INCREASING MARKET CREDIBILITY THROUGH CONTINUOUS VULNERABILITY REDUCTION
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SUMMARY

Green corridor concept is a European Commission initiative which is aimed at enhancing the competitiveness and sustainability of logistics industries. It is anticipated to promote smooth inter-modal large-scale and long-term transport solutions through attractive and high performing infrastructure with supportive regulatory framework. Among the motivating reasons for developing green corridors are:

- Facilitating collaboration between countries, society, industry, transport administrators, and logistics stakeholders,
- Environmental concerns, such as emissions, noise, etc.,
- Competitiveness of the manufacturing industry,
- Better use of money spent on infrastructure management,
- Manage expected increasing freight traffic across Europe and globally.

In supporting the green corridor concept, EU encourage through projects to speed up the shift towards greener and more efficient transport logistic solutions. Bothnian Green Logistics Corridor is one of the projects with the objective to increase the integration between the northern Scandinavia and Barents region, with its vast natural resources and increasing industrial production, with the industrial chain and end markets in the Baltic Sea Region and central Europe. An approach deployed in the project is the implementation of green corridor concept through improved planning, use and utilization of the infrastructure in the Bothnian Corridor.

METHODOLOGY

The approach mentioned above includes increase of market credibility through continuous vulnerability reduction. The study contained in this report investigates the vulnerability of railway infrastructure to failure and also methodology for continuous improvement of infrastructure performance and service quality through effective maintenance management. A link and effect concept for measuring and managing physical asset against agreed and set objectives is explained in the report. Furthermore, an adapted risk assessment technique using risk matrix is demonstrated in a case study to enhance maintenance decision and actions towards increasing operational reliability and availability of railway network, and thereby supporting a credible market required for a green logistic corridor. Bottlenecks regarding railway zones and systems have been identified for root cause analysis.

This report pertains to activity (A) 3.5, “Increasing market credibility through continuous vulnerability reduction”, which is a part of work package (WP) 3, of “Green corridors”. Involved partners in A3.5 are: Luleå Railway Research Center (JVTTC) at Luleå University of Technology (LTU) and Trafikverket (the Swedish Transport Administration; TRV).

FINDINGS

A link and effect model utilizing reliability centermaintenance (RCM) has been developed for a track section of railway infrastructure. A case study has been carried out to demonstrate the model for continuous improvement of railway infrastructure to meet the requirements of the anticipated green logistic corridor. This approach has shown track bottlenecks on the line section under consideration.

For further analysis relevant to the interest of the Bothnian green logistic corridor project, the model and the statistics of the delay indicator presented can be used as input into traffic management or capacity optimisation tool (Section 3.2.3). Similar, data collection and analysis with application of the model can be applied for other track sections of BGLC and Railway sectors.

Railsys simulation has been carried out but needs further adjustments for working satisfactory in this kind of set-up, i.e. with regard to run-time delays, entry delays and dwell times (Section 5.3). However, according to the collected data, 2536 trains were delayed in 3257 days. That gives 0.78 trains/day, or 2.4 % of the trains if there are 32 trains/day. The median delay is 19 min, but 84 trains were delayed more than 10 hours each. It must also be taken into consideration that the capacity consumption has not been very high. Moreover, studies shows that the railway
Increasing Market Credibility through Continuous Vulnerability Reduction

Infrastructure is responsible for 20-30% of the train delay, i.e. the train delays are larger than the figures just given above.

Performance measurement of operation and maintenance is important for punctual trains, but it is equally important for safety and cost of planning. For example, to reduce costs of planning, contracting and performance measurement is one of the main goals of Trafikverket. This can be achieved with better and automatically updated indicators.

Further Actions

It is well known that maintenance of railways is a major cost contributor, but studies on potential savings from preventive maintenance are lacking. Thus, it is not possible to estimate saving in this study at present. Study of present preventive and corrective maintenance in the European railways for return on investment is therefore a crucial part for all research related to investments in operation and maintenance, like performance measurement, condition monitoring and reengineering of components.

Performance measurement and monitoring of railways is essential for safety, efficient and effective maintenance and costs. Infrastructure managers use performance indicators in their strategic, tactical and daily work, but often in an *ad hoc* manner. Therefore, performance indicators and need to be mapped, standardised and harmonised. Similarly, methods and tools, like link & effect model and RCM (reliability center maintenance) need to be developed for railways. Specifically, further actions for increasing life cycle cost, safety and punctuality of trains are:

- Detailed mapping of performance indicators of railways for standardised, harmonisation, safety management and benchmarking
- Development of composite indicators (indices) to reduce the numerous indicators that make planning of operation and maintenance in railways time and resource consuming
- Development of RAMS and LCC decision support models, for vulnerability reduction in a cost effective way.
- Application of RCM methodologies such as three dimensional risk matrix for continuous improvement
- Analysis of preventive and corrective maintenance cost balance for return on investment (ROI) and LCC (life cycle cost) calculations
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CHAPTER 1
INTRODUCTION

The anticipation of increasing integration between the northern Scandinavia and Barents, with the Baltic Sea Region and central Europe is the fundamental objective of Bothnian Green Logistics Corridor (BGLC). The approach in the BGLC project is to contribute to an optimal use of the current infrastructure by promoting smooth inter-modal large-scale and long-term transport solutions, improved planning, use and utilisation of the infrastructure in the Bothnian Corridor and implementing other practices of green corridor concept.

The railway infrastructure of the Bothnian Corridor is of high importance for transnational cargo flows within EU and to the rest of the world. Thus continuous improvement of the infrastructure maintenance is essential to support high performance infrastructure required on a Green Logistic corridor. This will contribute to the credibility of railway transportation. This presents benefits to the operators, transport buyers, society and other stakeholders in terms of safe, reliable, green and cost efficient transportation.

Credibility of railway transport is a function of the performance of railway infrastructure management. The growing demand for capacity, safety, cost effectiveness and other service quality of railway transport requires improvement of infrastructure management responsibilities. The maintenance process is a responsibility whose improvement is promising and achievable in short term since capital expansion of the infrastructure is of very long term processes. Investigation into the present state of infrastructure management shows that the capacity and credibility of the railway transport market is influenced by the following:

- The frequency of traffic interruption due to infrastructure failure
- Longer track possession time due to poor planning
- Reduced functional performance due to degraded state of infrastructure

To achieve the objective of a green logistic corridor with improved utilization of the transport system, maintenance decisions and actions must be adequately monitored and managed. This will improve infrastructure performance, reliability, degradation and availability.

1.1 BACKGROUND

Reducing railway infrastructure failures will increase railway dependability, credibility and capacity. Performance measurement systems have shown to increase the performance and competitiveness of organisations through use of more balanced indicators, e.g. see (Kaplan et al. 1992, Kaplan et al. 1993). However, there are numerous issues in performance measurement and improvement initiatives, such as (Bourne et al. 2002):

- Poor integration of objectives at the strategic level to the operational level
- Overlooking strategy, its components and linkage, and instead implementing a data collecting system
- Too large number of indicators, which are lacking in definition and structure
- Hard to get data and to turn it into information
- Striving for perfection can undermine success
- A highly developed information system is called for instead of using the existing data
- Time, effort and expense
- Resistance to change
- State of the art improvement methods are not always used
- Not considering both quantitative and qualitative aspects
- Project overtaken by parental project
- Different usage of terminology among stakeholders

The purpose of this study is to develop a performance measurement system, by applying a link and effect model, to meet the objective of BGLC and some of the above mentioned issues for railway infrastructure (Stenström et al. 2013). Besides describing the methodology, the report contains a case study on the Swedish Iron Ore Line, more precisely on the northern part of the line, between Kiruna city and Riksrånsen, the border between Sweden and
Norway. The aim of the case study is to investigate possibilities of increasing railway infrastructure capacity and credibility by analysis of railway infrastructure failures.
CHAPTER 2
METHODOLOGY

The link and effect model is a performance measurement system that combines performance measurement and engineering principles for proactive management of physical assets (Stenström et al. 2013). This study combines the link and effect model with RCM (reliability center maintenance); see Chapter 2.2.

2.1 THE LINK AND EFFECT MODEL

The link and effect model is a performance measurement system that combines performance measurement and engineering principles for proactive management of physical assets. It follows a top-down and bottom-up methodology, breaking down overall goals to specific objectives, followed by aggregation of indicators to a vital few. See Figure 1.

![Diagram of the link and effect model](image)

KRA = Key result area
CSF = Critical success factor

**Figure 1:** The link and effect model with a one year cycle time, based on (a) a four steps continuous improvement process and (b) a top-down and bottom-up process. The numbers in (b) represents the steps in (a). Adapted from (Stenström et al. 2013).

Terminology of Figure 1, for a common language of strategic planning, is described as (Stenström 2012):

- **Vision statement** A statement of what an organisation hopes to be like and to accomplish in the future (U.S. Dept of Energy 1993).
- **Mission statement** A statement describing the key functions of an organisation (U.S. Dept of Energy 1993). Note: vision and mission are set on the same hierarchical level, since either can come first, e.g. an authority has a vision, and gives a mission to start a business; the business can develop its own vision later on.
- **Goals** A goal is what an individual or organisation is trying to accomplish (Locke et al. 1981). Goals are commonly broad, measurable, aims that support the accomplishment of the mission (Gates 2010).
- **Objectives** Translation of ultimate objectives (goals) to specific measurable objectives (Armstrong 1982), or targets assigned for the activities (CEN 2011), or specific, quantifiable, lower-level targets that indicate accomplishment of a goal (Gates 2010).
- **Strategy** Courses of action that will lead in the direction of achieving objectives (U.S. Dept of Energy 1993).
### Key result areas (KRAs)
Areas where results are visualised (Boston et al. 1997), e.g. maintenance.

### Critical success factors (CSFs)
Are those characteristics, conditions, or variables that when properly managed can have a significant impact on the success of an organisation (Leidecker et al. 1984), e.g. high availability. CSFs can be on several levels, e.g. organisational and departmental.

### Performance indicators (PIs)
Parameters (measurable factor) useful for determining the degree to which an organisation has achieved its goals (U.S. Dept of Energy 1993), or numerical or quantitative indicators that show how well each objective is being met (Pritchard et al. 1990).

### Key performance indicators (KPIs)
The actual indicators used to quantitatively assess performance against the CSFs (Sinclair et al. 1995). A KPI is a PI of special importance comprising an individual or aggregated measure.

Data overload, failing in turning data into information and lacking in defining performance indicators, are common deficiencies in organisations performance measurement. It is therefore essential to define and organize the PIs and related databases. See high level requirements (HLRs) for indicators and databases in Figure 2:

![Documentation of indicators (hard and soft aspects)](chart1)

![Documentation of databases](chart2)

![Setting up regulations](chart3)

**Figure 2:** High level requirements (HLRs) of indicators and databases.

Railway infrastructure is a complex system consisting of many electrical and mechanical systems integrated, thus, there are hundreds of parameters and PIs to monitor. Therefore, aggregation is needed as management can only monitor a limited number of indicators. Aggregated PIs, indices or composite indicators, can present a complex asset or feature in a single figure. Nevertheless, an aggregated PI can be abstract and an object of subjective interpretation. Therefore it is important to present PIs with the underlying factors, i.e. performance killers and drivers, for proactive management. Thus, when a threshold is reached, it is already known why it has been reached, or where to look further. See Figure 3, analogous to the stock market presentation of underlying information.
2.2 RELIABILITY CENTER MAINTENANCE APPROACH

Reliability center maintenance (RCM) is a method for establishing preventive maintenance programmes which is intended to result in improved overall safety, availability and economy of operation of equipment and structures (IEC 1999). It is a logical way of identifying what system, subsystem or component in a large facility is required to be maintained on a preventive maintenance basis rather than on a run-to-failure basis (Boom 2005). The end result of working through its principle is underscoring the necessity of performing maintenance tasks according to the safety, operational and economic consequences of identifiable failures, and the degradation mechanisms.

Prerequisite to successful application of RCM is a thorough understanding of the technical system and the associated systems, subsystems and components, together with the possible failures, and the consequences of those failures. The use of RCM is therefore dependent on the type and size of technical system. Its application requires detailed analyses of the product and its functions, which can be labour intensive and therefore comparatively cost demanding (IEC 1999). For this reason, the principles of RCM have been adapted in different ways to identify critical systems and develop preventive maintenance programme for them, so as to drive towards the achievement of maintenance objectives. An adapted RCM technique is relevant in continuous improvement of the railway infrastructure maintenance. The report of RAIL: Reliability center maintenance approach for the infrastructure and logistics of railway operation (Applying RCM in large scale systems) gives the details on the adaptation and implementation of RCM in railway networks (Carretero et al. 2003).

In railway industries, functional performance can be described on different indenture levels. It can be high indenture level, such as network, lines and systems, or low level, such as sections, zones, subsystems and components. A credible market for railway traffic on a corridor requires a maintenance function which adequately supports the inherent capacity and performance of the corridor, its routes, line sections, traffic zones, systems and so on. Since RCM recognizes that the consequence of failure ought to be the main driver of maintenance decisions, instead of the failure itself, thus, failures with critical consequence and high risk are given attention. For development of effective maintenance programme to support inherent performance of a railway network, Figure 4 shows the system breakdown structure of a corridor and the relevant maintenance analysis (RCM related).
2.2.1 CRITICALITY ANALYSIS
Criticality is the basis to link the overall performance of the network to the performance of the various indenture levels. It is a measure of the importance of any unit from a functional point of view. It is also a measure of the contribution of the constituent route or line section to the credibility of the corridor. A railway network is a linear and complex system with a number of lines, line sections, many systems and thousands of items, thus computation of criticality is recommended for high level system such as line and line sections. Table 1 shows the criteria that can be used for criticality analysis to identify bottlenecks on a corridor or route.

Table 1: Criticality study with criteria and their description

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
<th>Grade 1</th>
<th>Grade 2</th>
<th>Grade 3</th>
<th>Grade 4</th>
<th>Grade 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Model and complexity of technology</td>
<td>Very simple</td>
<td>Simple</td>
<td>Average</td>
<td>Complex</td>
<td>Very complex</td>
</tr>
<tr>
<td>Line class</td>
<td>Socio-strategic value</td>
<td>Very low</td>
<td>Low value</td>
<td>Average</td>
<td>High value</td>
<td>Very high value</td>
</tr>
<tr>
<td>Capacity</td>
<td>Time infrastructure is occupied over a specific period of time</td>
<td>&lt;&lt;&lt;40</td>
<td>&lt;40%</td>
<td>60&lt;traffic&lt;80</td>
<td>&gt;80%</td>
<td></td>
</tr>
<tr>
<td>Utilisation</td>
<td>Extra demand for train path</td>
<td>Very low</td>
<td>Low</td>
<td>Average</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td>Limitation</td>
<td>Probability to restore</td>
<td>Very low</td>
<td>Low</td>
<td>Average</td>
<td>High</td>
<td>Very high</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Cost</th>
<th>Revenues from traffic</th>
<th>Very low</th>
<th>Low</th>
<th>Average</th>
<th>High</th>
<th>Very high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenues</td>
<td>Revenues from traffic</td>
<td>Very low</td>
<td>Low</td>
<td>Average</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td>Logistic</td>
<td>Logistic of maintenance</td>
<td>Very low</td>
<td>Low</td>
<td>Average</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td>Safety risk</td>
<td>Risk of damage</td>
<td>Very low</td>
<td>Low</td>
<td>Average</td>
<td>High</td>
<td>Very high</td>
</tr>
</tbody>
</table>

The aggregation of the above mentioned factors in a criticality analysis requires the inclusion of weight from expert judgement. Techniques such as analytical hierarchical process (AHP) or fuzzy logic can be adapted for the aggregation of the above mentioned criteria and hierarchical listing of route and lines, based on their vulnerability to failure or negative contribution to market credibility. However, this part is within scope of future work.

2.2.2 RISK ANALYSIS (OPERATION CONSEQUENCE)

Furthermore, analysis is done on a low level indentre of infrastructure configuration for the development of a preventive maintenance program aimed at supporting a high performing infrastructure for a green logistics corridor. Risk assessment matrix are proposed in the standard The specification and demonstration of RAMS (CEN 1999) and also used in the RAIL project (Carretero et al. 2003) is applicable for identifying vulnerable points on the linear asset. Among several benefits of such approach is the opportunity to identify critical areas that are bottlenecks to the fulfilment of availability and operational capacity objective of green corridor concepts. Also, it helps to identify weak sections and systems on a line which are vulnerable to failure and contributing to a higher risk of quality loss and capacity reduction and consequently requires attention.

Applying the risk analysis using the risk assessment matrix shown in Table 2, two maintenance performance indicators were used as factors; the frequency of failure and the consequence of the failure on traffic operation in terms of punctuality. Using this approach will help to categorize the failure behaviour of each traffic zone, system or other lower indentre level. This will be resourceful information for prioritization during maintenance planning and scheduling.

Table 2: Typical risk evaluation matrices.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Likely impact or consequence of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Insignificant</td>
</tr>
<tr>
<td>Frequent</td>
<td>Undesirable</td>
</tr>
<tr>
<td>Probable</td>
<td>Undesirable</td>
</tr>
<tr>
<td>Occasional</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Remote</td>
<td>Negligible</td>
</tr>
<tr>
<td>Improbable</td>
<td>Negligible</td>
</tr>
<tr>
<td>Incredible</td>
<td>Negligible</td>
</tr>
</tbody>
</table>

For the case study, a hypothetical grading of the frequency of failure and consequential delay is done to demonstrate the mentioned methodology. This grading ought to be a subjective judgement of a group of expert within the IM organisation, and it should reflect both the acceptance limit and quality definition of the organisation.
Applying the link and effect model (Figure 1) and following the vision, goal and objectives of European Commission (EC) White paper 2011, “Roadmap to a Single European Transport Area” (EC 2011), breakdown and aggregation for railway infrastructure failures can be carried out; see Figure 5.

**Figure 5:** Break down and aggregation for railway infrastructure. Vision, goal and objectives are extracted from EC White paper 2011 on transportation (EC 2011).

### 3.1 DATA COLLECTION

Railway infrastructure failures and corresponding train delay data of the northern part of the Swedish heavy haul iron ore route were collected and analysed. It stretches between Kiruna city and Riksgränsen, border to Norway; see Figure 6. The infrastructure is divided according to Figure 4, viz.:

- Corridor → Routes/Lines → Line sections → Traffic zones → Systems → Subsystems → Components

Traffic zones are the points and connecting links between the points, see Figure 6. The case study is concentrated at these traffic zones and their systems.

The data span from 2001.01.01 to 2009.12.01. Failure data consist of urgent inspection remarks reported by the maintenance contractor, as well as failure events and failure symptoms identified outside the inspections, commonly reported by the train driver, but occasionally reported by the public. The work orders’ failure reports include the three categories of RAM (reliability, availability and maintainability) failure as identified by the European Standards EN 50126 (CEN 1999), see Figure 7. Failures identified outside inspections include the following (Banverket 2010):

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

Immediate action is required if the fault negatively influences: safety, train delays, third parties or the surrounding environment (Trafikverket 2010):
Figure 6: Breakdown structure of the railway infrastructure to strategic, tactical and operational levels.

Figure 7: Failure work order description. The three RAM (reliability, availability, maintainability) categories are: immobilising failure, service failure and minor failure (CEN 1999).
CHAPTER 4
RESULTS AND DISCUSSION

4.1 RISK ASSESSMENT MATRIX FOR TRAFFIC ZONES
The capacity, quality of service and other performance measures of a green logistic corridor are function of most restrictive infrastructure segment. It is therefore essential to use a methodology such as risk assessment described in previous section to identify such segment and related maintenance activities. This will give resourceful information for prioritization during maintenance planning and scheduling and also capital investment during continuous improvement. Using the risk assessment matrix and the traffic zone level of the system breakdown structure, the vulnerability of each traffic zone on the case study is categorized. See Figure 8. Data spans from 2001.01.01-2009.12.01, i.e. 3257 days, due to change in data collecting system in 2009.

![Risk assessment matrix for traffic zones and corresponding weights according to Table 2.](image)

To meet the operational requirements of the line section under consideration and achieve a credible market for railway transport, proactive measures must be developed and implemented based on the vulnerability category of the traffic zones. To this end zones with intolerable impact should be subjected to detailed failure analysis to eliminate the bottleneck. Zones with undesirable risk contribution should be maintained to reduce their impact. Zones with tolerable impact should be controlled with necessary measures while those with negligible impact should be observed and their maintenance should be standardised. This vulnerability categories and suggested intervention measures will facilitate the development of maintenance programme that will homogenize the
condition of the infrastructure along the line section. Furthermore, identifying critical spots or bottlenecks on the line sections also help to capture inherent locational problem.

4.2 SYSTEM RISK ASSESSMENT

Weight from the vulnerability categories can be cascaded down to respective lower level system in order to generate hierarchical listing of maintenance significant system that can inform maintenance decision. System risks have been calculated by applying the weights (w) according to the risk assessment matrix in Figure 8 and using $R = w \prod_{i=1}^{n} F_i = w F_1$, where $F_i$ is the train delay, see Figure 9. The most problematic systems have shown to be the positioning system, switches and crossings (S&C) and track; these have been analysed. For clarification, the track system consists of the rail, rail joints and fastenings.

As for the risk assessment matrix, the data spans from 2001.01.01-2009.12.01.

![Figure 9: System risk of the zones utilizing the weights obtained in from the risk matrix.](image)

Zone 3 shows a high risk value, above 4000. One possible explanation can be that it has six S&C, but on the other hand, zones 13 and 19 have six and twelve S&C, respectively (Table 3). Also zone 11 shows a high risk on the S&C, which has four S&Cs. Zones 2, 4, 10, 24 and 26 shows high risk on the track. The lengths of the zones are 4.4, 9.0, 8.9, 7.2 and 6.7 km, respectively. Zones 11 and 25 show high values on the positioning system. All these systems should be studied closer for their improvement. To facilitate detailed root cause analysis of vulnerable zones and system, Figure 10 is suggested. It will help to identify and address the cause of the poor technical performance of any system. This would require a collaborative effort of a group maintenance expert from the infrastructure manager, maintenance service provider and other relevant stakeholders. Furthermore, cascading down the weights have the advantage of highlighting problematic systems, however, it needs to be noted that the drawback is that the relative difference between the systems are less visible.
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Figure 10: Root causes of infrastructure vulnerability to failure (Famurewa 2012).

Table 3: Length and number of S&C of the zones.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Zone no.</th>
<th>S&amp;C no.</th>
<th>Length (m)</th>
<th>Zone</th>
<th>Zone no.</th>
<th>S&amp;C no.</th>
<th>Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KMB</td>
<td>1</td>
<td></td>
<td></td>
<td>AK - SOA</td>
<td>18</td>
<td></td>
<td>8974</td>
</tr>
<tr>
<td>KMB - KV</td>
<td>2</td>
<td>2</td>
<td>4394</td>
<td>AK</td>
<td>19</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>KV</td>
<td>3</td>
<td>6</td>
<td>9039</td>
<td>AK - AKT</td>
<td>20</td>
<td>12</td>
<td>912</td>
</tr>
<tr>
<td>KV - RUT</td>
<td>4</td>
<td>3</td>
<td></td>
<td>AKT</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RUT</td>
<td>5</td>
<td>3</td>
<td>8869</td>
<td>AKT - BLN</td>
<td>22</td>
<td>3</td>
<td>6562</td>
</tr>
<tr>
<td>RUT - RSN</td>
<td>6</td>
<td>3</td>
<td></td>
<td>BLN</td>
<td>23</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>RSN</td>
<td>7</td>
<td>3</td>
<td>7778</td>
<td>BLN - KÅ</td>
<td>24</td>
<td>3</td>
<td>7164</td>
</tr>
<tr>
<td>RSN - BFS</td>
<td>8</td>
<td>3</td>
<td></td>
<td>KÅ</td>
<td>25</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>BFS</td>
<td>9</td>
<td>3</td>
<td>8907</td>
<td>KÅ - LÅK</td>
<td>26</td>
<td>4</td>
<td>6742</td>
</tr>
<tr>
<td>TKN</td>
<td>10</td>
<td>3</td>
<td>8477</td>
<td>LÅK</td>
<td>27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TKN - BFS</td>
<td>11</td>
<td>4</td>
<td></td>
<td>VI - LÅK</td>
<td>28</td>
<td>4</td>
<td>1130</td>
</tr>
<tr>
<td>TKN - SBK</td>
<td>12</td>
<td>4</td>
<td></td>
<td>VI</td>
<td>29</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>SBK</td>
<td>13</td>
<td>6</td>
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<tr>
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<td>3</td>
<td>10612</td>
<td>KJÅ - RGN</td>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Sum** | 56 | 103344 |

4.3 DATA FOR RAILSYS SIMULATION

For further analysis relevant to the interest of the Bothnian green logistic corridor project, the delay indicator has been analysed. This delay indicator is the arrival non negative delay caused by infrastructure failure, the statistics has been presented in a such a way that it can be used as input into traffic management or capacity optimisation tool.
This will help in time table planning, scheduling, optimization and simulation. The outcome of such optimisation is improved utilization of inherent capacity of a corridor, creating additional capacity and facilitating credible market. Table 4 shows the statistics of infrastructure failure of the case study in a format usable for further simulation in the interest of achieving the objectives of green logistic corridor. The data stretches from 20010101-20091201, i.e. 3257 days.

Table 4: Failure statistics an input for capacity and timetablist optimisation. Zone numbers are found at the first row and train delay intervals in the first column. The numbers represents the number of trains experience delay within the intervals. 1949 trains are delayed.
CHAPTER 5
RAILSYS SIMULATION OF MALMBANAN – MODEL AND RESULTS

Railway infrastructure failures are further studied to find out whether reduction of infrastructure failures will increase the punctuality of the trains by using the simulation tool Railsys. The same data from Malmbanan (the Swedish Iron Ore Line), on the northern part of the line between Kiruna and Riksgränsen, are used in this study.

5.1 BACKGROUND

5.1.1 INFRASTRUCTURE
The Railsys infrastructure model contains the infrastructure from Peuravaara (just north of Kiruna) to Björnfjell in Norway, designed according to today’s infrastructure (2013); extracted from Trafikverket's asset structure. That means, there are still a few short passing sidings, with the consequence that two long iron ore trains, with a length of 746 meters, cannot meet and pass each other at those places.

The Railsys model is built with concurrent entrance, which means that two trains from different directions can enter the station at the same time. No passing sidings on Malmbanan have that function but it is a default setting in the Railsys program. However, if you compare two simulations with different delay distributions but based on the same infrastructure that difference does not affect the outcome.

5.1.2 TIMETABLE
The timetable includes all trains between Peuravaara to Narvik on Thursday the 21\textsuperscript{st} of February 2013. The trains run according to the planned timetable for 2013. There are, in each direction, 21 iron ore trains with a length of 746 meters from LKAB, 4 iron ore trains from Northland Resources are 430 meters, 4 freight trains with lengths between 520 to 600 meters and finally 3 passenger trains of which two are regional trains and one is a night train.

In Railsys the trains are divided into three different patterns; iron ore trains, other freight trains and passenger trains. In the graphical timetable the trains are colored differently depending of type of pattern; the iron ore trains are colored dark blue, the freight trains purple and the passenger trains green (see Figure 11 below).
INCREASING MARKET CREDIBILITY THROUGH CONTINUOUS VULNERABILITY REDUCTION

5.1.3 TRAIN DELAY DATA
The train delay data is collected from Trafikverket's follow-up systems. The run-time delays consist of infrastructure failures.

5.1.4 DELAY PARAMETERS
To make the Railsys model as correct as possible, the delay parameters should be in form of entry delays, dwell time delays and run time delays. However, the used model could not handle large entry delays (>10 minutes), since the cycle turned into deadlock which means the simulation stops. Too many deadlocks mean low reliability and difficulties to make conclusions of the result. Therefore, we choose to add only run-time perturbations and then compare and evaluate the result of two different types of run-time distributions. To minimize the deadlocks even further, run-time delays are set to a maximum of two hours.

5.2 METHOD
Two different simulations are done; one with run-time delays including all infrastructure failures and one with run-time delays with infrastructure failures except the ones coming from S&Cs. Each simulation contain 1000 cycles. The results from the two simulations are compared to see whether decreasing failures from S&Cs will improve the punctuality. Punctuality for passenger trains, iron ore trains and other freight trains are evaluated.

5.3 RESULTS
Comparison of the departure values at the end stations for the two different delay distributions shows small effect on punctuality, as seen in Table 5 below. When large delays occur in practice, trains are often cancelled and not
included in the punctuality statistics. The effect of decreasing infrastructure failures need to be shown in some other ways, maybe in costs of cancelled trains.

**Table 5:** Punctuality with run-time perturbations only. Note: The punctuality in the table can only be used to compare the different run-time perturbations.

The first column on the left side of Table 5 is the time interval for the train delay. The second one represents the outcome of the simulation with run-time delay including all infrastructure failures, and the third one the simulation excluding failures from S&Cs. For example; in the simulation including all infrastructure failures 98.74% means the amount of trains that arrive to the station Björnfjell in the interval 0-59 seconds.

Railsys simulation shows that >97 % of the trains are less than 360 seconds (6 minutes) delayed, except for freight trains to Krokvik station. Punctuality measures are commonly measured as delay over 5 minutes or 15 minutes depending on the traveling distance. Therefore, the simulation shows that the performance is high, even with the failures that have taken place in the railway infrastructure. However, train delays are known to be a problem at the railway section. 2536 trains were delayed in 3257 days according to the data. That gives 0.78 trains/day, or 2.4 % of the trains if there are 32 trains/day. The median delay is 19 min, but 84 trains were delayed more than 10 hours each. It must also be taken into consideration that the capacity consumption has not been very high. Moreover, studies have shown that the railway infrastructure and train operating companies (TOCs) are responsible for 20-30 % and 30-40 % of the train delay, respectively (Espling et al. 2004, Nyström et al. 2003, Granström et al. 2005). The studies also showed that the rolling stock, vehicle failures, is responsible for 10-20 % of the delay.

Switches and crossings are responsible for a large part of the failures and train delays, but it cannot be seen in Table 5, which in some cases shows more run time delay when the switches and crossing’s failures are discounted. Thus, the model needs further adjustments for working properly, i.e. with regard to run-time delays, entry delays and dwell times.
A link and effect model utilizing reliability center maintenance (RCM) has been developed for a track section of railway infrastructure. A case study has been carried out to demonstrate the model for continuous improvement of railway infrastructure to meet the requirements of the anticipated green logistic corridor. This approach has shown that track zones 3, 11, 24 and 26 are the bottlenecks or weak spots on the line section under consideration and require detail maintenance analysis for appropriate intervention. Furthermore, the following lower level systems require adequate maintenance measures; switches and crossings in zones 2 and 11, track in zones 2, 4, 10, 24 and 25, and also positioning system on zones 25 and 26. To address this deficiency or failure vulnerability, root cause analysis can be initiated using the model provided in this report.

For further analysis relevant to the interest of the Bothnian green logistic corridor project, the model and the statistics of the delay indicator presented can be used as input into traffic management or capacity optimisation tool (Section 3.2.3). Similar data collection and analysis with application of the model can be applied for other track sections of BGLC and Railway sectors.

Railsys simulation has been carried out but needs further adjustments for working satisfactory in this kind of set-up, i.e. with regard to run-time delays, entry delays and dwell times (Section 5.3). According to the collected data, 2536 trains were delayed in 3257 days. That gives 0.78 trains/day, or 2.4% of the trains if there are 32 trains/day. The median delay is 19 min, but 84 trains were delayed more than 10 hours each. It must also be taken into consideration that the capacity consumption has not been very high. Moreover, studies have shown that the railway infrastructure and train operating companies are responsible for 20-30% and 30-40% of the train delay, respectively (Espling et al. 2004, Nyström et al. 2003, Granström et al. 2005).

Performance measurement of operation and maintenance is important for punctual trains, but it is equally important for safety and cost of planning. For example, one of the main goals of Trafikverket is to reduce costs of planning contracting, and performance measurement. This can be achieved with better and automatically updated indicators.

6.1 FURTHER ACTIONS

Performance measurement and monitoring of railways is essential for safety, efficient and effective maintenance and costs. Infrastructure managers use performance indicators in their strategic, tactical and daily work, but often in an ad hoc manner. Therefore, performance indicators need to be mapped, standardised and harmonised. Similarly, methods and tools, like link & effect model and RCM (reliability center maintenance) need to be developed for railways. Specifically, further actions for increasing life cycle cost, safety and punctuality of trains are:

- Detailed mapping of performance indicators of railways for standardisation, harmonisation, safety management and benchmarking
- Development of composite indicators (indices) to reduce the numerous indicators that make planning of operation and maintenance in railways time and resource consuming.
- Development of RAMS and LCC models, for vulnerability reduction in a cost effective way.
- Application of RCM methodologies such as three dimensional risk matrix for continuous improvement
- Analysis of preventive and corrective maintenance cost balance for return on investment (ROI) and LCC (life cycle cost) calculations

It is well known that maintenance of railways is a major cost contributor, but studies on potential savings from preventive maintenance are lacking. Thus, it is not possible to estimate saving in this study at present. Study of present preventive and corrective maintenance in the European railways for return on investment is therefore a crucial part for all research related to investments in operation and maintenance, like performance measurement, condition monitoring and reengineering of components.
REFERENCES


