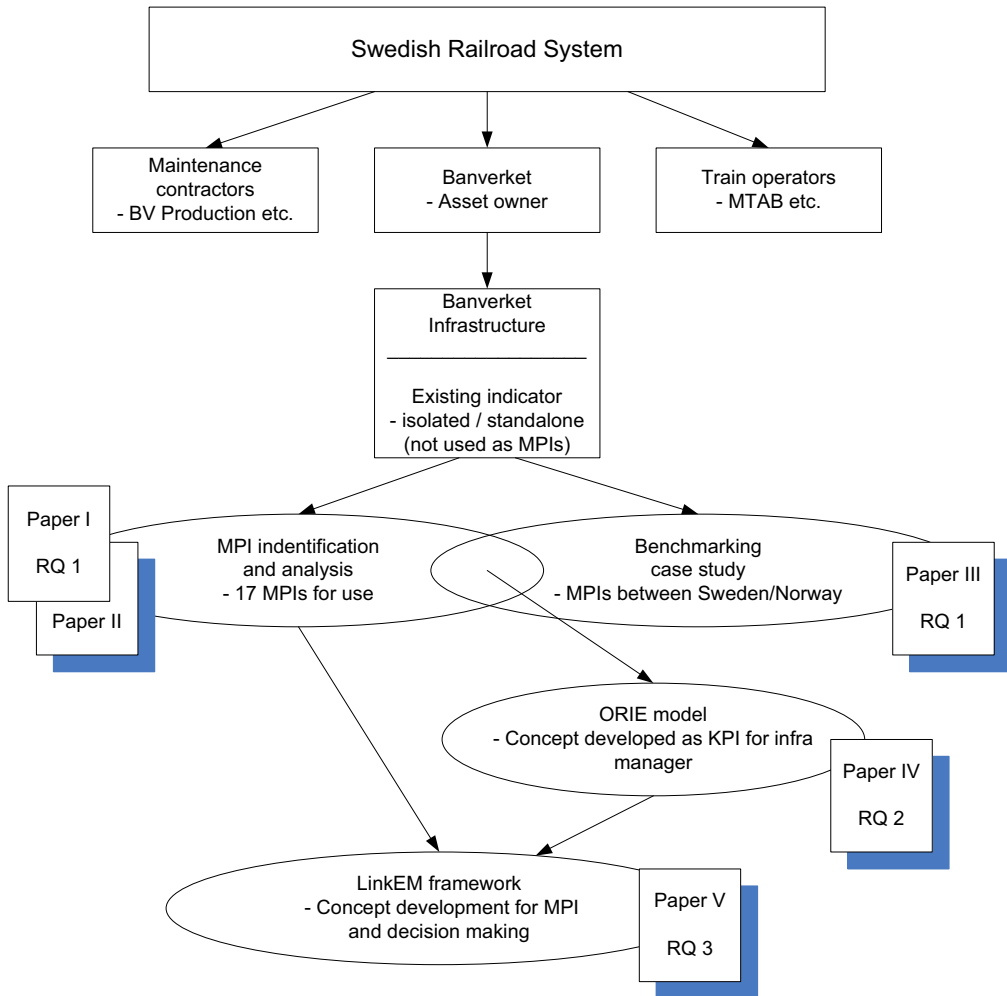


Figure 5.1. Research questions, methods, and results in the Swedish railway sector context

### 5.1 Findings regarding research question 1

The first research question deals with the issue of MPI identification and benchmarking. The MPIs in use at Banverket are presented in Paper II. The study shows that, although some MPIs were in use, they were not organized within the management hierarchy for decision-making. Out of the 17 MPIs identified, 10 are in use, eight of which match the MPIs identified through documents and two of which were identified through interviews, namely:

- train delays due to infrastructure
- hours of freight train delays due to infrastructure
- number of delayed freight trains due to infrastructure
- number of train disruptions due to infrastructure
- Q-factor (degree of track standard)

- markdowns in current standard
- maintenance cost per track-kilometre
- traffic volume
- total number of functional disruptions
- total number of urgent inspection remarks.

In Paper III, the railway infrastructure maintenance cost is benchmarked between different railway infrastructure manager organizations. The comparison from the Iron Ore Line between Kiruna and Narvik indicated more or less the same rail and track related maintenance costs in Norway as in Sweden. When the maintenance cost per track-metre is further analyzed, differences concerning how maintenance is carried out are revealed, e.g. the distribution of preventive and corrective maintenance, and the amount of snow removal, the values of which are given as percentages. The study identifies the fact that fixed costs, e.g. the overhead cost, must be analyzed and compared carefully. The infrastructure managers' organizations in Norway and Sweden are comparable when looking at the number of employees. When comparing the overhead cost per track-metre, the figure for the Norwegian side is 12 times higher. Two important factors affecting the figures are differences in the types of overhead cost included at the respective organizations, and the fact that the Swedish section between Kiruna and Riksgränsen is three times longer than the Norwegian section. Some overhead costs, e.g. administrative support, are distributed over the total Iron Ore Line in Sweden, which is ten times longer than the Norwegian track section of the Iron Ore Line.

In Paper I the technical and economic aspects of the rail grinding programme introduced on the Iron Ore Line between Kiruna and Riksgränsen are evaluated. The findings show that the introduced grinding programme reduces the annual need for rail renewal by a factor of five. This indicates that the rail maintenance costs, including rail renewal, decreased by 50%. Paper I also evaluates the wheel maintenance costs for the iron ore transportation company. Each wheel can be re-profiled 4 or 5 times. The type of wear/damage that dominates changes over time, but analyses show that as one wear mode decreases, another mode increases. More important is the fact that the total number of wheel sets replaced per annum has decreased. The major problem is that the cost of replacing wheels is at least ten times greater than that of re-profiling an old wheel. Different wheel wear modes will require different re-profiling. If one wear mode is very fast for short periods, this can result in high maintenance costs if that particular wear mode results in shifting to new wheels. Therefore, it is possible to incur higher overall costs, even if the total number of worked and shifted iron ore wheel sets decreases.

A discussion on the findings shows that eight of the 10 MPIs in use at Banverket reflect issues related to the railway infrastructure in terms of infrastructure condition and impact on traffic operation due to infrastructure malfunction. The traffic volume MPI reflects the use of the railway infrastructure, while the maintenance cost per track-kilometre MPI reflects the financial aspect of railway infrastructure maintenance. The maintenance cost per track-kilometre MPI can also be looked upon as an aggregated MPI reflecting different aspect of railway infrastructure maintenance costs. The

infrastructure maintenance costs are divided up according to different types of maintenance activities, such as corrective or preventive/predictive maintenance, as in Paper III, or according to the type of railway infrastructure, such as the permanent way, catenary, and signalling, as in Paper I, where the rail maintenance cost itself is a part of the permanent way, which in turn is a part of the railway infrastructure cost.

The identified MPIs in use all represent outcome measures, and are so-called lag indicators. However, although the MPIs related to the infrastructure are outcome measures, they can also be used as an input indicating necessary actions to improve the infrastructure for the future from a technical point of view. If necessary changes in maintenance activities are carried out due to, for instance, financial reasons, then the cost MPI alone is not capable to address the effect of such actions. Therefore, the cost MPI must also be more detailed, i.e. broken down into more maintenance cost MPIs in order to reflect the undertaken activities, such as introducing a rail-grinding programme or a shift from a corrective to a preventive/predictive maintenance regime.

## 5.2 Findings regarding research question 2

The second research question deals with the issue of how to develop and conceptualize Overall Railway Infrastructure Effectiveness (ORIE) as a Key Performance Indicator (KPI) for the railway sector. Paper IV presents a model for how to calculate ORIE. The ORIE calculation is similar to the OEE (overall equipment effectiveness) calculations used for the manufacturing and process industry. The proposed ORIE calculation is tested against real data for three track sections. The ORIE based on real data varies from 89.7 - 100%. The ORIE calculation is performed by multiplication of the infrastructure availability rate (A), the infrastructure performance rate (P), and the infrastructure quality rate (Q) as:

$$ORIE = A \times P \times Q$$

The infrastructure availability is a function of the planned uptime (UT), the train delays due to infrastructure failures (TDIF), and the train delays due to overdue maintenance activities (TDOM) as:

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

The infrastructure performance rate is a function of the planned total train operating time (TTOT), the train delays due to traffic disturbance where no maintenance is required (TDNMR), and the train delays due to speed reductions (TDSR) as:

$$P = \frac{TTOT}{TTOT + TDNMR + TDSR}$$

Finally, the infrastructure quality rate is a function of the actual Q-value (Qval) and the stated Q limit (Qlim) as:

$$\begin{cases} Q = \frac{Q_{val}}{Q_{lim}} & \text{if } Q_{val} < Q_{lim} \\ Q = 1 & \text{if } Q_{val} \geq Q_{lim} \end{cases}$$

A discussion on the findings from the case studies shows that ORIE can be used as a key performance indicator for the railway infrastructure owner. Delays of less than 40 minutes per train represent more than 90% of the train delays independent of the recorded repair time; i.e. the infrastructure is just temporarily blocked for operation. This indicates that the recorded repair time in the failure reporting system is not a true recorded period for the real infrastructure downtime. One solution is to update the failure reporting system database with recorded time that keeps a record of the actual infrastructure downtime.

The calculated and simulated ORIE figures show high values compared with the industrial OEE. The ORIE concept is intended to reveal how well the railway infrastructure system manages to deliver its agreed services in terms of train positions to the traffic operators. Therefore, high ORIE figures are required for punctual traffic. For example, a train delay-free journey for a passenger train requires 100% A and P values during that journey. ORIE reflects the infrastructure system's ability to make infrastructure available according to agreed plans independent of the actual capacity utilization, while OEE reflects the production system's ability to produce according to its full potential.

The major difference between the manufacturing industry and railway infrastructure is that railway infrastructure produces moving time slots that can be used for traffic operation. Since moving time slots cannot be stored, but can only be disturbed and parked and later on resumed or cancelled, this must be treated as the delivery of services. Consequently, the production system will be an intermittent one, where partial idling is necessary without a loss of capacity and availability.

### **5.3 Findings regarding research question 3**

The third research question deals with the issue of how to develop a maintenance link and effect model framework for railway infrastructure management. Paper V presents the conceptual link and effect model framework (LinkEM), taking into consideration the specific needs of the railway infrastructure manager, focusing on critical strategic areas determined by the nature of the railway industry and public requirements and regulations. The direct links between the overall objectives and the outcome measures for railway maintenance are in terms of health, safety, and the environment (HSE) and the return on maintenance investments (ROMI). The main performance driver for ROMI and HSE is the railway infrastructure integrity (RII). Adequate competencies, functional internal processes, and good internal and external relationships lay the foundation of RII.

The LinkEM model is built up by using a vertically aggregated PI subsystem, where the highest level in the subsystem is represented by the different critical strategic areas. In order to identify the specific key performance indicators (KPI) for the link and effect model's critical strategic areas (LinkEM-CSA), the subsystem needs to be broken down

into critical success factors (CSF), key result areas (KRA), and supporting KPI on one or more levels. A top-down approach is needed during the development phase, while a bottom-up approach is used for reporting. The LinkEM model is exemplified with some key performance indicators (KPI) for each CSA in Table 5.1.

*Table 5.1. Examples of KPI for the different critical strategic areas in the LinkEM model*

LinkEM CSA	CSF	KRA	KPI examples
ROMI	Budget deviation	<ul style="list-style-type: none"> <li>▫ Permanent way</li> <li>▫ Catenary / Power supply</li> <li>▫ Signalling / Telecom</li> <li>▫ Other objects</li> </ul>	Budget deviation for permanent way, catenary/power supply, signalling/telecom, and other objects
	Overall railway infrastructure effectiveness (ORIE)	Infrastructure availability, infrastructure performance, and infrastructure quality	Availability rate, performance rate, and quality rate
HSE	Health index	Reported 3rd party disturbances due to maintenance activities	Amount of reported disturbances due to noise, vibrations, platform lights, platform snow removal, and fallen tree protection programme
Railway Infrastructure Integrity (RII)	Infrastructure quality index	Permanent way	Level of track quality, urgent inspection remarks, Q-factor, and amount of defect sleepers
Processes	Internal process index	Information and analysis	Share of IT-system availability, confidence, and usefulness
Competences	Strategic competence provision index	IM organization	Strategic competence provision index

A discussion on the findings during the development of the conceptual LinkEM for the railway infrastructure manager shows that the model must be adjusted to meet their specific needs regarding railway infrastructure maintenance. What the infrastructure manager is striving for is a safe, available, and cost-effective railway system. The model should therefore provide the actual status for the infrastructure system independently of what and who is responsible for a train delaying failure, even if it is due to an extraordinary situation.

During 2007, Banverket moved from a traditional governmental authority organization to an organization more like that of an asset manager. In order to increase the availability and capacity of the infrastructure and prolong its useful life, the focus has moved from time-based maintenance to condition-based maintenance with a focus on the customer (traffic operation) needs; hence, the new organization is now set to adopt

a LinkEM model approach. All the key functions, such as the technical, economical, organizational, environmental, and safety functions, etc., are now in place at Banverket. The model can be considered to act as a backbone structure for Banverket's maintenance and operation activities in the near future.

Before a true condition test of the LinkEM model can be undertaken, it is necessary to prioritize and define the relative impact of the indicators in order to make it possible to take the right decisions in a trade-off situation. It is also important to validate LinkEM through simulation based on historical data, especially looking for changes in ROMI and HSE that cannot be explained by changes in any other CSA. If such changes occur, this might indicate that the relative impact of different performance drivers is misjudged or that important performance drivers are missing in the LinkEM, and that therefore the model might need to be re-configured.

#### **5.4 Contributions**

The study at Banverket shows that there are some indicators being used for the railway infrastructure for maintenance management that are not organized within the management hierarchy for decision-making. It is the first time that the identification and development of railway MPIs have been carried out at Banverket. Some of the identified MPIs are aggregated, such as the cost per track-kilometre MPI, reflecting different aspects of the railway infrastructure maintenance cost. Through analysis and benchmarking, the cost MPI can be broken down according to the type of activity, e.g. preventive/predictive and corrective maintenance, or according to the type of maintained infrastructure, e.g. the permanent way, catenary, and signalling.

A model developed for calculating the overall railway infrastructure effectiveness (ORIE) is presented in this thesis. Case studies performed on three track sections show similar ORIE figures that are significantly higher than the industrial OEE, and such high values are required for a punctual railway transportation system. The study indicates that ORIE must be calculated on a monthly basis, and it can be used as a key performance indicator by the railway infrastructure manager. It is also visualized that ORIE can provide important input and support in decision making for the infrastructure managers. The model developed for linking the different MPIs to the overall organizational objectives is presented in the conceptual LinkEM framework. The proposed framework provides a model for bridging the gap and linking the performed maintenance activities, so that they will support the overall objectives.

To conclude this research study, the main contributions are:

- The identification, analysis, and development of relevant MPIs for the effective management of the operation and maintenance of railway infrastructure at Banverket. Moreover, the development of MPIs which are not in use for decision making in the management hierarchy at Banverket (Paper I, II and III).
- The development and conceptualization of the overall railway infrastructure effectiveness model (ORIE) as a key performance indicator for the railway infrastructure (Paper IV).
- The development of the conceptual link and effect model framework (LinkEM) to support railway infrastructure managers in decision making (Paper V).

## 5.5 *Scope for further research*

There is always scope for undertaking further research on any research topic. Based on the findings of this thesis, some opportunities for further research in order to support continuous improvements of MPIs, ORIE models, and the LinkEM concept in the railway sector are:

- Further development, verification, and implementation of MPIs for the railway infrastructure management. One specific area of interest is the interface between the purchaser and the railway maintenance contractor in an open contractor market. Another area of interest is the MPI parameters related to railway RAMS (reliability, availability, maintainability, and safety)
- Further verification and implementation of the ORIE model to support the entire rail network, e.g. overcrowded track sections and double-line track sections. There is also scope for extending the ORIE model to include the impact of train dispatching and traffic operation to calculate the overall railway effectiveness, and for applying the ORIE model on the railway sector within or outside Sweden to improve management decision making, and to make it possible to compare the railway sector with other public transportation systems.
- Further development, verification, and implementation of the LinkEM concept to support the railway infrastructure manager's decision making. One specific area of interest is to automate the process of capturing necessary quantitative and qualitative data and information. Another area of interest is how to manage and transform the model and necessary data, for validation over time in a changing environment with changing requirements. There is also scope for generalizing the LinkEM concept in a wider perspective.
- Mathematical modelling and simulation of the MPIs to meet the future requirements of the railway sector.
- A further benchmarking study, to be undertaken to compare the MPIs amongst different railway infrastructures/sectors from wider perspectives, e.g. the EU perspective.
- Modelling and simulation of the LinkEM model for effective management decision making compatible with emerging remote maintenance.



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# *Paper I*



# Technical and Economic Evaluation of Maintenance for Rail and Wheels on Malmbanan

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**Summary:** This paper provides an overview of how maintenance costs for rails and wheels are distributed between infrastructure owner and rolling stock owner on the basis of a study performed in close co-operation with MTAB (Malmtrafik i Kiruna AB, iron ore transportation company), Banverket and Duroc Rail AB. This paper presents a technical and economic correlation between maintenance activities and decisions performed by MTAB, Banverket and Jernbaneverket. Technical aspects are generated by controlling rolling contact fatigue (RCF) failures and wear in combination with grinding. RCF damages such as head checks are a common problem on high rails gage corner, causing the main replacement cost for rails. To reduce replacement of rails caused by RCF a grinding program started 1997. The balance between controlled wear, with or without lubrication and grinding, are very important tools to ensure long life and effective maintenance operation for both the infrastructure and rolling stock. Rail profile measurement since 1997 gives an indication of parameters that have to be taken into account when choosing grinding strategy at Malmbanan.

Economic aspects are generated from different maintenance activities such as grinding and re-profiling wheel sets. The results give an indication of how different parameters affect maintenance performance. Aspects such as wheel/rail interface and car steering ability affect maintenance costs over the studied period.

**Index Terms:** Grinding, Wear, Costs, Wheel, Rail, Maintenance.

## 1. INTRODUCTION

In railroad heavy haul applications, grinding and lubrication are routinely used as a maintenance tool in curved track sections in order to reduce friction, wear and rolling contact fatigue (RCF). The cost of maintenance of wheel and rail for heavy traffic such as ore lines can be up to fifty per cent of the total maintenance cost of the rail/wheel system. For instance, proper lubrication can reduce wear rates by a factor of 20, Elkins et al. [1] and Waara [2]. Grinding programs can also produce significant cost savings for both the wheel and infrastructure owner, see Grassie et al. [3].

During the past 30 years axle loads have increased from 25 tons to 32.5 tons per axle, Allen [4]. This has been possible due to improvements in metallurgy, larger rail cross sections standardization of heat-treated wheels, development of new rail/wheel profiles and the extensive use of track lubrication and grinding.

Wear of rails and wheels has long been identified as a major reason for the high maintenance costs of rail infrastructure. A second major cause of the degradation of rail is rolling contact fatigue (RCF). As the wear rates of rail have decreased due to the factors described above and the axle loads have increased, RCF has become a more important problem.

If the wear rate drops below a certain value the rail surface reaches its fatigue limit before it can be worn away. Preventive grinding programs are designed to grind away a thin layer of material from the rail surface before RCF cracks can develop. The depth to which RCF cracks penetrate determines the amount of material that has to be removed. Lubrication can slow the initiation of surface and contact fatigue cracks, but it might accelerate crack propagation.

To optimize the life of railway infrastructure, wear rates, the development of RCF cracks and grinding have to be carefully balanced. The rate of wear is larger if softer rail steel is used and any damage or cracks are worn away before the critical deformation is reached. However, while no

cracks are observed in the softer rails, they are consumed earlier by wear, see Pointner and Frank [5]. A hard rail will not wear as much, but after a certain time it will suffer from RCF and may need replacement having suffered only a small amount of wear. Also, lubrication, which reduces wear, shifts the failure mode from wear to crack formation.

A systematic experimental test program of wheel/rail adhesion and wear was undertaken using the Illinois Institute of Technology's 1/4 scale wheel rail simulation facility, see Kumar et al.[6]. The tests determined the effects of axle load, adhesion coefficient, angle of attack, class of wheels and mode of operation. Wear was measured by overlaying profiles of the wheel/rail surface at different stages of wear and measuring the change in cross-section area. The hierarchy of influencing parameters for wheel/rail wear in order of priority was given as:

- 1) rail curvature or angle of attack
- 2) adhesion coefficient
- 3) axle loads

Lubrication improves interactions at both micro and macro level of the wheel/rail interface. However, today no general model or strategy that describes the interactions between wear, lubrication and grinding at the wheel/rail interface exists, see Clayton [7] and fundamental studies have only been carried out during the last thirty years. Models that have been developed to simulate real field phenomena are often designed for specific problems and cannot be extrapolated to the general situation.

More studies have to be completed before a general model can be developed to treat combination of technological-economic maintenance activities such as grinding and lubrication correlated with stringent cost efficiency evaluation. The challenge is in combining the outcomes of technical maintenance activities with an economic analysis.

## 2. WHEEL/RAIL INTERACTION

The ore car is a four-axle heavy-haul freight wagon specifically designed for the transportation of ore. This so-called BoBo vehicle contains a car body sitting on two two-axle bogies. A side view of an ore wagon is shown in figure 1.

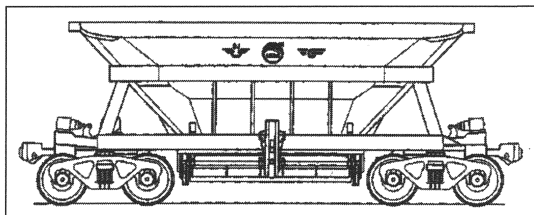


Figure 1. Four-Axle Ore Wagon with Three-Piece Bogies.

The bogies are so-called three-piece bogies, where the bogie frame consists of two side frames and a bolster coupled together into a bogie frame.

In service, the wheel and rail profiles change substantially due to wear and the fleet of trains passing over a section of rail will have a range of wheel profiles at any one time, ranging from new to worn. Simulations have been performed in order to investigate the wear rate sensitivity as function of the wheel/rail profiles. In this investigation steady-state curving of a Malmbanan ore car was investigated using a multi body dynamics model and the numerical algorithms implemented in the commercial software GENSYS [8]. The model was validated using field measurements, see Berghuvud [9]. Seven different wheel profiles, including a nominal S1002, were used to compare the influence of wear rate as function of wheel profile status. The vehicle is run on designed track with new (nominal) UIC60 rail profile, see figure 2.

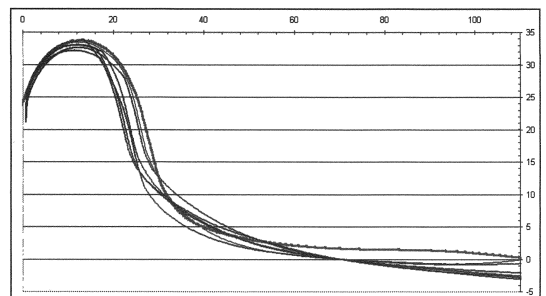


Figure 2. Measured in service measured wheel profiles (dark) and a new nominal (gray) wheel profile S1002. The scales is in mm.

### 2.1 Simulation Results

Changes in wheel profile have only a small influence on the contact forces, contact dimensions and positions on the high rail for the trailing wheel set. The contact conditions for the other contacts are significantly influenced by the change of wheel profile. Calculated energy dissipation is used as an indication of the amount of expected relative change of wear for the different profiles, [9]. High difference in creepage and tangential forces gives high difference in energy dissipation at the wheel/rail interface. Some combinations of profiles produce more severe wear than with a single contact patch, see table 1.

The results presented here should be viewed upon as examples of what types of results the developed model can support used in maintenance planning.

**Table 1. Energy dissipation for different wheel/rail profiles.**

Nominal rail profile		
	High Rail (J/m)	Low rail (J/m)
Leading wheel set	180-245	90-135
Trailing wheel set	45-55	45-130
Worn rail profile		
	High Rail (J/m)	Low rail (J/m)
Leading wheel set	50-250	75-175
Trailing wheel set	10-50	10-75

**3. RAIL PROFILE MEASUREMENT**

Transverse profile measurements of outer and inner rails were performed at 60 positions along the rail located on Malmbanan. Banverket used the MiniProf Rail system to measure the profiles. The profiles were measured shortly before and after the grinding of the rails. Results of these measurements are presented in different ways and the MiniProf Rail system provides an easy, portable tool to monitor and evaluate rail profiles. The system is a useful aid for rail grinding operations, providing instant information on profile and metal removal.

MINIPROF is a standard system for the determination of rail profiles in the field. The sensing element consisted of a magnetic wheel 12 mm in diameter attached to two joint extensions. When the magnetic wheel was moved manually over the rail surface, two angles were measured and stored in a computer. The profile was then transformed to Cartesian co-ordinates. Marks on the edge of the rail were used to ensure that the measurements were performed at the same location each time. Further information on the MINIPROF system can be found in Esveld and Gronskov [10]. The accuracy of the MINIPROF system is of the order ± 0.015 mm for similar profiles.

**3.1 Rail profile results**

A grinding program was initiated by The Swedish National Rail Administration (Banverket or BV) 1997 at Malmbanan, the Swedish ore track between Kiruna and Riksgränsen. The grinding is primarily to remove RCF, which has been an increasing problem in recent years. In the seventies, the axle load was increased on this track to 25 tonne and again in 2001 a new ore care was introduced giving 30 tonne axle loads. This rise in axle load increases the susceptibility of the rail to RCF. In 1997 a new asymmetric profile MB1 was introduced. As the contact path in this profile is wider than previous profiles, the onset of RCF should be delayed. Before the grinding program started the curved track was prepared with 60 measurement points and 10 points on the tangential track. BV has carried out rail profile measurements before and after the grinding activities every year since 1997. The grinding campaign is here evaluated at

the ore track between Kiruna and Riksgränsen with a total length of 127 km.

To evaluate the combined effects of the track wear and the grinding, the track is divided into three categories: track curves with radius under 800 m, track curves with radius over 800 m is another group and tangential track, see table 2. In this paper, the yearly wear and the amount of material removed due to grinding is evaluated at these points. The yearly wear and grinding indicate the proportion of the life of the rail consumed according to BV's regulations (BVF 524.1 [11]), which indicate when the rail should be replaced.

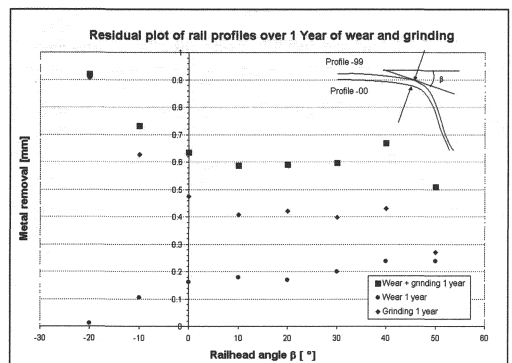
**Table 2. Grouping of grinding for Malmbanan.**

	Length [m]	Grinded/year
Radius<800	51 791	100%
Radius>800	30 526	100%
Tangential track	48 220	33%

The tolerances for the ground profile compared to the reference profile have been changed during the period from 1997 to 2001 and nowadays the high rail diverge should be within +0.3/-1.0 mm on the railhead between -20/50 Miniprof degrees. A minimum metal removal is set to be of at least 0.2 mm in the area between 0° and 45° every 23 MGT.

The grinding results were evaluated over year 2000 and the wear over 10 months in 1999/2000. The wear results over 10 months are afterward compensated to correspond to wear per annum based on ore traffic volume.

The results of grinding and wear from traffic at the high rail for curves under 800 m is summarized in figure 3. The mean yearly traffic wear was around 0,18 mm at β=10° (β is Miniprof degrees according to figure 3). As the figure shows, the average material lost on the railhead to grinding per annum was 0.4 mm and when coupled with the wear, 0.6 mm was lost on the railhead per annum.



**Figure 3. The mean wear for one year and the amount of removed material during one grinding campaign is presented in this diagram.**

The measurements in figure 3 also show that traffic wear and grinding wear is of the same order in the 45-50 degree region. Grinding wear (0.4 mm) is twice as much as traffic wear (0.18 mm) for the 10-40 degree region. The train/track simulations, table 1, indicate that it could be possible to use an other portion of the existing worn wheel profile population distribution to increase the traffic wear to the same amount as the total wear presented in figure 3. This might produce higher rail wear in the 10-40 degree region and hence save costs by prolonging the grinding intervals. The rail profile was evaluated due to the rail grinding campaign year 2000 as well as the wear for one year. This yearly rail profile evaluation will help to predict future renewal of rail. Around 20 profiles for high respective low rail and 10 profiles at tangential track were measured and used in this investigation. The profiles used here were measured before and just after a grinding campaign each year. The profiles were considered of measuring quality chosen among 60 profiles in curves and 20 profiles at tangential track. When evaluating the rail wear there are two measurement values to consider according to the Swedish standard for railhead wear measurement. The vertical wear on the railhead  $h$  and the flange wear  $s$ , 14 mm down from the top of a new rail profile ( $\beta=36.4^\circ$ ), see equation 1.

$$H = h + \frac{s}{2} \tag{1}$$

Once  $H$  reaches a critical value,  $H_{limit}$  determined by a rail classification system, the rail must be replaced. The rail life is separated into 5 different groups, high and low rail under 800 m curve radius, high and low rail over 800 m curve radius and tangential track. One third of the tangential track is ground each year. The yearly wear on the tangential track railhead is estimated to be the same as low rail in curves with radius  $> 800$  m. The cost of replacing the one rail side was 800 SEK/m rail (high rail=one side, low rail=one side) (87,5 USD\$/m). The rail life is evaluated in the Miniprof software and presented in table 3.

**Table 3. Calculated rail life, using equation, 1 and costs evaluated from one year of wear and one grinding campaign.**

	Curve radius <800		Curve radius >800		Tangential track
	High rail	Low rail	High rail	Low rail	
Life [years]	13,6	17,7	19,6	23,9	38,9
Length [m]	51791		30526		48220
Cost [MSEK]	3,05	2,34	1.25	1,02	1,98
Yearly needed rail investment cost [MSEK]					9,6

These lives are derived from equation 1 and assume that railhead material is removed only by traffic wear and

grinding. Using both traffic and grinding wear rates from rail profile measurements i.e. figure 3 is one example, it is possible to predict the total yearly vertical railhead wear ( $h$  mm/year) and the total flange wear ( $s$  mm/year) and hence calculate  $H$  mm/year for the different track sections. The safety wear limit  $H_{limit}$  is set to 11 mm for the 50 kg/m BV50-rail profile used. The average rail life is then calculated as the ratio between the safety limit  $H_{limit}$  and the measured  $H$  value of the studied section. Using this approach it is also possible to estimate the number of meters of rail in each section, that needs to be replaced due to railhead material loss each year. These calculations suggest that  $12000 \pm 1900$  m rail need to be replaced each year average, which corresponds to a yearly investment of 9,6 million SEK (1,05 million USD\$). The yearly cost of grinding this track should be around 4 million SEK, giving a total yearly maintenance cost of 13,6 million SEK.

#### 4. ECONOMIC EVALUATION

An economic analysis of Malmbanan made 1995 indicates that about 50% of the total cost for maintenance and renewal was related to traffic and 50% was related to other factors such as signaling, electricity, snow-clearance etc. Costs for maintenance and renewal of rails on some lines account for more than 50% of the costs related to traffic. The results from this analysis have made it possible for the mining company LKAB to start up the 30 tons traffic with new wagons and locomotives on the Malmbanan line in year 2001. The focus in this economic evaluation is therefore to examine the costs generated by maintenance and the replacement of rails and wheels.

The approach is to combine the technical and economic modelling to determine how decisions based on technical activity affects the economy of the wheel/rail interface. In this case the technical activity of concern is rail grinding.

##### 4.1 Data collection

Data were collected from a literature search, different databases at MTAB, Duroc Rail, BV and Norwegian Rail and from interviews with personnel at the different companies. It was found that primary data is located at different levels for each company, depending on internal needs and demands. It was also found that economic costs and results are presented and based on technical aggregated data, resulting in difficulties in comparing between different companies at primary information levels. Therefore it is not possible to determine how every technical detail affected the system.

##### 4.2 Infra structure maintenance activities and costs

The rail-grinding project on the Malmbanan line between Kiruna and Riksgränsen reduced the requirement for rail

replacement from approximately 25 000 meter to 5 000 meter annually, as shown in figure 4. In this paper the rail life due to wear and grinding was evaluated on the basis of material loss rates and the mean renewal level is suggested to be 12000±1900 m over the same distance. In figure 4 it is possible to see a very significant reduction of rail renewal during the first years after the grinding campaign started. However, it is likely that this effect is transient and is simply delaying the requirement for track replacement. After some years of grinding the track will become degraded and an accumulated volume of rail will need to be replaced. The track status is not considered in this paper and therefore it is not possible to make any more exact investment calculations. However it is likely that the cost level will be a bit over 13,3 million SEK. However this cost level is significantly reduced when compared with the years 93,94,95 and 96. The result so far in economic terms is a reduction in rail maintenance costs of approximately 50%.

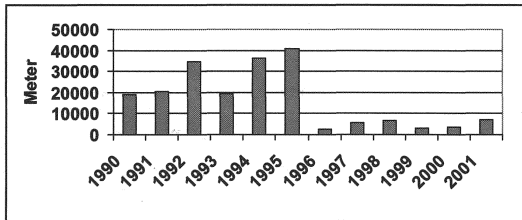


Figure 4. Quantity of annually rail renewals on the ore track between Kiruna and Riksgränsen.

In 2000 Norwegian Rail changed their maintenance strategy, deciding that renewal of rails shall be done only on the basis of MINIPROF data or similar objective measures. This new strategy has halved rail renewal demands. So far, economic results indicate reduced maintenance costs, but no deeper analyses are made to confirm new cost levels.

#### 4.3 Ore car maintenance activities and costs

MTAB's maintenance program is based on experience and relates to driven distance for the ore car. In practice this means that the ore car wheel set is checked every 30 000 kilometer. Normally the wheel profile lasts for approximately 120 000 kilometer, after which it is necessary to re-profile the wheel and its geometry. Each wheel can be re-profiled 4 or 5 times. The type of wear/damage that dominates changes over time, but analyses shows that as one wear mode decreases another mode increases. More important is that the total number of wheel sets replaced per annum decreased, as shown in figure 5. However, at this stage it is too early to link the reduction in wheel set replacements to the ongoing grinding program.

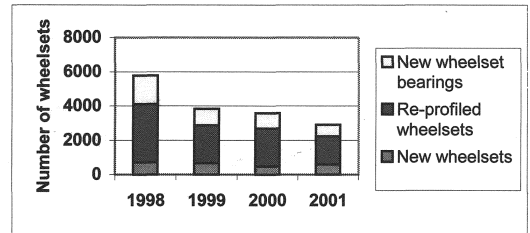


Figure 5. Number of worked/shifted wheel sets

The major problem for MTAB is that the cost of replacing wheels is at least ten times more than re-profiling an old wheel. During the last year, MTAB has introduced a new wheel material with better wear resistance. This could be one of the explanations why the turnover of wheel sets decreased. The distribution of wheel age in the population of wheels is not constant over the years and this will affect the cost levels between different years. Different wheel wear modes will require different re-profiling. If one wear mode is very fast for short periods this can result in high maintenance costs if that particular wear mode results in shifting to new tires. Therefore it is possible for MTAB to incur higher overall costs even if the total number of worked and shifted iron ore wheel sets decreases, which also happened in year 2001.

#### 4.4 Results from an economic perspective

Analysis made from an economic overview perspective for the Malmbanan as a transporting system, shows that maintenance processes and strategies related to rail/wheel interaction do not seem to affect the total system in a negative way. However, once again the problem is that all comparisons have to be made at high aggregated data levels, which make it possible for subsystems to show different results.

### 5. DISCUSSION

Using train/track simulation in maintenance planning provides a powerful tool to predict changes in wear due to different rail/wheel profile strategies. Simulations and field observations clearly suggest that, by altering load traffic direction of cars would produce longer wheel life. The results in table 1 indicate that for the same three-piece bogie a leading wheel set can have up to five times higher wear than a trailing wheel. Some years ago MTAB had problems with high leading wheel set wear. They introduced a logistic change of loaded car direction and hence prolonged the leading wheel life. This kind of train/track simulation is a powerful low cost tool for estimating and predicting traffic wheel and rail wear. It can be used in the optimization of wheel and rail profiles on a traffic routes such as Malmbanan. A technically optimized wheel/rail profile

combination can be used in maintenance planning to decide on new strategies such as maintenance intervals for both rail and wheels.

The grinding project was an important step to make it possible to increase the axle loads to 30 tonnes. The grinding program was also one of the main strategies to prolong the renewal of existing 50 kg rails. Even after only a short time, there are measurable costs savings for both infrastructure and traffic. However, this procedure may simply be delaying the costs and an accumulated rail renewal will appear in the future due to degradation of the rail. It is too early to suggest, that for the long time run, the introduction of grinding has led to decrease costs and an increase in rail and wheel life. Maybe future life cycle cost analysis can provide an answer. However, ultrasonic inspection is indicating that grinding has increased the number of rails replaced due to rolling contact fatigue.

This rail life investigation indicates that the maintenance program has delayed maintenance costs to the future and a suggested mean level of rail renewal is suggested. Optimizing the grinding process by for example using train/track simulations is one possible step to increase rail life, however it is uncertain if the economic potential is enough.

## 6. CONCLUSIONS

- The grinding campaign delays major replacement of rail to the future.
- The grinding program is evaluated to give a yearly cost of 13,6 million SEK included rail renewal and grinding campaign.
- Train/track simulations can be used as a tool in maintenance planning.
- Train/track simulation clearly suggests that by altering the load traffic direction of the cars it would be possible to obtain longer wheel life.
- Neither grinding campaigns on the Swedish side or objective measurements to increase rail life on the Norwegian side seems to affect the total system in a negative way.

## 7. ACKNOWLEDGEMENT

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## *Paper II*



## USE OF MAINTENANCE PERFORMANCE INDICATORS: A CASE STUDY AT BANVERKET

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### ABSTRACT

In Sweden, the national railroad system is owned and operated by the state which means that political and social considerations have to be taken in to account; e.g. safety and environmental impact as well as public demands for safe, reliable and cost-effective means of transportation. The railroad is therefore strictly governed by regulations and government legislations; containing technical limitations and financial targets, many of these are in use as performance indicators. In order to get a broader and better control of goal fulfilment, the Swedish National Rail Administration (Banverket) has introduced the balanced scorecard concept during the last year. In order to meet stakeholders' requirement, Banverket have modified the standard balanced scorecard. This paper presents a case study identifying the use of performance indicators by Banverket. We discuss the different types and forms of indicators used by Banverket. An attempt is also made to analyze the impact of such indicators on the organisational goal and strategy through a link and effect model. We also examine who owns these indicators, who uses them and for what purposes and whether these indicators conform to the recommended standards and prevalent regulations.

**Key Words:** Performance Management, Railway Engineering and Technologies.

### 1. INTRODUCTION AND BACKGROUND

Today there is no clear and unambiguous definition of performance indicators. Allander's (1997) definition of performance indicators concludes that performance indicators are measurements extended to a working environment. They are classified in seven main categories in order to highlight different activities in the organisation, namely; efficiency, effectiveness, productivity, quality, quality of working life, innovation and finally budget and profit. Wireman (1998) says that performance indicators are nothing else than just an indicator of performance. If the performance indicators are properly chosen and utilized, they will highlight opportunities for improvement within the organisations. In order to cover different aspects of the organisation, the indicators are arranged in a hierarchical structure similar to the organisational one. Therefore, it is important that the different indicators within this structure are defined with a top-down perspective, at the same time the indicators are connected to the corporate long-term objectives. At the top of the hierarchical indicator structure, financial indicators, efficiency and effectiveness indicators, tactical indicators, and functional indicators will follow corporate indicators respectively. Liyanage and Kumar (2002) define performance indicators as "a measure equipped with baselines and realistic

targets to facilitate prognostic and/or diagnostic processes and justify associated decisions and subsequent actions at appropriate levels in the organisation to create value in the business process". The development and implementation process for the indicators are similar to the previous one; a top-down perspective must be used, which is also recommended by Andersen and Fagerhaug (2002) as well as Engelkemeyer and Voss (2000).

Broadly, performance indicators can be classified as leading or lagging indicators. According to Liyanage *et al* (2001) is a lead indicator "a performance driver; i.e. a measure which drives the performance of the outcome measure". The outcome measure is simply the lag indicator. However, it is important to remember that an indicator, i.e. the measure, can act as both lead and lag indicators depending on in which situation the measure is used. Think of a process with several sub processes inside, the performance drivers of each sub process will be the lead indicators for the sub process. The result, i.e. the outcome measure of every sub process, will be the lag indicators to the same sub processes. These lag indicators will on the other hand be performance drivers to the main process, i.e. lead indicators to the main process. Sooner or later, this aggregation of indicators has reached a level inside the organisation that it is possible to see that these indicators can be seen as performance drivers for the organisation or company overall objectives. These performance drivers are normally called key performance indicators, which correspond to the definition made by Liyanage *et al* (2001) saying that key performance indicators is "a performance indicator with a strategic significance, which is perceived as critical under given business circumstances and preferably selected from a pool of performance indicators".

Kaplan and Norton (1992) introduced the balanced scorecard concept in 1992. The basic idea was to find a way of managing and measuring the company performance from a more holistic view, apart from financial performances. The old traditional way of measuring a company's performance, based on financial results alone, were found to be inadequate and inefficient, since all measures only reflect outcome results. In practice, the company was managed by looking into the mirror. The balanced scorecard concept introduced three more strategic perspectives in addition to the financial one, which were seen as critical to a company performance, reflecting not only the company's financial history but also its present and future performance; namely customers' perspective and internal business perspective reflecting the present performance, and finally learning and growth perspective reflecting what the company has to do to prepare themselves for the upcoming future i.e. innovations. The advantage of such a scorecard is that it is possible to manage and balance different activities within a company, even if the different activities can't be directly measured into economical terms. In order to develop and implement the scorecard into an existing company it will incorporate more than the top management, but to make sure that the overall objectives permeate all scorecard perspectives in the process, a top-down approach is necessary as well as the top management support. If necessary, the balanced scorecard can be broken down, further down into the organisation. According to Olve *et al* (1999) is the fundamental idea with the balanced scorecard that important values cannot always be related to financial measures. The balanced scorecard model is therefore suitable for long term non-business activities where profit is not the main purpose. This is especially the case for the public sector where long term public demands have to be taken into consideration e.g. public services as for example healthcare, education, environmental issues and transportation. The use of the balanced scorecard concept also gives the opportunity to highlight what will happen in the long term with different financial assumptions, i.e. how to act in the long term.

Another perspective is to study a so-called link-and-effect model. For an example introducing any performance measurement system which is meant to fulfil the needs of operations and maintenance processes in a company or a business unit, it is important that it focuses on critical-strategic areas determined by the nature of the specific business, business

concerns and public requirements and regulations, see Liyanage and Selmer (1999). The critical-strategic areas varies from business to business, but normally include areas as financial, health safety and environment, internal processes, plant technical status, competencies, and finally, internal and external relationships. When developing the performance measurement system it is important that it supports overall objectives for the company or the business unit, signifying a top-down approach. The direct link between overall objectives and the measures for operations and maintenance is in terms of return on investments (ROI) and health, safety and environment (HSE). The main performance driver for ROI and HSE is the integrity of the plant. The foundation for plant integrity is laid by adequate competencies, functional internal processes and good internal and external relationships. Therefore, when deriving the different performance indicators for each critical-strategic area to track the maintenance performance, it is also necessary to classify the degree of effect for every single indicator towards linked areas, i.e. create a logical cause-and-effect structure, to pinpoint those measures that are the key performance indicators. The final output from this is a link-and-effect model, showing how the operations and maintenance processes contributes to overall objectives for the company or the business unit. The same approach can be used to analyze an existing operations and maintenance performance measurement system.

As described earlier, there are similarities between the development and implementation processes for the balanced scorecard, performance indicators and the link-and-effect model. A properly developed scorecard gives normally the necessary key performance indicators that a company needs, and reflects the performance of the company from a holistic view. Using the link-and-effect model is suitable when it comes to the need of a measurement system for a more specific task, e.g. operations and maintenance processes, that's needed to be tied and connected to the general performance measurement system of a company. Examples of such companies are oil and gas industry, nuclear power plants, process industry and others where health, safety and environmental issues are significant for the society.

The Swedish National Rail Administration (Banverket) is the authority responsible for rail traffic in Sweden. Banverket follows and conducts development in the railway sector, assisting parliament and the government on the issues related to railway besides the operation and management of state track installations, co-ordinate the local, regional and inter-regional railway services, and provide support for research and development. In order to achieve that, Banverket's operations are divided into sectoral duties, track provision and production. The responsibility for track provision is imposed on five different track regions with the support from the head office. When it comes to maintenance, it is important to understand that none of the track regions do the maintenance by themselves, i.e. the maintenance is outsourced to different contractors. The national railroad system is today a complex system used for freight and passenger transportation, where political and social considerations have to be taken in to account; e.g. safety and environmental impact as well as public demands of safe, reliable and cost-effective transportations. The railroad is therefore strictly governed by regulations and government legislations; containing technical limitations and financial targets, many of these are used as performance indicators, see government appropriation letter (2002). In order to get a broader and better control of goal fulfilment, Banverket has introduced the balanced scorecard concept during the last year. In order to meet stakeholder requirement, Banverket have modified Kaplan and Norton's balanced scorecard by splitting the learning and growth perspective into two different perspectives and renamed them to co-operator perspective and development perspective. They have also renamed the financial perspective into commission perspective.

This paper presents a case study with the objective to identify the use of maintenance performance indicators by Banverket. We discuss the different types and forms of indicators used; who own them, who uses them and for what purpose et cetera. An attempt is made to

analyze the impact of such indicators on the organisational goal and strategy through a link and effect model. We also examine whether these indicators conform to the recommended standards and prevalent regulations.

## 2. METHODOLOGY

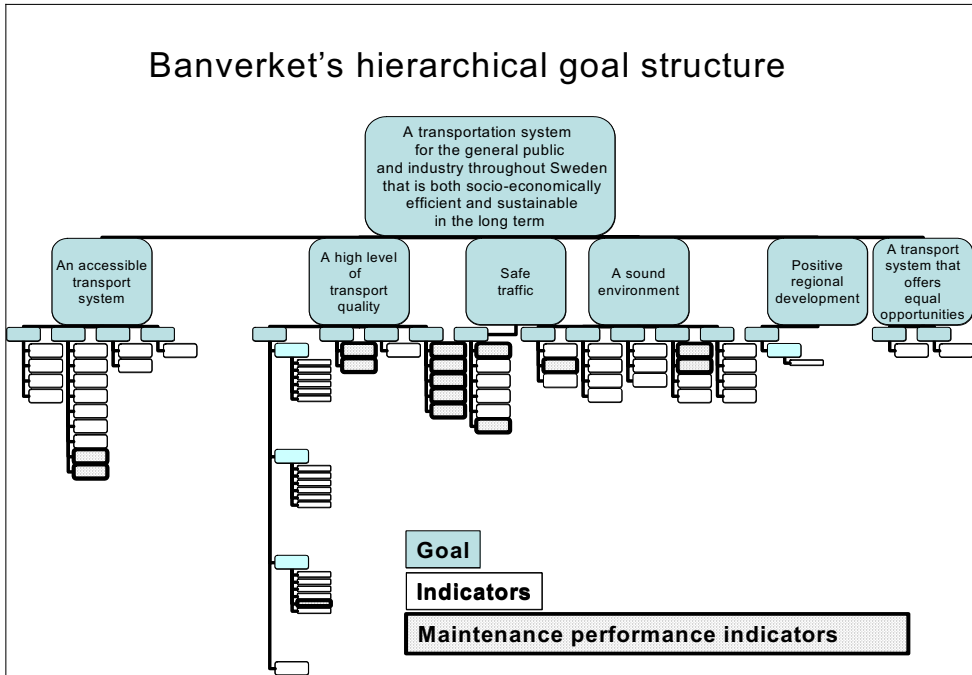
In order to make improvements in existing performance measurement processes supporting the decision making process for maintenance, it is necessary to study and map the requirements of the top management, i.e. the overall objectives for the business. These objectives will highlight what's important to focus on in the maintenance process. It is also important to map and analyse actual outcome measures for the maintenance performance measurement system, in order to see whether outcome measures meet or can be linked to overall business objectives or not, i.e. compare the requirements from top management with what they get from the maintenance performance measurement system. On the basis of this analysis, conclusions can be drawn.

In this study, overall business objectives and sub-goals are identified through the government appropriation letter for Banverket, as well as through Banverket's annual report. Both documents refer to year 2003. They contain, in addition to the objectives, a number of predefined measures that are supposed to be tracked in order to support the government evaluation of goal fulfilment for Banverket. These predefined measures, i.e. indicators, will in this study be analysed with the same approach used on Norwegian oil and gas industry to identify their maintenance performance indicators, as used by the Centre for maintenance and asset management at Stavanger University College. See Ellingsen *et al* (1999) and Kumar and Ellingsen (2000) for details. They conclude that maintenance performance indicators must relate to at least one of the sub-processes inside the maintenance process, namely; establishment of maintenance goals and strategies, establishment of maintenance program, planning, execution, and finally analysis and continuous improvement. Further, interviews are done with regional operations planners at Banverket to identify the use of maintenance related performance indicators at regional levels, as well as to identify if there are regional deviations in which indicators are in use. Identified maintenance performance indicators in use at Banverket, are then classified into lead or lag indicators, and examined whether they conform to the recommended standards and prevalent regulations. Finally, the impact of identified indicators on overall objectives are analysed with a link-and-effect model, as well as an examination to what extent the balanced scorecard is used and how it influences the use of maintenance performance indicators.

## 3. ANALYSIS OF PERFORMANCE INDICATORS AT BANVERKET

According to the appropriation letter and the annual report for Banverket, the overall objective for Banverket is; "a transportation system for the general public and industry throughout Sweden that is both socio-economically efficient and sustainable in the long term". The overall objective is broken down into six first level sub-goals, specifying the level of ambition in the long term. The six sub-goals are further broken down into seventeen different second level sub-goals, which are supported by almost 70 specified indicators. As seen, the goals within these documents are hierarchically structured.

When using the same approach, as was used for the Norwegian oil and gas industry, to identify maintenance performance indicators at Banverket 15 indicators can be identified as maintenance performance indicators. They are distributed as follows, namely; two of them support the sub-goal "an accessible transport system", 8 of them support "a high quality of transport", 2 of them support "safe traffic" and finally three of them support "a sound environment", see figure 1. An enumeration of these indicators is done in table 1.



**Figure 1.** Banverket's overall objective and six sub-goals.

From the interviews with the regional operations planners, it can be established that all regions uses the maintenance performance indicators attached to the sub-goal “a high level of transport quality”. These indicators are further broken down to reflect the same outcome measure but for the single type of components for the track system or broken down to reflect individual lines. The other three sub-goals and their accompanying maintenance performance indicators have not been used to support the maintenance process at a regional level. However, since Banverket have decided to implement the use of balanced scorecard, there are indications that some of these indicators are also now set on focus, and will be highlighted in those regions that have started to implement and use Kaplan and Norton’s balanced scorecard in a modified version.

**Table 1.** Identified maintenance performance indicators within the hierarchical goal structure at Banverket.

First level sub-goals	Second level sub-goals	Maintenance performance indicators	Relationship to BSC perspectives	
An accessible transport system	Improve the use of state infrastructure	<ul style="list-style-type: none"> <li>▫ Capacity utilization</li> <li>▫ Capacity restrictions</li> </ul>	<ul style="list-style-type: none"> <li>▫ Customers</li> <li>▫ Customers</li> </ul>	
	A high quality of transport	Decreased train delays	<ul style="list-style-type: none"> <li>▫ Train delays due to infrastructure</li> </ul>	<ul style="list-style-type: none"> <li>▫ Processes</li> </ul>
A high quality of transport	Decreased freight traffic disruptions	<ul style="list-style-type: none"> <li>▫ Hours of freight train delays due to infrastructure</li> <li>▫ Number of delayed freight trains due to infrastructure</li> </ul>	<ul style="list-style-type: none"> <li>▫ Processes</li> <li>▫ Processes</li> </ul>	
		Increased rail network maintenance efficiency	<ul style="list-style-type: none"> <li>▫ Number of train disruptions due to infrastructure</li> <li>▫ Q-factor (Degree of track standard)</li> <li>▫ Markdowns in current standard</li> <li>▫ Maintenance cost per track-kilometer</li> <li>▫ Traffic volume</li> </ul>	<ul style="list-style-type: none"> <li>▫ Processes</li> <li>▫ Processes</li> <li>▫ Processes</li> <li>▫ Processes</li> <li>Financial</li> </ul>
	Safe traffic	Reduced number of killed and injured persons	<ul style="list-style-type: none"> <li>▫ Number of accidents involving railway vehicles</li> <li>▫ Number of accidents at level crossings</li> </ul>	<ul style="list-style-type: none"> <li>▫ Customers</li> <li>▫ Customers</li> </ul>
			A sound environment	Reduced energy consumption Effective natural resource consumption
	<ul style="list-style-type: none"> <li>▫ Use of environmental hazardous material</li> </ul>	<ul style="list-style-type: none"> <li>▫ Innovation</li> </ul>		
	<ul style="list-style-type: none"> <li>▫ Use of non-renewable materials</li> </ul>	<ul style="list-style-type: none"> <li>▫ Innovation</li> </ul>		

The interviews also shown that there are two more commonly used indicators that can be identified as maintenance performance indicators, namely; total number of functional disruptions and total number of urgent inspection remarks. Those indicators, i.e. measures, have also been broken down in the same manner as the previous ones, and are used on both regional levels as well as reported to and used on a national one.

The result of this study shows that, in total, 17 maintenance performance indicators are identified at Banverket. Out of these, 15 are identified by studying the appropriation letter and the annual report for Banverket, while only 10 indicators are identified through the interviews with the regional operations planners; eight of them matching the documents and two additional ones. The eight matching maintenance performance indicators identified both through the documents and through the interviews, are supporting the sub-goal “a high level of transport quality” and reflecting the performance of the maintenance process in terms of costs, delays and track integrity. The same holds for the two additional indicators identified through the interviews.

#### 4. DISCUSSION

In this study, the use of maintenance related performance indicators at Banverket is carried out. Since they are the responsible authority for the entire Swedish railway sector, they also are responsible for track provisions. Though maintenance is a part of track provision, the management has decided not to do the track maintenance by them selves and subsequently maintenance is outsourced to different contractors. Banverket is providing the necessary



documents and specifications for the maintenance performance detailing objectives and strategies for infrastructure maintenance along with necessary resources.

A comparison with the link-and-effect model with the purpose to link the identified indicators through the interviews and the matching ones from the documents to different critical-strategic areas, gives that ROI, plant integrity and internal processes is covered. In order to analyse and find out what type of component for the track system that creates problems, or which line having the largest problem, these maintenance performance indicators are broken down to reflect these questions.

The seven remaining maintenance performance indicators found in the documents were identified by using the link-and-effect model, and reflects how the maintenance process can contribute to the overall objectives in term of health, safety and environment (HSE), as well as the degree of capacity utilisation of the track which can be linked to ROI. Why these indicators were not identified to be in use at a regional level, through the interviews, are not deeply analysed in this study. However, during the interviews it was stated that maintenance is done in order to keep the track in a safe mode, i.e. proper maintenance gives safe tracks. Since it is also compulsory for the track regions to report even these indicators, it can be assumed that they also are evaluated even at a regional level, but not necessarily mentally linked to maintenance.

During the interviews two major problem areas came up for discussion. The first one reflected the problems of knowing the actual use of the tracks in terms of gross tonnage and numbers of passengers. The second one reflected upon the fact that the economical account system doesn't have the ability to show the costs for specific maintenance tasks or show the costs related to a specific type of components.

Liyanage *et al* (2000) discuss the importance of defining the degree of ownership and responsibilities to control a specific indicator, saying that the ownership and responsibilities to control an indicator only can be laid on those who have the ability to influence it. Since the track regions are responsible for the track provision, including maintenance even if it is outsourced, they are both the owners and also have the responsibility to control the different maintenance performance indicators. It can also be stated that they confirm to prevalent regulations, since it's mandatory to report them.

In those track regions where the balanced scorecard is introduced, a broader maintenance perspective has emerged. This is especially the case for the northern track region, where also the HSE issues are taken into account as well as the degree of track utilisation, visible in the balanced scorecard's internal process perspective. In the scorecard's customer perspective exist a measure that can be linked to the link-and-effect model's critical-strategic area named relationships, as well as the scorecard's co-operators perspective can be linked to the critical-strategic area named competences. A summary of the balanced scorecard in use at the northern track region, gives that the scorecard reflects all the critical-strategic areas in the link-and-effect model. Though, it is important to remember that the scorecard doesn't reflect the executive parts of the track maintenance process, it's only reflecting the outcomes of it.

## 5. CONCLUDING REMARKS

In order to identify necessary maintenance performance indicators (MPI), or as in this case study, analyse which performance indicators in a pool of indicators that can be classified as MPI, there exist methods that can be used. In this case study a link-and-effect model is used, implying that several critical-strategic areas must be supported by a number of performance indicators in order to cover the whole spectra of both the performance and outcomes from the maintenance process, as well as that maintenance can contribute to fulfilment of business overall objectives in terms of return on investments (ROI) and health, safety and environment (HSE). The other critical-strategic areas in the model are technical integrity, processes,

competencies and relationships. There are also done interviews at all track regions at Banverket to identify the use of common MPI.

To summarise the findings in this case study, there are 15 MPI identified in the appropriation letter and the annual report for Banverket. They are linked to the critical-strategic areas ROI, technical integrity and processes. The MPI are reflecting four out of six sub-goals for Banverket. Through the interviews 10 MPI can be identified, where eight of them match the MPI identified through the documents. The matching MPI all reflects the sub-goal “a high level of transport quality”. Therefore, the common maintenance related performance indicators in use at regional and central level in Banverket, can be identified to the number of ten MPI reflecting outcome measures for the maintenance process, i.e. lag indicators supporting the sub-goal “a high level of transport quality” plus two more indicators, namely;

- Train delays due to infrastructure
- Hours of freight train delays due to infrastructure
- Number of delayed freight trains due to infrastructure
- Number of train disruptions due to infrastructure
- Q-factor (Degree of track standard)
- Markdowns in current standard
- Maintenance cost per track-kilometer
- Traffic volume
- Total number of functional disruptions
- Total number of urgent inspection remarks.

Today some of Banverket’s track regions have introduced and started to implement the use of Kaplan and Norton’s balanced scorecard in a modified version, where especially the northern track region’s balanced scorecard must be highlighted, since it contains and reflect different aspects of the maintenance process and its contribution to overall objectives. A comparison with the link-and-effect model, gives that it is possible to link all the performance indicators in the scorecard to a corresponding critical-strategic area in a way that all critical-strategic areas are covered.

## ACKNOWLEDGEMENTS

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## *Paper III*



# Maintenance performance indicators (MPIs) for benchmarking the railway infrastructure – a case study

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## Abstract

**Purpose** - For railway infrastructure, benchmarking is an effective tool that can support the management in their pursuit for continuous improvement by the use of maintenance performance indicators (MPIs). Hence, there is a need to study and link the MPIs with benchmarking. This paper presents case studies dealing with the application of benchmarking and maintenance performance indicators for the railway infrastructure. The studies were conducted at Swedish National Rail Administration (Banverket) and at the Norwegian Infrastructure Manager (Jernbaneverket); the Norwegian part of the Iron Ore Line between Kiruna in Sweden and Narvik in Norway.

**Methodology/Approach** - In this study, the results from two cases are compared and analyzed. The benchmarking data of railway infrastructure are retrieved, classified and analyzed for best practice improvement.

**Finding** – MPIs can successfully use benchmarking as a tool for improvement by learning from within or other organizations for continuous improvement which is a rather new phenomenon in the railway industry.

**Research limitations** – Each railway infrastructure is unique due to its geographical locations and constraints, besides the organization, management and other resources. These factors need to be considered while benchmarking the railway infrastructures.

**Practical implications** – The results obtained in this case study can be used by the railway infrastructure managers for continuous improvements. Also, other relevant MPIs as required by the railway infrastructure managers can be benchmarked in the similar manner.

**Originality/value** – The paper presents a structured way for continuous improvement of railway infrastructure by using MPIs for benchmarking.

**Keywords** – Benchmarking, maintenance performance indicators, maintenance cost, Swedish railway infrastructure

**Category of paper:** Case study paper

## 1 Introduction

Maintenance is one of the largest controllable expenditure for the railway industry, as it could reduce cost; improve equipment effectiveness, reliability and performance. Management of railway infrastructure is the mutually supportive activities and interaction amongst all stakeholders involved in the infrastructure needs, procurement, testing and installations, operation and maintenance, and replacement. Successful implementation of railway infrastructure system and its utilization can result in performance enhancement and cost reduction, while providing a dependable and sustainable system. Implementing effective maintenance programs for the critical railway infrastructure system can control the loss of performance and revenue due to unexpected breakdowns. Therefore, contribution of maintenance to asset performance is a problem of both risk and value (Liyanaage and Kumar, 2002).

The measurement of maintenance performance has become an essential element of strategic thinking of assets owners and managers. Also, without having a formal measurement system of performance, it is difficult to plan, control, and improve the maintenance process. Performance measurement of railway infrastructure system provides a basis for improvement, as without measurement improvements achieved cannot be judged. Maintenance performance measurement is a complex task, since multiple inputs and outputs are involved in the process (Parida et al, 2003). Maintenance performance indicators are used for the measurement of maintenance performance, as performance indicators are just that of an indicator of performance (Wireman, 1998). An indicator is a product of several metrics (measure), when used for measurement of maintenance performance in an area or activity; is called the maintenance performance indicators. Overall equipment effectiveness (OEE) is used as a key performance indicator for the manufacturing industry continually looking for new ways to reduce down time, costs and waste, operate more efficiently, and achieve more capacity. The three elements of OEE; availability, performance speed and quality helps to determine the impact of the performance of an individual piece of equipment, the concept of which can be applied for the railway infrastructure.

Benchmarking is used for business development, as well as for improving efficiency and effectiveness of maintenance process in any industry. Though introduced in the early 1990's, benchmarking provides a basis for learning from the established business leader and provides a road map for performance improvement. Benchmarking is an effective tool which supports the management in their pursuits of continuous improvement of their operations. Thus, benchmarking helps in developing realistic goals, strategic targets and facilitate the achievement of excellence in operation and maintenance (Almdal, 1994).

This paper discusses the problem domain of performance measurement with relation to benchmarking for the railway infrastructure and finding a linkage of MPis with benchmarking. Thereafter, a case study from Swedish and Norwegian rail road sector is presented to link the MPis with benchmarking process.

## **2 Benchmarking for railway infrastructure**

Railway Infrastructure Managers, world over are putting high demands to improve their efficiency using internal methods and measurements (Jernbaneverket, 2004, Banverket, 2004, ORR, 2004, Banförvaltningscentralen, 2004). Benchmarking is used more and more to learn from each other's experience, as the railway history in Europe is having similarity of governmental control. Lot of changes has taken place for the European railway in the last decade. Deregulation, privatization and outsourcing have created new situations, new organizations and new structures for collecting decision support data. More and more authors have reported that; maintenance today is considered from a more holistic point of view (Dunn, 2003); as an integration of production asset management and maintenance management (Peterson, 1999, Woodhouse, 1997) and maintenance is not longer viewed as a cost-profit centre, since it creates value to the business process (Liyanage and Kumar, 2002, Liyanage and Kumar, 2003).

Railway industries today are compelled to run leaner, reduce waste, improve quality and maximize the infrastructure effectiveness. It is essential that monitoring and measurement is to be understood to increase its capacity utilization and effectiveness. A proactive approach using dynamic variables influenced by the six big losses, like: failure from breakdown, set up and adjustment, idling and minor stops, reduced speed, process defect and reduced yield can be used for measuring the effectiveness of the railway infrastructure (Nakajima, 1988, De Groote, 1995).

The meaning of the word benchmark refers to a metric unit on a scale for measurement. Benchmarking will mean differently for different authors and for industry applications.



Therefore, benchmarking is still not well defined as over 42 definitions are available (Sarkis, 2001). From managerial perspective, benchmarking has been defined as a continuous, systematic process for evaluating the products, services, and work processes of organizations that are recognized as representing best practices, for the purpose of organizational improvement (Sarkis, 2001). As per Wireman (2004), benchmarking is defined as; the search for industry best practices which lead to superior performance. The term best practices enable a company to become a leader in its respective marketplace. Benchmarking is a continuous improvement tool which is used by the by companies that are striving to achieve superior performance in their business. Benchmarking also provides a deep understanding of the processes, parameters and skills that create superior performance.

All successful benchmarking projects starts with an deeper understanding and better knowledge regarding organization's own processes; i.e. to learn about own technical process and get the core business under control to be able to learn from others (Wireman, 2004). An essential part of benchmarking is to analyze the management skills and attitudes and to allow them to be enablers. Enablers and critical success factors can be found anywhere and they work over all kinds of boundaries, e.g. political, industrial and geographical. The first step is to start with an internal analysis to get true knowledge and understanding of its own internal processes, so it would be possible to recognize its own differences with the benchmarking organizations. The second level is benchmarking with similar industry/competitive and the third is to benchmark for best practice.

As per Wireman (2004), it is important that the areas (enablers) and the success factors for good performance need to be identified, so that the smallest denominator or a common structure that are important to compare can be described in indicators or other types of measurements, often presented as percent (%), in order to make the benchmarking for an organization a success. Some of the enablers for data collection are; man hour, material cost, cost for preventive maintenance, predictive maintenance and maintenance contracting. After benchmarking, the results are used for improving and developing core competence and core business leading to lower cost, increased profit, and better service towards the customers, besides, increased quality and continuous improvement. The maintenance management impact on return on fixed assets (ROFA) can be measured by two indicators, namely (Åhren et al, 2005);

- maintenance cost as a percentage of total process, production, or manufacturing cost
- maintenance cost per maintained unit expressed in length meter, square meter, etc.

Experiences from different benchmarking projects in US have identified some thumb rules that can be used to evaluate the results as well as suggestions for future actions (Wireman, 2004, Wireman, 1998). One of the criteria for benchmarking result is the ratio of corrective maintenance with total maintenance and a level higher than 20 % indicates a reactive situation which needs to be controlled by the management. Another criterion, which indicates reactive situations in the maintenance process, is the high overtime cost, as labor cost is a cost driver for maintenance. The European Federation of National Maintenance Society's (EFNMS) Benchmarking Working Group have worked on the definition for benchmarking and suggested 16 different areas important to get data for benchmarking. The definitions and indices are now approved by the EFNMS Council (EFNMS, 2002).

A case study at Banverket covering nine track areas shows that the portion of corrective maintenance varies between 22 – 44 %, i.e. a factor of two (Espling, 2004). The focus was on maintenance costs, failure statistics, inspection remarks, and train delays. Another MPI; maintenance cost varies greatly per asset or per track meter unit among the compared track areas due to asset standard, type of wear, climate and how they are used. The variation between the track areas is also for this case a factor of two. An identified problem area is that

infrastructure managers usually define the work in their own way and fail to use the prescribed structure of data collection for corrective and preventive maintenance correctly.

In the international benchmarking project InfraCost, the project focused on the life cycle costs in terms of investments and renewals, maintenance, and network operations (Stalder et al., 2002). The results indicated that the maintenance cost range was wide between the different rail networks as well as the maintenance and renewal strategies among the infrastructure organizations which differed significantly. Due to different accounting policies and budgets, only highly aggregated costs can be compared to each other if they can be expected to cover the same type of activities with the same type of requirements, i.e. tracks, switches and catenaries (Stalder et al., 2002). Factors related to the network complexity; such as the density of switches, bridges, tunnels, curvature, and traffic load are important cost drivers.

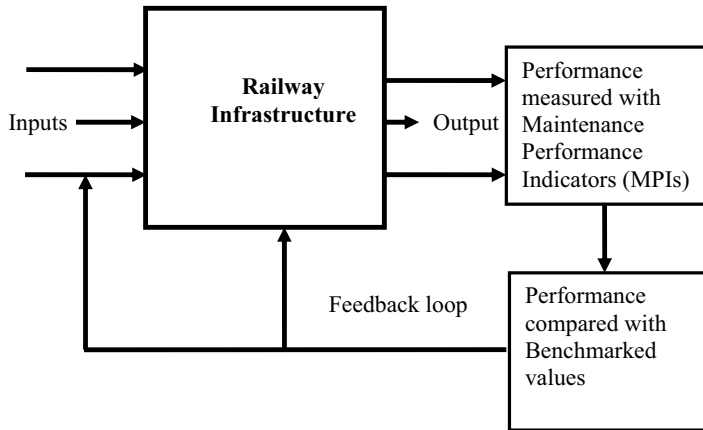
From benchmarking point of view, there is a need to study the maintenance benchmarking for railway infrastructure and also, to find a linkage between the MPIs and the benchmarking. In this paper, an attempt has been made to present a case study carried out at the Swedish National Rail Administration (Banverket) and Jernbaneverket which is the corresponding infrastructure manager organization in Norway. The case study compares the use of maintenance performance indicators (Åhrén and Kumar, 2004, Åhrén, 2005) with some of the benchmarking results. Besides, maintenance strategies, i.e. proactive or reactive, impact of the MPIs like; maintenance costs and the ratio of unplanned maintenance are also considered. Some of the MPIs used by various organizations abroad provide Banverket an opportunity to benchmark its operation internationally to improve its own performance.

### **3 Linking MPI with benchmarking**

MPIs are used by the companies to understand the present maintenance status and the opportunities for improvement. MPIs identify the weak spots in the maintenance process which can further be analyzed to specify the problem and ultimately finding a solution for best practices. The difference between MPIs and benchmarking must be understood. MPI and its use is an internal function for the organization, where as benchmarking is an external goal that is recognised as an industry standard. It is also important to learn the method of deriving the benchmarked figure. Therefore it is required to understand the enablers and success factor for the benchmarking. Benchmarking is also one of the key parameters for continuous improvement process, as continuous improvement is an ongoing evaluation program using the benchmarking.

MPIs can be used for identifying the areas of potential improvement and benchmarking. For example; MPIs can indicate the ratio of corrective maintenance to preventive maintenance is 35:65, which shows a higher level of corrective maintenance figure i.e. more than 20% industry benchmarked figure. So, the failures and failure reasons need to be analysed for reducing the number of corrective maintenance and converting these failure to preventive or predictive maintenance.

The MPIs measures the output of the railway infrastructure with the standard set by the railway management. These measures are compared with the benchmarked values of the railway industry and the deficiencies are analyzed and used as a feedback to the inputs and/or railway infrastructure system. The concept of linkage between the MPIs with benchmarking is used for achieving the effectiveness for the railway infrastructure. See Figure 1.



**Figure 1. Linking MPIs with benchmarking for effectiveness of railway infrastructure**

#### 4 Case study

Studies were undertaken at Banverket in Sweden and at Jernbaneverket in Norway, where the maintenance performance indicators were identified for application and to study the maintenance benchmarking for railway infrastructure. Also, a linkage between the MPIs and the benchmarking for infrastructure’s effectiveness and continuous improvement was studied and analyzed.

##### 4.1 Methodology

In this study, the results from two case studies carried out at Banverket and Jernbaneverket are compared and analyzed. In the first study, the objective was to identify the maintenance performance indicators in use at Banverket (Åhrén and Kumar, 2004, Åhrén, 2005). The second study was conducted at the Norwegian Infrastructure Manager (Jernbaneverket); the Norwegian part of the Iron Ore Line between Kiruna in Sweden and Narvik in Norway (Åhrén and Espling, 2003). Since, Norwegian infrastructure managers were struggling with high administrative and maintenance costs, they needed to find out if those costs were comparable with the costs on the Swedish side.

The two case studies are examined and the results are compared with benchmarks at the national and international levels. The problem was of finding relevant data, defining and classifying the data and so on. A comparison of four similar rail networks in Scandinavia and UK is carried out, by studying annual reports etc. The list of infrastructure managers for railway industries from different countries is given in Table 1, with some organizational differences.

**Table 1. Infrastructure Managers**

Railway Infrastructure Manager	Outsourcing of Maintenance	Traffic operation	Traffic operators
Banverket (Sweden)	External / Internal	Free service	Many
Banedanmark (Denmark)	Internal	Free service	Few
Jernbanverket (Norway)	Internal	Included	Few
Network Rail (UK)	External / Internal	Free service	Many
Banförvaltningscentralen (RHK, Finland)	External / Internal	Is bought	Few

## ***4.2 Use of maintenance performance indicators at Banverket***

During the year 2004, a case study was performed to identify maintenance performance indicators (MPI) as in use at Banverket. The aim of the study was to identify common MPI covering the whole spectra of both the performance and outcomes from the maintenance process, as also to confirm contribution of maintenance for the overall business objectives in terms of return on investments (ROI) and health, safety and environment (HSE).

From the findings of the results of the interviews from the case study, 10 MPIs were identified, as in use at the regional and central level in Banverket. These MPIs reflect outcome measures for the maintenance process, i.e. lag indicators supporting the area of a high level of transport quality and asset integrity, namely;

- train delays due to infrastructure
- hours of freight train delays due to infrastructure
- number of delayed freight trains due to infrastructure
- number of train disruptions due to infrastructure
- Q-factor (degree of track standard)
- markdowns in current standard (speed restrictions)
- maintenance cost per track-kilometer
- traffic volume
- total number of functional disruptions
- total number of urgent inspection remarks

Two major problem areas came up for discussion during the interviews. The first one reflected the problems of knowing the actual use of the tracks in terms of gross tonnage and numbers of passengers. The second one reflected on the economical account system not having the ability to indicate the costs for specific maintenance tasks or the costs related to a specific type of components.

## ***4.3 Operation and maintenance benchmark of the Iron Ore Line between Kiruna and Narvik***

The case study conducted at Jernbaneverket is dealing with the Ofotenbanen, the Norwegian part of the Iron Ore Line between Kiruna in Sweden and Narvik in Norway. They had high administrative and maintenance costs, and needed to find out if those costs were comparable with the costs on the Swedish side (Åhrén and Espling, 2003).

One of the findings was that the amount of corrective maintenance was very high; more than 32 %. The main cost drivers were tracks, switches, and insulated joints. However, the operation and maintenance cost was approximately the same when compared by track meter, but the overhead costs on Norwegian side was 12 times higher doing the same comparison, due to its geographical isolation requiring its own administration. The benchmarking result for the Narvik – Kiruna track section is given in Table 2. As shown in the figure, the organization size quite similar, but the track area covered by the Swedish side is ten times larger than the Norwegian side. Also, the cost of renewals and investments are higher on the Norwegian side of this track.

**Table 2. Benchmarking results for Narvik – Kiruna railway track section**

MPIs/activities	Norway	Sweden
Snow removal per cost percentage	24 %	20 %
Preventive maintenance (cost %)	19 %	48 %
Corrective maintenance including stand-by organization for immediate emergency maintenance (cost %)	50 %	32 %
Maintenance cost / track meter	285	280
Share of renewal/investment of total track budget	81 %	77 %
Infrastructure manager's organization size (number of staff employed)	9	8

#### 4.4 Analysis of benchmarking results

From the results of two conducted studies at Banverket and Jernbaneverket, it is seen that quantifying the maintenance performance indicators in use, are possible and can be used for benchmarking. The comparison from Iron Ore Line between Kiruna and Narvik indicated more or less the same rail and track related maintenance costs in Norway as in Sweden. The geographical location and other factors have a large impact on overhead costs; for example; a 12 times difference between Swedish and Norwegian organizations when comparing the costs per track meter. A comparison by the actual size of the infrastructure manager organizations shows equality.

The results indicate that cost related to the amount of assets, like track, can be compared to each other. Overhead cost must on the other hand be treated and compared by real figures, i.e. a comparison to identify best practice regarding the size of the infrastructure manager organization. When comparing equal sized track areas the benchmark can be done straight forward but a comparison between different sized track areas needs cautiousness.

## 5 Discussion and further research

Two case studies carried out at the Banverket and Jernbaneverket during 2003 - 2005, for identifying the maintenance performance indicators in use and for benchmarking the maintenance process. On comparing the results of studies performed at Banverket, it is confirmed that the findings are comparable to each other. Also, the identified maintenance performance indicators can be used as benchmark measures and vice versa.

Comparing data from EFNMS (2002) and Wireman's (2004) suggested indicators, conducted case studies, and the annual reports from Banverket, Jernbaneverket, Banedanmark, Banförvaltningscentralen, and Network Rail identifies 137 different maintenance benchmarking parameters. Of these 38 % could not be verified by field data, including two major cost drivers such as labor and material, as also; overall equipment effectiveness (OEE), equipment availability, equipment efficiency, and overtime. Subsequently, the enablers were classified by the unit of measure, e.g. hour, percentage, and costs, resulting in the following groups:

- assets and assets history (produced volume maintenance)
- economy
- labor and material
- quality
- safety and environment
- traffic

Another way of classifying the MPIs can be indicated through the frequency of data collected by the organizations considering the group of MPIs mentioned in the Table 3 below. For example financial data is collected by all organizations, asset related data is collected by more

than 50 % of the organizations, and finally, quality related data is collected by less than 50 % of the organizations. It is important to notice, that “traffic” is the total traffic volume on a national level.

**Table 3. Frequency of data collected by the organizations**

MPI Groups	Data collected by everyone (100 %)	Data collected by some (>50 %)	Data collected by some (<50 %)
Asset		x	
Economy	x		
Labor			x
Quality			x
Safety	x		
Environment			x
Traffic	x		

The comparable indicators as in use are:

- corrective maintenance cost / total maintenance cost including renewal
- total maintenance cost / turnover
- maintenance and renewal costs / cost for asset replacement
- maintenance cost / track meter

These MPIs can be used as benchmarking measures, which lagging indicators (outcome measures) are showing yesterday’s performance. Therefore, these areas of interest are important for the railway management. However, it has not been possible to find any MPI reflecting the actual maintenance performance. This was mostly due to the fact that the maintenance activities are carried out by either in-house or out-house maintenance contractors and maintenance data are not available.

As per international railway benchmarking, the most important cost drivers for railway maintenance are cost of labor and spare parts. These cost drivers can be looked upon as lead indicators for the maintenance process. They can’t be identified as these cost drivers belong to the maintenance process, and are generated at the contractors end. In order to develop a more proactive maintenance strategy, lead indicators must be developed and based on parameters that make it possible to identify important cost drivers e.g. labor and spare parts (material), executed maintenance cost and resources per asset.

The use of asset, their status and age are other important factors needed for support of the maintenance decision. For classifying and defining the boundaries between operation, maintenance and renewal, a common structure is needed for increasing the possibilities of future benchmarking.

To identify the parameters which are essential for developing lead indicators by finding methods for selecting and evaluating them and how these could be used when outsourcing the railway assets maintenance, could be the scope for further research.

## 6 Acknowledgements

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## *Paper IV*



# **Overall Railway Infrastructure Effectiveness (ORIE): a case study on the Swedish rail network**

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## **Abstract**

**Purpose** – The main purpose of this paper has been to develop an approach to analyzing the factors influencing the performance of railway infrastructure, to propose an approach to measuring the overall railway infrastructure effectiveness (ORIE), and to test these approaches in a case study to verify their effectiveness.

**Design/methodology** - The methodology adopted in this study was to develop a concept for measurement of the overall effectiveness of a railway infrastructure similar to that for measurement of the OEE. The concept thus developed was applied on Swedish railway track sections for collecting data and for their ORIE validation, as a case study.

**Findings** – The results of the ORIE case study show that the model can be used for other sections of the Swedish railroad. It can also be applied to other railways with some modifications.

**Practical Implications** – ORIE can measure the extent to which the railway infrastructure system manages to deliver its agreed performance to the traffic operators. Infrastructure managers can also use the ORIE as a key performance indicator, which can provide important input for effective decision-making.

**Originality/value** – The paper presents a structured way of developing a conceptual ORIE model applied to the railway sector. This model can be used by other railways with suitable modifications.

**Keywords:** Railway system, Overall railway infrastructure effectiveness (ORIE), Overall equipment effectiveness (OEE)

**Paper type:** Research/case study paper

## **Introduction and Background**

The Swedish national railroad system is a complex system, which is used for freight and passenger transportation and where political and social considerations have to be taken into account; e.g. the safety and environmental impact, as well as public demands for safe, reliable and cost-effective transportations. There has been a positive growth in the traffic volume over a long period of time, leading to a high infrastructure capacity utilization, but at the same time the punctuality has decreased (Banverket, 2007). Therefore, it is important to maintain the existing infrastructure through effective (doing the right things) and efficient (doing things right) maintenance in order to keep a high capacity utilization with the highest possible safety levels as well as increased punctuality. There is a need for continuous improvements in the area of maintaining the railway infrastructure.

With the increasing awareness that maintenance not only ensures safety and track performance, but also creates additional value in the business process, the Swedish Rail Administration (Banverket) is treating maintenance as an integral part of the business process, i.e. applying a holistic view of the infrastructure maintenance process in order to fulfil

customer requirements (Karlsson, 2005). The measurement of maintenance performance has become an essential element of the strategic thinking of assets owners and managers. Without any formal measures of performance, it is difficult to plan, control, and improve the maintenance process (Liyanage and Kumar, 2000).

The railroad is strictly governed by regulations and government legislation and Banverket is the authority responsible for rail traffic in Sweden. Banverket's operations are divided into sectoral duties, track provision and production. One key issue for Banverket is therefore to verify that the undertaken maintenance activities provide the expected results. All the outsourced maintenance activities lay the foundation for Banverket to deliver a safe and reliable transportation system measured in terms of the railway infrastructure's overall productivity, i.e. the ORIE.

The purpose of this paper is to develop an approach to analyzing the factors influencing the performance of railway infrastructure, and propose an approach similar to OEE to measuring and studying the ORIE.

The overall equipment effectiveness (OEE) is an index frequently used in the manufacturing industry to calculate the overall equipment effectiveness of a production system or parts of it. The index itself was presented as an overall metric in the Total Productive Maintenance (TPM) concept (Nakajima, 1988). OEE is an aggregated productivity measure that takes into consideration the six big losses that affect the productivity of equipment in production systems. Equipment failure, setup, and adjustments are related to the downtime and expressed in terms of availability. Idling and minor stoppages, together with reduced speed, are related to speed losses and expressed in terms of the performance rate. Finally, process defects and reduced yield are related to defects and expressed in terms of the quality rate. OEE itself multiplies the equipment's availability, performance rate, and quality rate. The three factors involved in this calculation are independent of each other; i.e. variations in one of the three factors will not affect the other two. Normally, OEE figures can be found from 30 – 95% (Ljungberg, 1998, Ahlmann, 1995).

The definition varies among applications by different industries, and therefore it is difficult to identify the ideal OEE figures as well as compare the OEE figures among different companies (Jonsson and Lesshammar, 1999). Generally, availability is defined as the ratio of the actual uptime and the intended uptime, the performance rate as the ratio of the actual production time and the intended production time, and finally the quality rate as the ratio of the good items produced and the total amount of produced items. The availability and performance rate normally refer to the loading and operating time (Nakajima, 1988) or the planned time and amount of production (De Groote, 1995).

Various aspects of OEE can be found in the literature. The availability metric is targeted in these discussions. Some authors claim that the availability metric is influenced by factors beyond the equipment itself, such as operators, facilities, the availability of input materials, scheduling requirements, etc.; i.e. the OEE metric reflects the integrated equipment system and not the equipment itself (De Ron and Rooda, 2005, De Ron and Rooda, 2006). Others argue that the OEE metric does not take into consideration all the factors that reduce the availability, such as the planned downtime and the lack of material and labour (Ljungberg, 1998, Sheu, 2006).

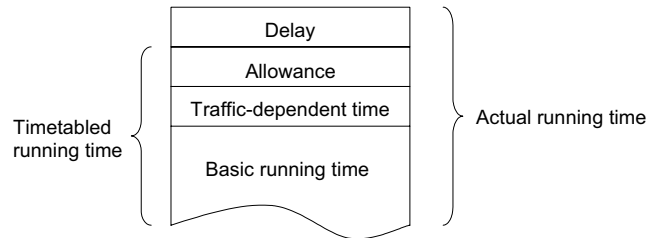
The basic question is therefore as follows. What is the overall railway infrastructure effectiveness (ORIE) concept, and how are ORIE values calculated? The limitation for this study is the ORIE concept from the infrastructure manager's perspective, meaning a focus on the overall railway infrastructure effectiveness. The scope involves taking into consideration the fact that the infrastructure should deliver its services according to agreements with the traffic operators, and does not include discovering the full potential of the railway infrastructure system.

The approach used in this study is to conceptualize ORIE model for the railway infrastructure system, by modifying the industrial OEE model in a suitable way and adapt it for application. The ORIE model is suggested for assessing the effectiveness of railway infrastructure capacity and the applicability of the model is demonstrated using data and information from Banverket through three case studies.

The following is the outline of this paper. The first section provides the introduction and background of the paper. In the second section, the concept of ORIE is presented. The third section presents three case studies where the concept of ORIE is tested. The fourth section discusses the results and the fifth section summarizes the findings.

### Train running time and delays

The actual running time of a train consists of four different parts: the basic running time, traffic-dependent time, allowance, and delay (Nyström, 2008). The actual running time can be divided into the timetabled running time and delays, see Figure 1. The timetabled running time can further be divided into the basic running time, which corresponds to the theoretical running time, the traffic-dependent running time, corresponding to the extra time needed for trains meeting each other and passenger exchange, and allowance, corresponding to the built-in slack in the timetabled running time.



**Figure 1. Subdivision of the actual running time (Nyström, 2008)**

A delay occurs when a train is not capable of following the stated timetable. Train delays are due to different factors, e.g. infrastructure failures, train-dispatching problems, train operator problems, rolling stock failures, environmental accidents etc. Train delays induced by infrastructure traffic disturbances can be classified into four major groups:

- a) infrastructure failures leading to the infrastructure being out of service due to maintenance repair
- b) overdue work on planned maintenance activities hindering planned traffic operation
- c) infrastructure failure events where no maintenance repair is required to restore the system, but which still lead to train delays
- d) speed restrictions due to markdowns in the infrastructure standard

### Concept of Overall Railway Infrastructure Effectiveness (ORIE)

The conceptualization and development of ORIE model needs to be considered to meet the specific needs of the railway system from an infrastructure manager's perspective, and to reflect the effects of undertaken maintenance activities. 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. In this paper, it is assumed that the rolling stock is available to 100%. The calculation of the ORIE for railways follows the same concept as that for the industrial OEE, i.e. a multiplication of the independent factors: the availability, performance rate, and quality rate. The calculation of the overall railway infrastructure effectiveness

(ORIE) is performed by multiplication of the infrastructure availability (A), the infrastructure performance rate (P), and the infrastructure quality rate (Q), see Equation 1.

$$ORIE = A \times P \times Q \quad (1)$$

### ***Infrastructure availability***

The calculation of equipment availability in the manufacturing industry is normally performed by comparing the planned uptime minus the unplanned downtime with the planned uptime; i.e. planned downtime such as preventive maintenance does not affect the equipment availability. This calculation is therefore related to calendar time; i.e. the different time measures used in the calculation are not related to the speed of the production system. The loss of production in terms of a specific number of non-produced products during the downtime period is therefore of no interest in the availability calculation. What is important is the loss of production time.

The first variable that needs to be identified for the railway infrastructure availability rate is the planned downtime required to undertake preventive maintenance, inspection etc. In Sweden, the available period for planned downtime is predetermined by the actual traffic load for a specific track section; i.e. it is dependent on whether the track section is used for either day and night traffic or mainly day traffic only.

The unplanned downtime is related to the first and the second big losses in terms of equipment failure, and setup and adjustments. The availability for the railway infrastructure can be calculated, in principle, in the same way as that for the manufacturing industry. The unplanned downtime due to equipment failure is the second variable to be defined. Theoretically, this measure should reflect the time when the railway infrastructure is unable to deliver time slots used for traffic operation; i.e. it should reflect the total time needed to restore the railway infrastructure after a traffic-disrupting failure has occurred, including the waiting time and the repair time. However, no such clear measure is available or in use for the Swedish rail network (Nyström and Kumar, 2003).

The unplanned downtime due to setup and adjustments is the last variable to define. Theoretically, this measure should reflect the railway infrastructure unavailability due to planned actions related to setup and adjustments. For the railway infrastructure, this can be translated into terms such as major planned track work and minor planned maintenance activities affecting traffic operation, i.e. overdue maintenance activities.

The availability (A) related to infrastructure failure is a function of the allocated uptime (UT) and unplanned downtime due to infrastructure failure (DTIF) and unplanned downtime due to overdue maintenance activities (DTOM), see Equation 2.

$$A = \frac{UT - (DTIF + DTOM)}{UT} \quad (2)$$

where:

UT = allocated UpTime, DTIF = DownTime due to Infrastructure Failures, DTOM = DownTime due to Overdue Maintenance.

### ***Infrastructure performance rate***

In the manufacturing industry, the performance rate is calculated as the actual production speed compared with the planned or theoretically calculated production speed for the equipment or system when it is available, i.e. the number of produced items compared with the planned or theoretical production during a given time. If the production speed is measured and calculated on time data, it is important to note that the recorded time is not the same as

the calendar time; i.e. the recorded production time can assume whatever value it takes depending on its relationship to the production speed.

Speed losses are related to the third and the fourth big losses in terms of idling and minor stoppages, together with reduced speed. From the railway perspective, speed losses in the production of time slots will be visible as longer time needed for the delivery of planned time slots from point A to B on an available track.

When calculating the actual speed of the railway infrastructure system, two factors must be taken into account, namely the unplanned and planned speed reductions of the available time slots. Unplanned speed losses for moving time slots can be represented by delayed trains due to failure events where no maintenance is required (NMR) to solve the problem, i.e. failure events where no recorded repair time exists in the failure report. Planned speed losses can be represented by delayed trains caused by speed restrictions due to a reduction in the current infrastructure standard. The performance rate for both types of speed losses can be calculated as the planned train operating time compared with the planned train operating time plus train delays due to NMR or speed restrictions.

The performance rate (P) is a function of the unplanned and planned speed reductions of the available time slots. Unplanned speed losses are train delays due to no maintenance required (TDNMR); i.e. train delays are reported although no repair activity is performed on the railway infrastructure. Planned speed losses are train delays caused by speed restrictions due to markdowns in the current infrastructure standard (TDSR). The performance rate can be assumed to be a function of the scheduled total train operating time (TTOT) and the train delays due to NMR and speed restrictions, see Equation 3.

$$P = \frac{TTOT}{TTOT + TDNMR + TDSR} \quad (3)$$

where:

TTOT = scheduled Total Train Operating Time, TDNMR = Train Delays due to No Maintenance Required, TDSR = Train Delays due to Speed Reductions.

### ***Infrastructure quality rate***

In the manufacturing industry, the quality rate is normally calculated as the rate of produced items fulfilling the predefined standards, i.e. the amount of good items compared with the total amount of items produced. Quality losses are related to the fifth and sixth big losses in terms of process defects and reduced yield related to defects. When looking at the railway sector from an infrastructure perspective, quality losses in the delivery of possible time slots used for traffic operation can be related to how smoothly the train is running.

Banverket uses two quality values, K and Q, describing the quality of the permanent way in terms of vertical and lateral alignment (Banverket, 1997). The measurements are carried out by the railway measurement wagon called STRIX. Primarily, the quality values are used to predict the additional dynamic forces generated due to traffic operation. High additional dynamic forces may damage the infrastructure and are a potential risk for derailment. K and Q can also be used to describe the riding comfort. K and Q limits are defined depending on the track section class, and the measurements are carried out up to six times a year. Since K and Q values are calculated on the same measurement raw data, the ORIE calculation of quality losses can be performed by using the K or Q value. Since the Q value is more frequently used in Banverket, the calculation will be based on the measured Q value and its deviation from the stated target values.

The quality rate (Q) is a function of the measured Q value (Q<sub>val</sub>) and its deviation from the stated Q limit (Q<sub>lim</sub>), see Equation 4. In OEE calculations, the quality rate varies between zero and one. Therefore, the quality rate is not supposed to exceed one in the ORIE

calculations as well, although the measured Q value can have a higher value than the stated Q limit if the track section standard is higher than the stated objectives.

$$\begin{cases} Q = \frac{Q_{val}}{Q_{lim}} & \text{if } Q_{val} < Q_{lim} \\ Q = 1 & \text{if } Q_{val} \geq Q_{lim} \end{cases} \quad (4)$$

where:

$Q_{val}$  = measured Q Value,  $Q_{lim}$  = stated Q Limit.

### ***ORIE sampling frequency***

How often the ORIE will be updated is dependent on the sampling frequency of the different parameters in the ORIE. The failure reports recorded in the Ofelia database and the train delays related to these failure reports recorded in the TFÖR database are updated daily. The K and Q parameters, on the other hand, are not updated with a higher frequency than the maximum of 6 times a year. For example, on the Boden – Gällivare track section the K and Q values are measured twice a year. This means that the ORIE for the Boden - Gällivare track section is not updated with new availability, performance rate, and quality rate parameters more often than two times a year. A higher ORIE sampling frequency than twice a year will therefore result in just a partial update of the ORIE value. When deciding the ORIE sampling frequency, it is appropriate to choose sampling periods that correspond to other reporting periods in use at Banverket for data related to the infrastructure, such as punctuality, maintenance costs, number of failures etc. The ORIE sampling period chosen in this study is therefore one month.

### **Case study**

The case study focuses on three single-track sections. The first track section is located between Bräcke and Östersund in the middle part of Sweden on the main coast-to-coast line between Sundsvall and Trondheim in Norway. The section is roughly 70 km long and its seven stations are distributed evenly. It is a line operated in the daytime with moderate mixed traffic. The second track section is located between Järna and Åby south of Stockholm. This track section is operated on average with 25 passenger trains and 6 freight trains per day. The average train operating time is estimated to be 78 minutes and the allocated uptime is 18 hours. The third track section is the Boden – Gällivare section, located in the northern part of Sweden on the Malmbanan main line (the Iron Ore Line). It is operated with 6 passenger trains and on average 22 freight trains per day. The average train operating time is estimated to be 150 minutes. The allocated uptime is 18 hours per day. The data for the three single-track sections are summarized in Table 1.

**Table 1. Track section description**

	Bräcke - Östersund	Järna - Åby	Boden - Gällivare
Section class	2	2	4
Allocated uptime	18 h	18 h	18 h
No. of passenger trains / week	110	175	42
No. of freight trains / week	49	42	154
Estimated running time / train	45 min	78 min	150 min

### ***Availability analysis***

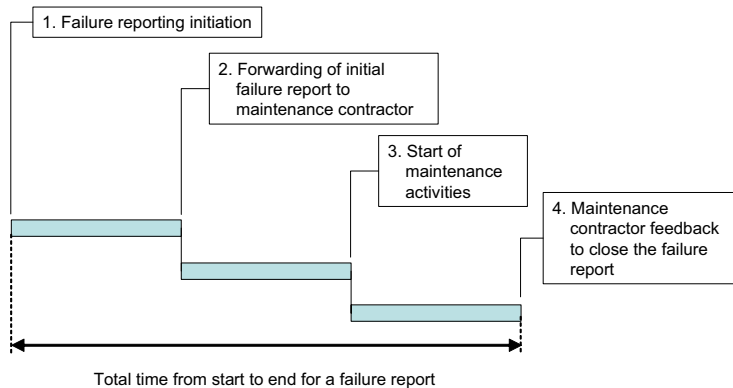
The parameters for calculating the infrastructure availability are the allocated uptime and the unplanned downtime. In Sweden, the allocated uptime is determined by the available period for planned downtime. If the track section is used for day and night traffic, the necessary time



predetermined for preventive maintenance is set to be a two-hour time slot, i.e. the allocated planned uptime is 22 hours (Nilsson, 2007). If the track section is used mainly for daytime traffic, the allocated planned uptime is 18 hours and the planned downtime that can be used for preventive maintenance is six hours. Since the traffic load, as well as the type of traffic, varies among different track sections, the allocated planned uptime variable is set to be 22 or 18 hours, depending on the traffic situation for the specific track section.

The unplanned downtime due to equipment failure should reflect the time when the railway infrastructure is unable to deliver time slots used for traffic operation, i.e. reflect the total time needed to restore the railway infrastructure after a traffic-disrupting failure has occurred, including the waiting time and the repair time. The recorded train delay for a disrupted train due to infrastructure failure represents the loss of the availability of the railway infrastructure for that specific train; i.e. the recorded train delay is the maximum unavailability of the railway infrastructure. The question arises whether this recorded train delay is representative of the infrastructure unavailability, or whether the infrastructure unavailability is only a part of the recorded train delay.

In Banverket's failure reporting database, Ofelia, four different recorded times related to the failure report are saved in the database. The four different recorded times concern the failure reporting initiation, the forwarding of the initial failure report to the maintenance contractor, the start of the maintenance activities, and the maintenance contractor's feedback to close the failure report, see Figure 2. The database contains information related to each specific failure, such as the time and location, failure symptom, real fault, and maintenance activities.



**Figure 2. Graphical illustration of the four recorded times related to a failure report at Banverket**

The analysis of the failure reports from Ofelia for the track section from Bräcke – Östersund during 2007 shows that the use of the period between the recorded time for the initial failure report and the maintenance initiated is not useful as unplanned downtime, i.e. more specifically unplanned maintenance waiting time. This is because the period is more than two hundred times longer than the actual train delay time. See failure report B in Table 2. In failure report C, the recorded train delay is 36 minutes, although the maintenance activities were carried out more than 60 hours after the failure report was initiated and recorded in the database. See Table 2.

The use of the period between the failure report forwarded and the maintenance initiated, as a measure of the maintenance waiting time, is indicated as unrealistic, since that time is more than 20 times longer than the actual train delay in failure report A. See Table 2. The remaining period representing the recorded repair time may be used as a measure of the

unplanned downtime, if the ongoing maintenance activities can be assumed to be carried out on a track out of service; i.e. no train movements are possible due to ongoing maintenance activities. If this period is going to be used, a correlation between the repair time and the actual train delay time should be established.

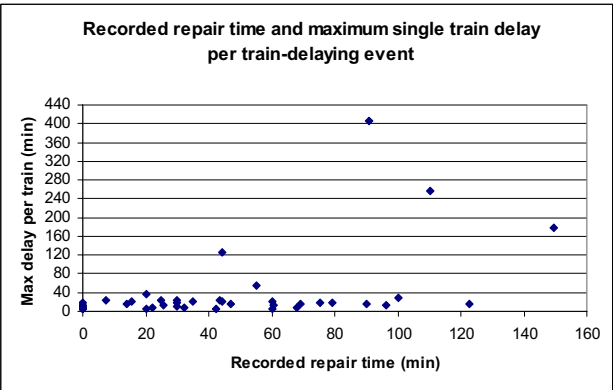
**Table 2. Examples of failure reports from the Ofelia database for track section Bräcke – Östersund during 2007, showing the total train delay connected to a specific failure report and the length of the different periods between the different recorded times in the failure report.**

Failure report	A [min]	B [min]	C [min]
Total train delay	12	6	36
Failure reported – Report forwarded	554	1559	3648
Report forwarded – Maintenance initiated	287	74	104
Maintenance initiated - Contractor feedback	26	60	20
Failure description	Switch heat	ATC	Elk collision

Note: ATC = Automatic Train Control

As stated before, the infrastructure unavailability cannot be longer than the recorded train delay for the trains disrupted by that specific infrastructure failure. If more trains are disrupted by the same infrastructure failure, still the infrastructure unavailability cannot exceed the recorded train delay of that train which has the longest recorded delay for that specific infrastructure failure. As soon as that train which has waited the longest time for the infrastructure to operate again starts to move, the infrastructure is available for traffic operation.

For train-delaying events on the track section Bräcke – Östersund, a comparison between the recorded repair time and the longest recorded train delay for one of the involved trains, shows that 88% of the recorded train delays are less than 40 minutes, independent of the repair time. See Figure 3. This indicates that the repair time is not a valid measure of the infrastructure downtime, i.e. the traffic can be managed and operated although maintenance activities are going on simultaneously. The five remaining train delays with a recorded train delay time of more than 40 minutes are all related to contact wire breakdowns, i.e. traffic-disturbing faults that can be assumed to shut down the entire railway infrastructure system in the specific fault area.



**Figure 3. Recorded repair time and longest recorded train delay for one of the involved trains per train-delaying event for the Bräcke – Östersund track section during 2007**

The infrastructure availability as a result of infrastructure failure can therefore be calculated using the longest recorded train delay for every traffic-disturbing event. Since the recorded train delays can be used for the availability calculation related to infrastructure failures, the same approach can be used for overdue maintenance activities, i.e. recorded train delays due to overdue maintenance activities. From equation 2, the downtime is DTIF, as per the discussions in the infrastructure availability section. Thus, the availability function used in the case study is calculated as:

$$A = \frac{UT - (TDIF + TDOM)}{UT} \quad (5)$$

where:

UT = allocated UpTime, TDIF = Train Delays due to Infrastructure Failures, TDOM = Train Delays due to Overdue Maintenance.

The ORIE sampling period can also be analyzed with respect to the amount of train delaying event due to infrastructure failure (TDEIF) and the length of the TDEIF-free periods. For the Bräcke – Östersund track section, the total number of TDEIF during 2007 was 43 events; i.e. 88% of the days during 2007 were TDEIF-free. During March, there were three TDEIF reported. Before the first TDEIF occurred in March, there was a TDEIF-free period of 20 days. This means a constant ORIE value over almost a three-week period. The benefits of using an ORIE sampling frequency much shorter than the TDEIF-free period can be discussed. Both the availability and the performance rate will be equal to 100%, since they are updated daily in the database. However, the quality rate may be less than 100%, since its updating frequency is not more than 6 times a year.

Using an ORIE sampling frequency of once a day for the Boden – Gällivare track section with the K and Q values being updated twice a year, all the TDEIF-free days will result in the same ORIE value during that six-month period, while the TDEIF days will show a random behaviour. This phenomenon can be avoided with an ORIE sampling frequency longer than the longest TDEIF-free period. For the Bräcke – Östersund track section this period is longer than 20 days. An appropriate ORIE sampling frequency is therefore once a month, which corresponds to the reporting periods frequently in use at Banverket.

### ***Case study ORIE calculation***

The calculation of the monthly ORIE for the Boden – Gällivare track section is summarized in Table 3 and based on the following parameters. UT is based on the dominant day traffic (Banverket, 2005, Banverket, 2001). TTOT is the mean value based on the timetables for 2007 and calculated to 12300 minutes. TDIF and TDNMR are extracted from Banverket's failure reporting database Ofelia and train delay reporting database TFÖR. Qval and Qlim are identified through Banverket documents. For calculations where the Q value is used, often only the autumn measurement of the Q value is used; i.e. the Q value is updated once a year (BVH 820). All the time-dependent parameter units are in minutes.

The resulting average ORIE value during 2007 for the Boden – Gällivare track section was 90.6%. The maximum ORIE was 91.0%, which occurred in November, while the minimum ORIE was 89.7%, which occurred in January, see Table 3.

**Table 3. ORIE and ORIE parameters for the Boden – Gällivare track section during 2007**

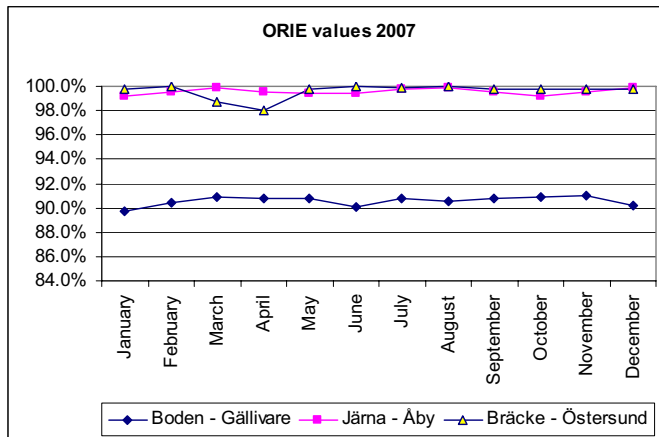
Month	UT	TDIF	TTOT	TDNMR	Qval	Qlim	ORIE
January	33480	432	130200	291	82	90	89.7%
February	30240	168	117600	161	82	90	90.5%
March	33480	39	130200	147	82	90	90.9%
April	32400	122	126000	15	82	90	90.8%
May	33480	116	130200	109	82	90	90.7%
June	32400	361	126000	18	82	90	90.1%
July	33480	139	130200	11	82	90	90.7%
August	33480	186	130200	34	82	90	90.6%
September	32400	105	126000	65	82	90	90.8%
October	33480	56	130200	56	82	90	90.9%
November	32400	34	126000	67	82	90	91.0%
December	33480	339	130200	8	82	90	90.2%

Note: UT: allocated planned uptime; TDIF: unplanned downtime in terms of the longest recorded train delays for a single train during a traffic-disturbing event due to infrastructure failure; TDNMR: unplanned downtime in terms of recorded train delays due to no maintenance required; Qval: measured Q value; Qlim: Q value limit.

In order to compare the calculated ORIE value for the Boden – Gällivare track section, two additional track sections were investigated for the year 2007. The delay statistics and Q values for the Bräcke – Östersund and Järna – Åby track sections are summarized in Table 4. The resulting ORIE value per month varies from 89.7 – 100%, see Figure 4. When comparing the product of the infrastructure availability and the infrastructure performance rate between the three track sections, the result varies from 98.0 – 100%.

**Table 4. TDIF, TDNMR, Qval, and Qlim for the Järna – Åby and Bräcke – Östersund track sections during 2007**

Month	Järna - Åby				Bräcke - Östersund			
	TDIF	TDNMR	Qval	Qlim	TDIF	TDNMR	Qval	Qlim
January	250	44	98	90	38	26	87	80
February	130	63	98	90	6	7	87	80
March	29	57	98	90	436	0	87	80
April	148	22	98	90	647	6	87	80
May	104	190	98	90	55	7	87	80
June	161	29	98	90	9	0	87	80
July	74	7	98	90	32	0	87	80
August	17	45	98	90	8	5	87	80
September	114	122	98	90	64	0	87	80
October	261	51	98	90	58	30	87	80
November	100	77	98	90	58	8	87	80
December	42	18	98	90	76	5	87	80



**Figure 4.** ORIE values per month for Bräcke – Östersund, Järna – Åby, and Boden - Gällivare track sections during 2007

### Discussion

In the manufacturing industry, OEE is a measure frequently used to calculate and evaluate the production equipment effectiveness or productivity. OEE as an aggregated measure takes into consideration the equipment availability, performance rate, and quality rate. It is used both internally within a company and externally within a branch of industry, and can therefore be seen as a good key performance indicator.

In this paper, an attempt is made to identify and conceptualize ORIE for the railway sector from a railway infrastructure perspective. Unlike the manufacturing industry, railway infrastructure produces moving time slots that can be used for traffic operation. A moving time slot cannot be stored, but can only be disturbed and parked and later on resumed or cancelled. It must therefore be treated as a delivery of services. Therefore, the production system will also be an intermittent one, where partial idling is necessary and therefore does not necessarily mean a loss of capacity and availability.

The proposed ORIE calculation is tested against real data for the Boden – Gällivare, Bräcke and Östersund, and Järna and Åby track sections. The ORIE values for these track sections vary from 89.7 – 100%. The ORIE values for the track section between Boden and Gällivare vary from 89.7 – 91.0%, while the ORIE for the Bräcke and Östersund, and Järna and Åby track sections vary from 98.0 – 100%. The lower ORIE values for the Boden – Gällivare track section can be explained through differences in the infrastructure quality rate, i.e. 91.1% for the Boden – Gällivare track section and 100% for the Bräcke and Östersund, and Järna and Åby track sections. The ORIE calculations need to be tested against more different track sections with full data sampling in order to validate the ORIE calculating concept.

The comparison between the recorded repair time and the longest recorded train delay for one of the trains involved in train-delaying events shows that over 90% of the recorded train delays are less than 40 minutes, independent of the repair time. This indicates that the repair time is not a valid measure of the infrastructure downtime; i.e. the traffic can be managed and operated while maintenance activities are going on. The remaining train delays with a recorded train delay time of more than 40 minutes are all related to traffic-disturbing faults when the track is totally out of service. This area needs to be studied in detail in the future.

The calculated ORIE figures show high values compared with the industrial OEE. The ORIE concept is intended to reveal how well the railway infrastructure system manages to

deliver its agreed services to the traffic operators, i.e. the railway infrastructure's ability to deliver train positions to passenger and freight operators. Therefore, high ORIE figures are required for punctual traffic. For example, a train delay-free journey for a passenger train requires 100% availability and performance rates during that journey. The difference between ORIE and OEE is that the former reflects the infrastructure system's ability to make infrastructure available according to agreed plans independent of the actual capacity utilization, while the latter reflects the production system's ability to produce according to its full potential.

### **Concluding Remarks**

The development of overall railway infrastructure effectiveness (ORIE) model must be adjusted to meet the specific needs of the railway infrastructure system, i.e. reflecting the effects of undertaken maintenance activities from an infrastructure manager's perspective. ORIE measures the extent to which the railway infrastructure system manages to deliver its agreed performance to the traffic operators.

The performed case study shows similar ORIE figures for the studied track sections. High ORIE values are required for a punctual railway transportation system. The study indicates that ORIE must be calculated on a monthly basis. The findings of the ORIE calculation are ORIE values of 89.7 – 100%.

The findings indicate that ORIE can be used as a key performance indicator for the railway infrastructure manager. It is also visualised that ORIE can provide important input for the infrastructure managers and support in decision-making. ORIE can affect the infrastructure capacity through availability, speed, and quality, which needs further investigation.

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## *Paper V*



# Railway maintenance link and effect model: a conceptual framework

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## Abstract

**Purpose** – The purpose of this study is to present how to develop a link and effect model (LinkEM) framework for management of railway infrastructure maintenance taking into consideration the specific needs of the railway infrastructure manager.

**Design/methodology/approach** – The approach for this study is to re-design a conceptual link and effect model originally developed for the offshore industry. The method used during this re-design and development process of LinkEM is the Multi Criteria Decision Analysis methodology. The LinkEM is adapted on Banverket.

**Findings** – The conceptual LinkEM is focusing on critical-strategic areas determined by the nature of the railway industry and public requirements and regulations. The direct link between overall objectives and the outcome measures for railway maintenance are in terms of health, safety, and environment (HSE) and return on maintenance investments (ROMI). The main performance driver for ROMI and HSE is the railway infrastructure integrity (RII). Adequate competencies, functional internal processes, and good internal and external relationships lay the foundation for RII.

**Practical implications:** – LinkEM can provide the railway infrastructure managers with a framework that can link the effect of undertaken maintenance activities for achieving the organisational overall objectives in terms of ROMI and HSE.

**Originality/value** – The paper presents a structured way of developing a conceptual link and effect model framework for maintaining the Swedish Rail Administration's (Banverket) infrastructure assets. The approach and suggested model is generic in nature and may therefore be useful for not only the railway infrastructure managers, but also other infrastructure.

**Keywords:** Link and effect model, Performance measurement, Performance indicators, Maintenance performance indicators, Railways, Sweden

**Paper type:** Research paper

## 1 Introduction and Background

Maintenance as an important support function in business with significant investment in physical assets plays an important role to achieve the organizational goals (Liyanage and Kumar, 2000). When introducing any performance measurement system to optimize operations and maintenance processes in a company or a business unit, it is important that it focuses on such specific issues as nature of the business, business concerns and public requirements and regulations (Liyanage, 2003). With increasing awareness that maintenance not only ensures safety and track performance but creates additional value in the business process; Swedish Rail Administration (Banverket) is treating maintenance as an integral part of the business process, i.e. applying a holistic view on the infrastructure maintenance process in order to fulfil customer requirements (Karlsson, 2005). The measurement of maintenance

performance has become an essential element of strategic thinking of assets owners and managers. Without any formal measures of performance, it is difficult to plan, control, and improve the maintenance process. One key issue for Banverket is to verify that the undertaken maintenance activities provides expected results, measured in terms of technical, economical, and organizational performance indicators (PI). Measurement tells the status of the job carried out and what action to be taken there after, and to indicate where those actions should be targeted.

The use of performance measurements in a wider perspective started in 1880s in USA (Segovia and Thornton, 1990). The management accounting and the management accounting systems (MAS) provided the management with relevant, accurate, and timely information regarding an organization's internal activities, using an engineers approach to ensure good resource allocation and utilization, i.e. focus on management decisions. From the 1920s, the use of MAS declined due to ever-increasing costs just to keep the MAS in function when the firm growth. At the same time the influence of public accountants was increasing, focusing more on reported profit, i.e. the auditors approach. During the late 1960s, once again the need of complementary engineering management decision making parameters increased (Husband, 1976). Today, there are numbers of Computerized Maintenance Management System (CMMS) available on the market. The important issue is to bridge the gap between overall objectives, strategies, and the performance measurement system (Espling, 2007).

The basic concept of performance is function of ability, efforts, and opportunity (Salminen, 2005). Performance is the ability of an organization to implement a chosen strategy and achieve organizational objectives (Tsang, 2002). The organizational performance is the results of the performance of individuals and groups. Performance can be examined from different perspectives, such as customer, financial, process, employee, safety, environment etc. , and covers both processes and results (Kaplan and Norton, 1992, Feurer and Chaharbaghi, 1995). Performance measurement (PM) is the process by which a company manages its performance and the performance measures are the set of metrics used to quantify the efficiency and effectiveness of actions (Neely *et al.*, 1995, Bititci *et al.*, 1997). Measurement provides the basis for an organization to assess how well it is progressing towards its predetermined objectives, helps to identify areas of strengths and weaknesses, and decides on future initiatives, with the goals of improving organizational performance (Amaratunga and Baldry, 2002, Rouse and Putterill, 2003). The decision making process must consider multiple criteria since both economic and non-economic factors are involved (Blanchard and Fabrycky, 1998).

The selection of maintenance performance indicators (MPI) depends on the way in which the maintenance performance measurement (MPM) system is designed and developed for application (Parida and Kumar, 2006). In order to make improvements in existing performance measurement processes supporting the decision making process for maintenance, it is necessary to study and map the objectives and requirements of the top management. These will highlight what is important to focus on in the maintenance process. The selection of PIs to follow up the contribution of maintenance is an important but a complex issue.

Broadly, PI can be classified as leading or lagging indicators (Stricoff, 2000). Leading, lead, or prospective indicators is a performance driver, i.e. a measure that drives the performance of the outcome measure. The outcome measure itself is simply the lagging, lag, or retrospective indicator; often different financial measurements. Leading and lagging indicators can also relate to strategy or goals, i.e. important not mixing means and ends (Failing and Gregory,

2003). There exist other important contradictory indicator characteristics when developing and implementing indicators such as:

- Off the shelf or tailor made indicators: important if the indicators are supposed to be used in benchmarks (Wireman, 2004)
- Long or short term indicators: important when deciding how long time indicator measures have to be stored (IAEA, 2000)
- Slow or fast changing rate indicators: important for trend calculations or to decide if slower/faster redundant indicators must be used or developed, often the case for environmental issues (Miljövårdsberedningen, 1998, Kimberling et al., 2001).

When designing PIs it is important that they act as a signal or indicator that something is happening and give a hint of the characteristics of necessary decisions (Mossberg, 1977). The relation between different PIs can be studied from three different perspectives, namely relationships through signal characteristics, decision characteristics, or signal and decision characteristics. The chosen PIs must also be scalable, i.e. the indicator must be able to be used locally at the same time as it is possible to aggregate them to be valid on a global level or vice versa (Failing and Gregory, 2003). Since the development process for PIs follows a top-down approach where the business overall objectives are cascaded down to specific PIs to be measured in the organization, the reporting and aggregation of PIs follows a bottom-up perspective (Andersen and Fagerhaug, 2002, Engelkemeyer and Voss, 2000). This approach also makes it possible to fully integrate the PI system into other performance management system in use, for instance balanced score cards (Parida et al., 2003).

When developing and implementing the use of PIs within an organization in a more systematic way, three basic models or systems are used. In a horizontal grouped indicator system the indicators are arranged in independent logical groups; covering perspectives related to the maintenance process such as reliability/maintainability, preventive/predictive maintenance, planning and scheduling, materials management, skills training, maintenance supervision, and work process productivity. For detailed examples, see (Smith, 2003, Cummings, 1993, Allander, 1997). In a vertical aggregated indicator system, the indicators are arranged in a pyramid structure, where a large number of indicators on a bottom level are aggregated upwards in the pyramid structure and often reduced to one or a few indicators at strategic level, such as ROI etc. For detailed example, see (IAEA, 2000, Lyons et al., 2000, Kimberling et al., 2001). An indicator system can also be build up of a combination of horizontal grouped indicators with the vertical aggregated one, giving a model of semi-independent logical indicator groups arranged in a horizontal or vertical structure, i.e. no indicator aggregation between the indicator groups though logical links exist between them. Every separate indicator group themselves can be looked upon as a sub-system of indicators reflecting the different areas of interest from a maintenance point of view, i.e. economy, equipment, organizational, and health, safety, and environmental (HSE) issues. For detailed example, see (Wireman, 1998).

The opportunities to monitor and control all kind of assets is today's reality but also a source of data overload for the managers; often visible in terms of redundant performance reports (Parida et al., 2004, Neely, 1999). When it is time for decision making the manager is still not able to take into consideration more than just 5 to 8 parameters at the same time (Wickens and Hollands, 1999), which impose the importance of choosing the right indicators for decision making, i.e. parameter aggregation is often necessary.

In the late 1990s a conceptual operation and maintenance link and effect model was presented, taking into consideration the specific needs of the offshore industry performance measurement systems focusing on critical-strategic areas determined by the nature of the specific business, business concerns and public requirements and regulations (Liyanage and Kumar, 2003, Liyanage, 2003). The link and effect model has its roots in a combination of asset management including physical, human, financial, and intangible ones (Woodhouse, 1997) and the concept of balanced scorecards (BSC) measuring the company performance from a more holistic view, apart from financial performances only (Kaplan and Norton, 1992). Since HSE issues are important aspects of the offshore industry, it had to be included in a scorecard like the link and effect model reflecting business asset management from an operation and maintenance perspective.

The BSC concept introduced three more strategic perspectives in addition to the financial one; namely customers' perspective, internal business perspective and finally learning and growth perspective; all from a corporate top management level (Kaplan and Norton, 1992). The BSC is therefore suitable for long term non-business activities where profit is not the main purpose (Olve et al., 1999). To make sure that the overall objectives permeate all BSC perspectives in the process, a top-down approach is necessary as well as the top management support (Kaplan and Norton, 1992). Empirical studies has shown that use of more holistic performance measurement systems like BSC or the Malcolm Baldrige Criteria to assess organizational performance have a positive impact on business results and performance (Evans, 2004, Alsyouf, 2006).

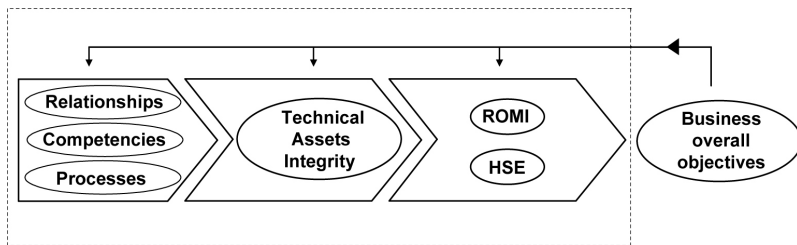
Banverket is the authority responsible for rail traffic in Sweden. Banverket's operations are divided into sectoral duties, track provision and production. All maintenance activities are outsourced and contracted out on the open market. To establish a win-win situation for all involved in the maintenance management process, Banverket uses the partnering concept and incentive-based contracts as a tool to create a win-win situation together with different contractors (Espling and Olsson, 2004). The national railroad system is today a complex system used for freight and passenger transportation, where political and social considerations have to be taken in to account; e.g. safety and environmental impact as well as public demands of safe, reliable and cost-effective transportations. The railroad is therefore strictly governed by regulations and government legislations. There has been a positive growth in the traffic volume over a long period of time leading to high infrastructure capacity utilization at the same time as the punctuality has decreased (Banverket, 2007). Therefore, it is important to maintain existing infrastructure due to effective and efficient maintenance in order to keep high capacity utilization with highest possible safety levels as well as increased punctuality; there is a need of continuous improvements in the area of maintaining the railway infrastructure. During 2006, Banverket presented their new strategic plan representing Banverket's increased and strengthened focus to fulfil their own overall business objectives as well as society and governmental expectations (Banverket, 2006b).

This paper aims to present a conceptual railway maintenance link and effect model, i.e. how to develop it and use it as a pre-defined framework for measuring railway infrastructure performance.

## **2 Link and effect model design**

When designing a generic maintenance link and effect model (LinkEM) it follows the same format as for the offshore industry designed link and effect model (Liyanage and Kumar,

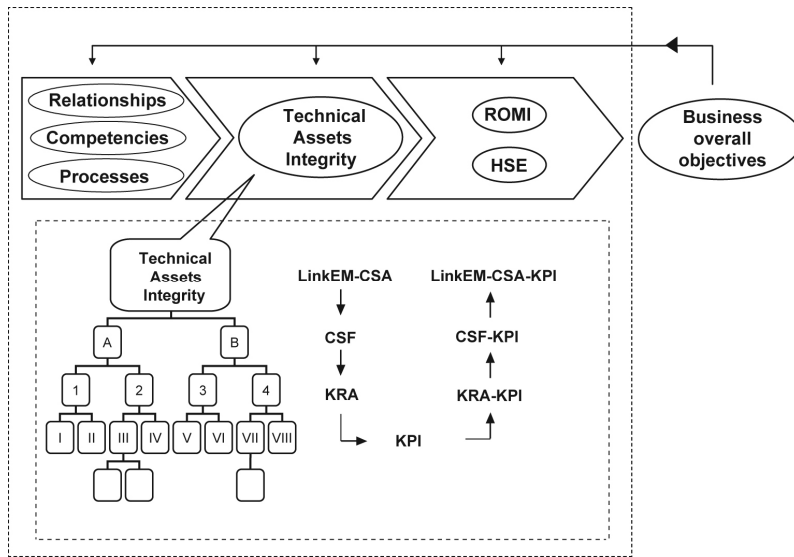
2003, Liyanage, 2003). It is important that it support overall objectives for the company or the business unit, signifying a top-down approach. The direct link between overall objectives and the outcome measures for maintenance are in terms of HSE and ROI, i.e. return on maintenance investments and therefore classified as ROMI (Parida et al., 2004). The main performance driver for ROMI and HSE is the integrity of the plant. Adequate competencies, functional internal processes, and good internal and external relationships lay the foundation for plant integrity. Therefore, when deriving the different PIs for each critical-strategic area (CSA) to trace the maintenance performance, it is also necessary to classify the degree of effect for every single PI towards linked CSAs, i.e. create a logical cause-and-effect structure, to pinpoint those measures that are the key performance indicators (KPI). The LinkEM itself is a horizontal arranged indicator system based on semi-independent logical groups see Figure 1.



**Figure 1. General link and effect model (LinkEM) framework.**

The different semi-independent logical groups in the LinkEM are built up as vertical aggregated PI subsystem, where the highest level in the subsystem is represented by the different CSAs of the LinkEM. In order to identify the specific key performance indicators (KPI) for the link and effect model critical-strategic areas (LinkEM-CSA), the subsystem needs to be broken down into critical success factors (CSF), key result areas (KRA), and supporting KPI in one or more levels (Parida et al., 2003). A top-down approach is needed during the development phase, while a bottom-up approach is used for reporting. The bottom-up approach is resulting in an aggregation of KPI values, where the resulting LinkEM-CSA-KPI is representing the highest level of aggregation within each CSA. Figure 2 illustrates the general LinkEM framework, including the technical assets integrity CSA that is one out of six different LinkEM-CSA perspectives. The different steps can be illustrated by the following example. The top management decides to increase the business performance (critical-strategic area) by better cost control (critical success factor). This might be done by focusing on reducing maintenance costs (key result area) through changed maintenance instructions for the top-ten most costly units in order to lower the maintenance cost per unit (key performance indicator).

When indicators and indicator system like LinkEM are implemented in an organization is it helpful if indicators in use can be presented and visualized to the user in a user-friendly interface. Aggregated indicators are often visualized in diagrams showing both indicator history and predicted trends (IAEA, 2000). User experiences indicate that diagrams and bar charts are preferable, since they indicate how far away from desired targets the actual indicator value is, as well as it gives an indication of what to do next based on trend predictions, i.e. do nothing, wait and see, or immediate action needed (Åhrén, 2005).



**Figure 2. General link and effect model framework including one highlighted semi-independent logical group or subsystem.**

Diagrams and bar charts will also highlight major changes in indicator outputs, indicating need for a renewed validation process of input data. The reasons might be inappropriate input data or just natural causes like changes in the production process leading to new indicator output levels though everything is in order (Smith, 2003). When displaying the total indicator system it is common that different indicators are visualized with help of different colours depending on the actual indicator value in relation to a desired target or goal, the so-called traffic lights. The use of traffic lights makes it easy for the user to identify indicators showing a specific colour.

### 3 Method

Development of a conceptual LinkEM must be adjusted to meet the specific needs regarding railway infrastructure maintenance, i.e. reflect the effects of undertaken maintenance activities regarding punctuality, economy, HSE etc. A conceptual framework explains either graphically or in narrative form, the main issues to be studied, the key factors, variables and the presumed relationship amongst them (Miles and Huberman, 1994).

The approach used in this study to identify and configure the different CSAs in the LinkEM is based on the concepts of Multi Criteria Decision Making (MCDM) and Multi Criteria Decision Analysis (MCDA) (Dodgson et al., 2000, CIFOR, 1999, Spengler et al., 1998). A total MCDA consists of eight stages that can be divided into three process steps, namely;

- Scope and objectives; consider context, identify options, and establish objectives and criteria, i.e. stage 1 – 3.
- Scoring and weighting; score option on the criteria, assign importance weights to the criteria, and calculate overall values, i.e. stage 4 – 6.
- Results and analysis; examine results and sensitivity analysis, i.e. stage 7 – 8.



The first MCDA process step is used during the conceptual development phase of the railway maintenance LinkEM. The second process step can later on be used to evaluate, simulate, and re-configure the LinkEM with help of historical data. Finally, the third process step can be used when the LinkEM is going to be implemented into the railway IM organization. However, since this study is focusing on development of a conceptual LinkEM, only the first MCDA process step will be used. The first stage will verify if pre-chosen CSAs from the original link and effect model is valid for railway maintenance LinkEM. The second and third stage will identify options and criteria, i.e. KRA and KPI. Since the LinkEM design is using aggregation of parameter values, it is necessary to include some basic design methods; otherwise, a change of one parameter during operation will result in multiple changes in the LinkEM. The design method used in this study is the Requirement Tree Method (Pahl et al., 1996).

The LinkEM has been applied on Banverket and the input to stage 1 – 3 is literature studies, benchmarks and case studies on Banverket, and Banverket documents and data. A discussion on how to score and weight the criteria will also be included.

#### **4 Railway maintenance link and effect model (LinkEM)**

The first stage in developing conceptual railway maintenance LinkEM is to verify that pre-chosen CSAs from the original link and effect model is valid for the railway industry. A benchmarking study comparing railway infrastructure managers in Scandinavia (Banverket, Jernbaneverket, Banedanmark, RHK) and UK (Network Rail) found that only highly aggregated outcome measures could be compared to each other in terms of economy, punctuality, safety, the amount of staff employed, track quality, and total traffic volume divided in passenger and freight kilometers (Åhrén et al., 2005). The international railway benchmarking project InfraCost showed that the infrastructure account for 58 % of the maintenance costs or 68 % of the renewal costs (Stalder et al., 2002). It is therefore important to keep track of the infrastructure status, i.e. the track quality. These studies show the importance of the ROMI and Railway infrastructure integrity (RII) CSA. A case study performed at Banverket identified in total 17 maintenance performance indicators. Out of these, 15 are identified by studying Banverket documents, while only 10 indicators are identified through interviews with the regional operations planners; eight of them matching the documents and two additional ones (Åhrén and Kumar, 2004). They correspond to maintenance costs and assets utilization for the ROMI-CSA, safety and environment for HSE-CSA, and infrastructure quality for the RII-CSA.

Empirical studies has shown that use of quality evaluating tools have a positive impact on business results and performance (Evans, 2004, Alsyouf, 2006). One such a quality-evaluating tool is the SIQ (Swedish Institute for Quality) customer-oriented quality-evaluating model. The model is taking in to consideration seven different business perspectives, namely: leadership, information and analysis, strategic planning, employee development, business processes, business performance, and customer satisfaction (SIQ, 2007). The SIQ-model verifies the need of the CSAs named process, relationships, and competences. Additionally, is Banverket's annual report and strategic plan (Banverket, 2006b, Banverket, 2007) together with the government appropriation letter (Ministry of Industry Employment and Communication, 2006) verifying the need of all pre-chosen CSAs.

#### **4.1 Options and criteria identification**

The second and third stage is to identify options and criteria, i.e. CSF, KRA, and KPI. The first LinkEM-CSA logical group is representing ROMI and is dealing with both financial and non-financial terms. Identified financial CSF are in addition to maintenance and infrastructure renewal costs; predicted infrastructure renewal costs considered as important when changes in maintenance strategies are supposed to prolong the infrastructure life such as grinding (Åhrén et al., 2003), and theoretical infrastructure delay costs (Lundin, 2007). Related KPI is representing the three major interfaces between infrastructure and rolling stock namely; permanent way, catenary and power supply, and signals and telecom. According to delay statistics for the Swedish network these interfaces are representing the major causes for infrastructure related train delays (Banverket, 2006a). To sum up the remaining objects not included in the first three ones, the category other objects is used. Identified non-financial CSA is assets utilization including capacity utilization and a suggestion to sum-up the overall effectiveness of the railway infrastructure system which is a measure that has not been used before (Åhrén et al., 2005). The ROMI-CSA is summarized in Table 1.

The second LinkEM-CSA logical group is the HSE reflecting health, safety, and environmental issues. Supporting KRA and KPI are given by government appropriation letter, Banverket strategic plan, and annual report (Banverket, 2007, Banverket, 2006b, Ministry of Industry Employment and Communication, 2006). The health perspective is dealing with issues related to third part disturbances and accidents. The environmental perspective is dealing with issues related to sustainable and renewable use of nature and energy resources. The safety perspective is looking into issues related to accidents and near-accidents due to the infrastructure. The HSE-CSA is summarized in Table 2.

The third LinkEM-CSA model is the Railway Infrastructure Integrity (RII). Since all technical system in use will suffer from wear and tear, it is important that RII-CSA will reflect the general condition of the railway infrastructure, its degradation rate, and its availability to deliver required function. The infrastructure quality perspective deals with the actual condition of the technical system. Related KPI are already in use (Åhrén and Kumar, 2004). The infrastructure utilization perspective deals with the actual use of the system from a technical point of view. Studies have shown that the infrastructure degradation rate is related to traffic in terms of axle load and tonnage (Larsson, 2004). A similar scenario is also relevant for the technical interface between the train pantograph and the catenary/power supply interface. The infrastructure availability perspective is a part of the assets overall effectiveness. Identified KRA and KPI are adapted from general standards (SIS, 1999). The RII-CSA is summarized in Table 3.

**Table 1. The Link and effect model's critical strategic area (LinkEM-CSA) ROMI.**

LinkEM CSA	CSF	KRA	KPI examples	
ROMI	Budget deviation	<ul style="list-style-type: none"> <li>▫ Permanent way</li> <li>▫ Catenary / Power supply</li> <li>▫ Signalling / Telecom</li> <li>▫ Other objects</li> </ul>	Budget deviation for permanent way, catenary/power supply, signalling/telecom, and other objects	
	Maintenance cost index	<ul style="list-style-type: none"> <li>▫ Permanent way</li> <li>▫ Catenary / Power supply</li> <li>▫ Signalling / Telecom</li> <li>▫ Other objects</li> </ul>	Maintenance costs for permanent way, catenary/power supply, signalling/telecom, and other objects	
	Infrastructure renewal cost index	<ul style="list-style-type: none"> <li>▫ Permanent way</li> <li>▫ Catenary / Power supply</li> <li>▫ Signalling / Telecom</li> <li>▫ Other objects</li> </ul>	Infrastructure renewal costs for permanent way, catenary/power supply, signalling/telecom, and other objects	
	Predicted infrastructure renewal cost index	<ul style="list-style-type: none"> <li>▫ Permanent way</li> <li>▫ Catenary / Power supply</li> <li>▫ Signalling / Telecom</li> <li>▫ Other objects</li> </ul>	Predicted infrastructure renewal costs for permanent way, catenary/power supply, signalling/telecom, and other objects	
	Theoretical infrastructure delay (unpunctuality) cost index	<ul style="list-style-type: none"> <li>▫ Permanent way</li> <li>▫ Catenary / Power supply</li> <li>▫ Signalling / Telecom</li> <li>▫ Other objects</li> </ul>	Theoretical infrastructure delay costs for permanent way, catenary/power supply, signalling/telecom, and other objects	
	Asset utilization index		Planned traffic (capacity utilization)	Planned capacity utilization regarding passenger and freight traffic
			Planned maintenance and renewal	Planned renewal and maintenance activities
Overall railway infrastructure effectiveness (ORIE)		Infrastructure availability, infrastructure performance and infrastructure quality	Availability rate, performance rate, and quality rate	

**Table 2. The Link and effect model's critical strategic area ( LinkEM-CSA) HSE.**

LinkEM CSA	CSF	KRA	KPI examples
HSE	Health index	Reported 3:e part disturbances due to maintenance activities	Amount of reported disturbances due to noise, vibrations, platform lights, platform snow removal, and fallen tree protection program
	Safety index	Accidents involving railway vehicles	Number of accidents with and without derailments
		Accidents at level-crossings due to infrastructure related faults	Number of accidents at level-crossings due to infrastructure related faults
		Accidents and near-accidents due to safety system faults	Number of accidents and near-accidents due to safety system faults
	Environment index	Use of environmental hazardous materials	Amount of environmental non-hazardous materials
		Use of non-renewable materials	Amount of renewable materials
Use of non-renewable fuels		Amount of renewable fuels	

**Table 3. The Link and effect model's critical strategic area (LinkEM-CSA) Railway Infrastructure Integrity (RII).**

LinkEM CSA	CSF	KRA	KPI examples
Railway Infrastructure Integrity (RII)	Infrastructure quality index	Permanent way	Level of track quality, urgent inspection remarks, Q-factor, and amount of defect sleepers
		Catenary / Power supply	Level of urgent inspection remarks, catenary quality and alignment
		Signalling / Telecom	Level of urgent inspection remarks and signal system quality
		Capacity restrictions	Number of capacity restrictions
		Speed restrictions	Number of speed restrictions
		Markdowns in current standard	Markdowns in current standard
	Infrastructure availability index	Reliability	Amount of functional disruptions leading to train disruptions
		Maintainability	Average MTTR for train disruptive faults
		Maintenance safety/support index	(See Table 4)
	Infrastructure utilization (degradation) index	Permanent way	Amount of lateral and vertical forces, speed, and counted axles
		Catenary / Power supply	Amount of lifting forces, speed, and counted trains

The fourth LinkEM-CSA is the Process-model reflecting the two CSFs internal and external processes given by the original link and effect model. Identified KRA and KPI for the internal process index are given by the SIQ-model, Banverket's strategic planning, government appropriation letter, and conducted case studies (Banverket, 2006b, Espling, 2007, Ministry of Industry Employment and Communication, 2006, SIQ, 2007). KRA and KPI for the external process index is given by the measurement appendix in Banverket strategic plan (Banverket, 2006b). The LinkEM-CSA named Processes is summarized in Table 4.

**Table 4. The Link and effect model's critical strategic area (LinkEM-CSA) Processes.**

LinkEM CSA	CSF	KRA	KPI examples
Processes	Internal process index	Information and analysis	Share of IT-system availability, confidence, and usefulness
		Employee satisfaction	Share of reduced stress and absence due to illness
		Strategic planning	Share of strategic planning revisions
		Leadership	Share of personal commitment, continuous improvement, and management development
		Maintenance purchasing process	Share of outsourcing evaluations regarding objectives, organization, contract forms, contract ending, supplier market, and share of partnering and incentive contracts
		Development	Share of started, on-going, and finished R&D projects
	External process index	Maintenance support index	Change of average logistic delay time
		Planned maintenance	Share of planned maintenance
		Used maintenance slots	Share of used maintenance slots
		Used large planned track work slots	Share of used large planned track work slots
		Non-delaying A-works	Share of non-delaying A-works

The fifth LinkEM-CSA is the Competence-model dealing with both strategic and individual competencies. Finally, the sixth LinkEM-CSA is the Relationship-model reflecting internal and external relationships for the infrastructure manager perspective. Supporting KPI are given by SIQ and Banverket strategic plan (Banverket, 2006b, SIQ, 2007), summarized in Table 5.

**Table 5. The Link and effect model's critical strategic area (LinkEM-CSA) Competence and Relationships.**

LinkEM CSA	CSF	KRA	KPI examples
Competences	Strategic competence provision index	IM organization	Strategic competence provision index
	Individual development planning index	IM organization	Individual development planning index
Relationships	Employee dialogue index	IM organization	Share of employee dialogues
	Customer dialogue index	IM organization	Share of satisfied customers
	Contractor dialogue index	IM organization	Share of smoothly running contracts

## 5 Discussion

During 2007 Banverket has moved from a traditional governmental authority organisation to a more asset manager organisation. In order to increase the availability and capacity of the infrastructure and prolong its useful life the focus has moved from time based maintenance to condition based maintenance with focus on the customer (traffic operation) needs; hence the new organisation is now set to adapt a LinkEM model approach. All key functions such as; technical, economical, organisational, environmental, safety etc. are now in place at Banverket and hopefully this model can act as a backbone structure for Banverket's maintenance and operation activities in a near future.

When developing a conceptual LinkEM for the railway infrastructure manager (IM) the model must be adjusted to meet their specific needs regarding railway infrastructure maintenance. What IM is striving for is a safe, available, and cost-effective railway system (Banverket, 2007). The model should therefore provide the actual status for the infrastructure system independently of what and who is responsible for a train delaying failure even if it is due to an extra-ordinary situation. In the end, the IM is always responsible for keeping the infrastructure within required standard limits. If, for instance, train delaying causes later on is to be distributed to the different railway system players, this is something that must be managed outside the link and effect model, i.e. the model should not take into account who to blame.

Before a true condition test of the railway link and effect model can be undertaken it is necessary to prioritize the different indicators amongst each other's, i.e. define the relative impact of the indicators in order to make it possible to do the right decisions in a trade-of situation. It is also important to validate LinkEM through simulation on historical data; especially looking for changes in ROMI and HSE that cannot be explained by changes in any other CSA. If such changes occur, it might indicate that the relative impact of different performance drivers are misjudged or that important performance drivers are missing in the LinkEM and therefore might need to be re-configured.

When it is time for implementation of LinkEM into the IM organization some important issues need to be addressed. One issue is dealing with the problem of breaking down the

LinkEM into smaller comparable result units. Historically, Banverket has used track section and track kilometres as a comparable unit. However, other units might be fruitful to use like track class, traffic line, or traffic volume. Another issue to have in mind is, if the LinkEM can be used for more than just management of the railway infrastructure maintenance. If so, the model must be evaluated for that new and extended purpose. One example of such a possible extension is to use the model from a total railway system perspective, i.e. include traffic operators in the model. The output will then reflect the society and end customers' experience of the railway system, but can it still be used as a railway management tool.

## 6 Concluding remarks

In this paper, a conceptual railway infrastructure maintenance link and effect model (LinkEM) is presented, which was originally developed for the offshore industry. LinkEM is taking into consideration the specific needs of the railway infrastructure manager, focusing on critical-strategic areas determined by the nature of the railway industry and public requirements and regulations. The direct link between overall objectives and the outcome measures for railway maintenance are in terms of health, safety, and environment (HSE) and return on maintenance investments (ROMI). The main performance driver for ROMI and HSE is the railway infrastructure integrity (RII). Adequate competencies, functional internal processes, and good internal and external relationships lay the foundation for RII.

LinkEm is developed for the railway industry and adapted on Banverket for their specific needs by using the first process step of the Multi Criteria Decision Analysis (MCDA), and the concept of the Requirement Tree Method dealing with the specific problem of parameter aggregation and interrelationships. Ongoing simulation, testing, and validation, as well as future implementation of LinkEM will require the use of the remaining two process steps in MCDA.

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