Capacity Enhancement through Optimized Maintenance of Railway Networks
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Abstract
Rail traffic has increased manifold during the last decade. This development and the need for shift transportation from road to rail to decrease CO₂ emission, creates a challenge for the railway industry to improve capacity in the network. The challenge is to do more effective inspection and maintenance in less time. An EU project ‘AUTOMAIN’ was initiated to optimize and automate maintenance and inspection activities with introduction of new planning and scheduling tools and methodologies. The project looked into reducing the maintenance possession time by around 40%.
The project aim was to; adopt best practices from other industries in maintenance optimization, developing novel track inspection approaches for freight routes. The scope was for in-train measuring and self-inspecting switch, researching and assessing innovations that can improve the effectiveness and efficiency of large scale inspection and maintenance processes with a scope on track and switch maintenance, track inspection; developing key technologies that will drive the development of modular infrastructure design, and developing a new maintenance planning and scheduling tool to optimize the maintenance activities, taking account of the benefits brought about by other improvements in this project.
The Consortium composition covers the railway maintenance and inspection field like; infrastructure managers, contractors, train operating companies, railway component industry, research organizations, small and medium enterprises (SMEs) and railway industry related organizations. In this paper, the authors have tried to summarize the methodology and results achieved in this project and how it has achieved the reduced maintenance possession time for higher railway traffic movements.

1. Introduction
Railway freight transportation is finding it increasingly difficult to have availability and utilisation of the European railway network with passage of time. The increased passenger demand has further reduced the availability of the track to run the freight trains during the day. Due to the increase in total traffic, more frequent maintenance is required due to increased track degradation. The compelling reasons have also forced the infrastructure managers (IMs) to focus on undertaking the maintenance activities during the night, when passenger traffic is low. Therefore there is a scope to create additional availability and utilization to accommodate increasing capacity need, by improving the track maintenance efficiency and reducing the track possession time for maintenance.
There are various infrastructure maintenance activities which can be considered for undertaking detailed study and analysis for achieving reduced maintenance possession time as per the EU Seventh Framework Programme (FP7) AUTOMAIN (Augmented Usage of Track by Optimisation of Maintenance, Allocation and Inspection of railway Networks) objectives. Considering the scope of AUTOMAIN [1] and the resources allocated to high performance maintenance, it is only possible to look into the infrastructure maintenance activities of grinding, tamping and switches and crossings (S&Cs). Besides, these are the infrastructure maintenance activities which contribute to a large extent of maintenance possession time.
Rail grinding and milling can restore and preserve the rail head from defects. The traffic degrades the rail over the time and grinding is the most common method of preventive and corrective actions of the rail surface. Tamping is the common method of restoring vertical and lateral track quality to restore the riding comfort caused due to track degradation over time. Tamping is done for a number of reasons, typically to improve or maintain the overall quality of track top and alignment, or following renewals to restore the required track geometry. S&Cs consumes a lot of maintenance possession time, for which the modular approaches for S&C’s renewal are considered, including future technological requirements and current IMs’ practice. It is accepted that renewal work will also have a major impact on capacity; however, renewal work is outside of the scope of the AUTOMAIN project. High performance maintenance is a combination of all innovative, technical, logistic and...
managerial actions during the life cycle of any engineering asset to assure high dependability and sustainability with minimum cost.

Possession time is related to availability, which is reflected through high dependability for the IMs. To achieve high capacity utilization through efficient and effective maintenance performance to maximize life cycle profit is reflected through “the life cycle of any engineering asset to assure high dependability and sustainability with minimum cost”.

The maintenance process of railway infrastructure differs from other branches of railway due to various factors; e.g. EU and governmental objectives, longer planning processes, safety demands, yearly governmental funding, etc. The maintenance process for railway starts with setting the goals, objectives and strategy as formulated in line with the EU commission guide lines and National transportation policy for the railway infrastructure managers. The EU commission goals are: to have a Single European Transport Area, towards a competitive and resource efficient transport system, which has the target of a modal shift of 30% of road freight over 300km should shift to rail or waterborne transport by 2030 and 50% modal shift by 2050, this equates to 3 times as much rail freight by 2030 and 4 times as much by 2050 [4]. To accommodate this modal shift will require far greater utilisation of the existing infrastructure and periods to maintain the railway will be severely reduced.

This projects work is guided by a set of stakeholder functional performance requirements. These requirements describe the functions that stakeholders, such as IMs, contractors and regulators, want the system to be capable of doing and the level of performance required. This project studies the overall capacity enhancement need, capacity optimization and capacity allocation and inspection.

In this paper, the authors have tried to summarize the methodology and results achieved by this project for reduced maintenance possession time for higher railway traffic movements. After introduction in section 1, section 3 discusses the models used for capacity enhancement and optimization, followed by discussion in section 3. The results and conclusions are given in section 4.

2. Methodology and case studies

In order to find the improvement areas in current practice of maintenance activities like; conventional grinding, tamping and switches and crossings (S&Cs), besides lean analysis approach and value stream mapping (VSM) have been conducted to describe current practices. Based on the current practice new improvements and innovations has been identified. See Figure 1.

The methodology for lean thinking uses two methodologies to describe applied practice:

- Structured Observations – where an actual maintenance shift was observed in detail for each railway administration, through an independent third party perspective, noting key parameters such as the timing of key activities and opportunities to reduce waste
- Value Stream Mapping (VSM) workshops – a paper based exercise that maps out processes and procedures, used as a means of identifying issues and suggestions for improvement

The studies resulted in performance killers and opportunities that have high potential to be improved or obtained. Following the identification

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Figure 1: Interrelation of activities and strategy to achieve the results
of performance killers and opportunities, ranking was carried out using three criteria: If it is in our hands, how important it is to solve and if it is possible to implement. The criteria were given values as per high, medium and low. This step points out the elements we want to work further on. Moreover, the criteria have been set with reference to their positive effect on the maintenance possession time and capacity utilization. Thereafter the performance killers were linked back to the railway maintenance flow process. This was to be done since the VSM and lean analysis presented a total approach including long time planning, for identifying performance killers without linking them back to AUTOMAIN objectives.

The three-stage approach that was planned to increase the availability of freight train tracks, like; to reduce current night-time track closures through best-practice maintenance technologies and procedures; investigating innovative techniques to facilitate day-time maintenance; and exploring radically new techniques and procedures for high performance maintenance for improvements and innovations were considered and evaluated. Subsequently, a link and effect model, besides a capacity optimization study were undertaken for validation, and accordingly, new objectives and strategy, as required for the reduced maintenance possession time with suitable KPIs were suggested for following it up and to achieve the set objectives.

2.1 Link and effect model

The link and effect model develops performance measurement systems by combining performance measurement and engineering principles for proactive management of physical assets [8]. The model is built on continuous improvement to ensure a dynamic performance measurement that will accommodate changes [2] such as the following:

- Change in business goals, objectives, strategy, policies, etc.
- Change in technology and communication, e.g. maintenance procedures and ERP
- Organisational changes
- Evolving regulations, e.g. health, safety, security and environment
- Stakeholder requirements
- Fluctuations in economy, i.e. the business cycle
- Changes in physical assets

The model has a top-down and bottom-up approach to handle such issues in performance measurement. Many improvement methods are based on a continuous improvement process, including the plan-do-study-act (PDSA) cycle, also known as the Deming cycle, Shewhart cycle or Kaizen cycle [6]. Furthermore, organisations use the key elements, or components, of strategic planning differently, e.g. vision, mission, goals, objectives, etc. [8]. The link and effect model is therefore based on the PDSA cycle with emphasis on the key elements of strategic planning. The model has two main components: a four-step continuous improvement process and a top down and bottom-up approach; see Figure 2.

The methodology starts by breaking down the objectives; this is followed by updating the

![Figure 2: Link and effect model with a one year cycle, based on (a) a four step continuous improvement process and (b) a top-down and bottom-up process](image-url)

KRA = Key result area
CSF = Critical success factor

1. Breakdown of objectives
2. Updating the measurement system and aligning of indicators to objectives
3. Analysis of data for indicators, performance killers and drivers
4. Identification of improvements through indicators, ranking and implementation

Mission/Vision
Goals
Objectives
Strategies
KRAs
CSFs
PIs
PI
PI
PI
KPI
KPI
KPI

Figure 2: Link and effect model with a one year cycle, based on (a) a four step continuous improvement process and (b) a top-down and bottom-up process
measurement system accordingly, analysis of data and finally identification and implementation of improvements. The model is preferably used on a yearly cycle as the IMs’ objectives commonly change with annual appropriation letters.

2.2 Capacity model

Capacity performance is a measure of the ability of an item to meet the service demands of given quantitative characteristics under given internal conditions [5]. The ability of a maintenance machine to deliver or function according to designed capacity and/or current demands is referred to as its capacity performance. This is constrained by the structural decisions made in the early phase of equipment’s life cycle. The model to calculate track possession time and life cycle costing is in Figure 3. This model considers 0.2 mm metal removal while grinding as described in INNOTRACK [7]. This is discussed in following sections, along with grinding parameters for track replacement.

The data used in the model are taken from Value Stream Mapping and INNOTRACK [7] project and track data are taken from different Swedish track sections to give a variety of track curvatures. One of the track sections is also used for the tamping study; this is the section between Långsele and Mellansel with 23 freight trains and 4 passenger trains per day and approximately 12 MGT/year; see Figure 4.

The grinding machines discussed in the project are a conventional grinding machine with 48 stones and a High Speed Grinding train with 96 stones. The 48-stone machine is able to remove 0.2 mm in two passes. The capacity is 5 000 m/h. However, in the UK, the practice is to use a single pass with a 64-stone machine operating in traffic (approximately 7 500 m/h); this is used as an improved conventional grinder. The High Speed Grinding train is able to remove 0.1 mm in three passes, with a capacity of over 28 000 m/hour. In practise, the total time is 60% of a given shift or less, for both conventional and High Speed Grinding.

On mixed lines within Europe, the track possession time is decreasing, so it is difficult to achieve maintenance windows of 6 hours. Increasing the track possession time from 6 hours to 8 hours will decrease the total time on the track by about 7% as each shift will be more efficient and fewer shifts will be required. In short, minimising the track possession time requires maintenance windows that are long enough to complete the work. When this is not possible, higher machine speed, longer trains with more stones or high performance

![Figure 3: Theoretical framework of the mathematical model for calculating track possession time and life cycle cost for grinding](image-url)
grinding trains are alternatives.

![Figure 4: Track section 130 Långsele – Mellansel (Trafikverket, Sweden)](image)

The track geometry selected for the simulations represents the IMs' tracks and matches the criteria for lines and routes for this project. For instance, all sections have a curve radius greater than 800 m, and the line speed is less than 160 km/h with a load of 20-60 MGT/year; for more information, see the milestone 6 document of AUTOMAIN. The different tracks/routes for the simulations are shown in Table 1.

<table>
<thead>
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<th>Tracks/route</th>
<th>130</th>
<th>814</th>
<th>912</th>
</tr>
</thead>
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<tr>
<td>Amount of circular curves with $R = 800 -2500, \text{in length} [%]$</td>
<td>40</td>
<td>2</td>
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<tr>
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<td>2</td>
<td>18</td>
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<tr>
<td>Amount of sections &gt;2500 m, in length [%]</td>
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<td>96</td>
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<tr>
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<td>49</td>
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<td>8</td>
<td>30</td>
</tr>
<tr>
<td>Simulated traffic [MGT]</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Rail/Material</td>
<td>60E/ R260</td>
<td>60E/ R260</td>
<td>60E/ R260</td>
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<tr>
<td>Technical Life time, rail (TLT) [MGT]</td>
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<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Technical Life time, track (TLT) [MGT]</td>
<td>900</td>
<td>900</td>
<td>900</td>
</tr>
</tbody>
</table>

Table 1 – Cost Elements

3. Results and discussions

This project study has presented two models and discussed two case studies for the optimization of track possession time for tamping and S&Cs' maintenance.

3.1 Optimization of track possession time for tamping

A maintenance optimisation approach consisting of predetermined and corrective policies has been described in this report in a bid to improve maintenance quality (condition and life span of track) and track possession time. The case study leads to the following conclusions:

- An adequate maintenance window leads to reduced track possession time in the long run. For the case study, about 5 hours appears optimal; further increases in the maintenance window give very small additional benefits.
- Optimum possession length is required to reduce the impact of necessary non-value added tasks.
- Total elimination of unnecessary non-value added tasks will provide additional, albeit short, track possession time.
- Improvement of tamping speed gives the highest reduction in track possession time.
- A 10% improvement in tamping activities (travelling speed, tamping speed and other non-value added tasks) gives 11% reduction in the track possession time required for tamping the 90km line; a 40% improvement gives about 35% reduction.
- The behaviour of the track becomes unreliable if the tamping cycle becomes too large (or if there is no cycle), owing to an increased number of spot failures and high variations in track possession time.
- The number of isolated geometry failures over time follows a power law process. Thus, an optimum strategy for track possession is to have a tamping interval of 6 years. This prevents excessive periodic line tamping and too many spot tamping actions which reduce the life of the track and increase LCC.

3.2 Maintenance possession time simulation tool for switches and crossings (S&Cs)

An algorithm for simulating maintenance between trains was developed. One study examined crossing (frog) replacement, and another considered the optimal maintenance window between regular departures, i.e. urban areas.

- Value stream mapping together with the model simulation show that a time saving of 50% in crossing replacement is possible; this answers KPI4 in Section 2.4.1. However, it requires two welding teams compared to one, as is current practice, i.e. a maintenance team of eight people instead of six; see Figure 5.
In the study of optimal maintenance windows between regular departures, a fictional maintenance work of 120 minutes was simulated using regular timetables but at different frequencies. Results indicate that 40 minute train frequency creates an optimal window for train service and maintenance cost, saving 35% saving compared to a train frequency of 20 minutes. Also, the safety of the personnel is increased as the number of going in and out of the track is half.

3.2 Link and effect model

The link and effect model used here was developed after a thorough literature review. To achieve an efficient and effective performance measurement system, the following are required:

- A continuous improvement policy is essential; it also must be easy to understand and follow. Such a policy will make the performance measurement system flexible enough to handle changes in organisations, physical assets, goals and technology, and to integrate other project initiatives. Assuring an easily understood continuous improvement process is necessary for communicating vision, mission, objectives and KPIs throughout the whole organisation, from senior management to the operational level.

- Key components of strategic planning need to be clear within each organisation. If the terminology and language are unclear or hard to understand or if the performance measurement system is unclear, organisational units may not be aligned.

- Databases and performance indicators should be organised, documented and regulated. Organising and documenting parameters and indicators can save resources so that different organisational units do not calculate the same indicators. In addition, the data quality and need will be known and analysis can be automated, making ordering of analyses unnecessary.

- Indicators must be persistent, transparent and presented with background information for less reactive work and efficient management. An example is train delay; this should always be presented with its contributors.

The result of applying the link and effect model to AUTOMAIN is seen in Figure 6. The overall goal of AUTOMAIN is broken down to various KPIs for capacity optimisation. The data collected have been analysed and aggregated through simulation and models and the savings calculated. It shows that the AUTOMAN objective of reducing the maintenance possession time by 40% is an achievable target.

![Figure 5](image_url)  
Figure 5: a) Current practice takes 367 min b) Dual weld teams takes 180 min. The time saving is 51%
4. Conclusions

The models in this study have the potential to drive maintenance decision-making towards the reduction of track possession time. As for the objectives of the AUTOMAIN project, the simulation and optimisation models for grinding, tamping and S&Cs presented here can be suitably adapted for any track section after necessary modifications to suit the specific requirements of the individual IMs.

The proposed best practices, improvements and innovations for the three maintenance activities suggested for improvement analysis of high performance maintenance can be further studied before implementation to achieve the possible reduction in track time.

Another essential element in the successful implementation of the approaches/models is the quality and reliability of historical data of maintenance possession time and condition data of the track structure.

Finally, the present work is directed towards the objectives of AUTOMAIN; further work could include the development of a prognostic health management programme using practical infrastructure prognosis models.

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References


