



# AUTOMAIN

## Augmented Usage of Track by Optimisation of Maintenance, Allocation and Inspection of Railway Networks

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## Document Summary Sheet

The main objective of this report is to deliver results from WP4.2, 4.3 and 4.4. The purpose is to study, identify and assess innovations that can improve the effectiveness and efficiency of large scale maintenance processes, including the improvement of track possession time. The maintenance activities considered include rail grinding and tamping and maintenance of switches and crossings

This document is the report covering deliverable D4.1.

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## Contents

Executive Summary.....	3
1. Introduction .....	5
1.1. Objectives .....	8
1.2. Methodology and Approach.....	9
2. Current practices.....	11
2.1. Possession time .....	11
2.1.1. Breakdown structure of maintenance possession time in practice. ....	11
2.1.2. Transportation and setup time.....	12
2.1.3. Maintenance on the track .....	13
2.1.4. Maintenance between trains .....	13
2.2. Grinding .....	14
2.2.1. Strategies and objectives.....	15
2.2.2. Measuring systems .....	16
2.2.3. Grinding methods .....	16
2.2.4. Workflow .....	19
2.2.5. Findings of lean analysis .....	19
2.3. Tamping .....	21
2.3.1. Strategies and objectives.....	22
2.3.2. Measuring systems .....	22
2.3.3. Tamping methods.....	22
2.3.4. Workflow .....	23
2.3.5. Findings of lean analysis .....	23
2.4. Switches and crossings .....	25
2.4.1. Strategies and objectives.....	26
2.4.2. Measuring systems.....	26
2.4.3. Methods.....	27
2.4.4. Workflow .....	27
2.4.5. Findings of Lean analysis .....	29
3. Improvements, Innovations and Best Practice .....	32
3.1. Best Practice for Grinding.....	33
3.1.1. High Speed Grinding .....	33
3.1.2. Automated slag collector.....	36
3.1.1. Pre and post measurements.....	37
3.1.2. Maintenance strategy.....	37
3.1.3. Adopted grinding machine .....	38
3.1.4. Grinding trolley .....	38
3.1.5. Speed up production by combining two or more machines .....	39
3.2. Innovations for Tamping.....	41
3.2.1. Quality versus speed.....	41
3.2.2. Automatic adjustment of machine parameters for tamping requirements (Improvement)	43
3.2.3. Further Investigation and analysis of track geometry for different tamping techniques	43



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3.2.4.	Improvement of recording and transfer of all maintenance relevant parameters together with GPS coordinates.....	43
3.2.5.	Root cause analysis of single failure .....	43
3.2.6.	Combination of maintenance activities in order of importance .....	44
3.2.7.	Improvement of existing tamping machines or development of special single failure tamping machines for sections up to 100 m (Innovation) .....	44
3.2.8.	Use of track recording measurements directly for tamping machines .....	45
3.2.9.	Higher priority of maintenance .....	45
3.2.10.	Optimised tamping strategy .....	46
3.3.	Switches and Crossings.....	51
3.3.1.	Increase inspectors' skill .....	51
3.3.2.	Grinding of built up welding .....	51
3.3.3.	Water cooling equipment for build-up welding .....	51
3.3.4.	Replacement strategy (modular concept) instead of repair and build-up welding on track 51	
3.3.5.	On-line measurement through camera from Overhead (OH) line .....	52
3.3.6.	Modular concept .....	52
3.3.7.	Extended rail parts.....	54
3.3.8.	Create standard work .....	54
3.3.9.	Implement strategy for stock of non-standard material.....	55
3.3.10.	Display contact information for train dispatchers on the IM's web-site.....	55
3.3.11.	Work inside a maintenance shed .....	55
3.4.	Lean thinking approach .....	56
3.5.	Robust infrastructure database and data system.....	57
4.	Conclusions, Key findings, and Recommendations .....	59
4.1.	General Observation.....	59
4.2.	Key findings for AUTOMAIN innovation 2 and 3 .....	60
4.3.	Recommendations .....	61
	References .....	62
	Appendix A: Glossary and Acronyms .....	63
	Appendix B: Milling. ....	64
	Appendix C: High Performance Grinding – Lean Analysis of Current Processes .....	66
	Appendix D: Supplemental Report on the Use, Benefits and Limitations of Stoneblowing.....	87
	Appendix E: S&C Maintenance – Lean Analysis of Current Processes.....	101

## Executive Summary

The purpose of this deliverable is to study, identify and assess innovations that can improve the effectiveness and efficiency of large scale maintenance activities (such as; rail grinding, tamping and maintenance of switches and crossings) with a view to reduce the maintenance track possession time. It also identifies key technologies that will drive the development of modular infrastructure design. These will result in reducing the benchmarked possession time by up to 25 % for tamping and grinding and also contribute toward augmented utilisation of track thereby creating more capacity to accommodate the anticipated traffic increase. The issues and concerns raised in the lean analysis make a crucial contribution in the work carried out in this deliverable.

First, from existing methods, techniques and approaches and by looking at the derivation of best practices in other industries (RAMS, LCC, Lean thinking), the study has identified a set of best practices. The implementation of these practices will enhance the effectiveness of the maintenance activities considered and improve the allocation and utilisation of track possession time. The best practices for tamping, grinding and S&C maintenance in the railway include the following:

- High Speed Grinding (HSG).
- Grinding with reduced number of passes but same material removal,
- Use of Adaptable Grinding machine,
- Use of maintenance shed to create suitable working conditions.
- Further investigation and analysis of track geometry for different tamping techniques.
- Enhanced recording and transfer of all parameters relevant to maintenance together with GPS coordinates.
- Extended rail parts on switches and crossing.
- Skill upgrade of S&C inspectors.
- Replacement strategy (Modular concept) instead of built-up welding.
- Standard working procedure for switches & crossings.

The second category is the analysis for high performance maintenance is the improvement of existing practices and methods to improve the condition maintainability and supportability of the track system. These improvements cover the aspects of maintenance procedures, logistics, human factors and machine conditions. They include;

- Use of Standard Operating Procedures (SOPs) to drive correct behaviour and support error proof process.
- Improve grinding speed without jeopardising the quality outcome with the use of new grinding stones and cooling procedure.
- Reduce time spent on traversing unground section by optimising all actions during a shift.
- Prioritisation and combination of maintenance activities in meaningful order.

- Structured root causes analysis of isolated geometry defects (single failures),
- Use of track recording measurements directly on tamping machines.
- Automatic adjustment of machine parameters with respect to tamping requirements.
- Water cooling equipment for manganese S&C.
- Implementation of optimum strategy for stock and non-standard material.
- Display of contact information for train dispatchers on the IM's web site; best practice.

Third, the analysis of high performance maintenance has identified some innovations to be developed over the long term horizon. Some of these innovations are mechanised systems which will require detailed product design & development. Others are innovative reasoning, projection and methodology which will require field validation and verification besides the simulation carried out in the deliverable D4.2. The innovative ideas for the maintenance activities considered in this project are given below:

- Grinding trolley.
- AUTOMAIN production speed-up by combining two machines.
- Simulation based grinding strategy.
- Automated slag collector.
- Prognostic tamping strategy.
- Development of special single failure tamping machine for sections up to 100 m ,
- On-line measurement using a camera from OH.
- Modular concept for switches & crossings.
- Robust infrastructure database and data system.

The identified best practices, improvements and innovations for the three maintenance activities under consideration can be modeled and simulated after making modifications to suit the needs of the various IMs to ascertain the possibilities for achieving the anticipated 40% reduction in maintenance possession time. D4.2 makes comments on the modeling & simulation and suggests procedures which would help achieve AUTOMAIN's goals.

## 1. Introduction

Railway freight transportation is finding it increasingly difficult to use the European railway network because the increased passenger demand has reduced the availability of the track to run freight trains during the day. With the increase in total traffic, more frequent maintenance is required due to increased track degradation. Infrastructure managers (IM) are forced to carry out maintenance activities at night, when there is less passenger traffic. Improving the efficiency of track maintenance and reducing the track possession time for maintenance would result in better availability.

Various infrastructure maintenance activities can be considered in a detailed study of reduced maintenance possession time as per the AUTOMAIN objectives. Considering the scope of AUTOMAIN and the resources allocated to WP4 High Performance maintenance, it is only possible to look into the infrastructure maintenance activities of grinding, tamping and switches and crossings (S&C). However, these infrastructure maintenance activities make a large contribution to maintenance possession time.

Rail grinding and milling can restore and preserve the rail head from defects. The traffic degrades the rail over time, and grinding is the most common preventive and corrective action on the rail surface. Tamping is the most common method of restoring vertical and lateral track quality to restore the riding comfort lost with 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 to restore the required track geometry following renewals. S&C consumes a great deal of maintenance possession time; thus, modular approaches for S&C renewal are considered, including future technological requirements and current IM practice.

This deliverable is therefore limited to a discussion of improvements in high performance maintenance and modular S&Cs of the infrastructure. It is accepted that renewal work will also have a major impact on capacity, but renewal work is outside of the scope of the AUTOMAIN project. The definition of 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.

Track possession time is related to availability. Achieving high capacity utilisation through efficient and effective maintenance performance to maximise life cycle profit is a main goal.

The maintenance process of railway infrastructure differs from other branches for several reasons; e.g. EU and governmental objectives, longer planning processes, safety demands and yearly governmental funding etc. The maintenance process (see Figure 1) for the railway starts with setting the goals, objectives and strategy as formulated in line with EU commission guidelines and national transportation policy. The EU commission goals include having a single European transport area, a competitive and resource-efficient transport system. Its target is a modal shift of 30% of road freight over 300km to rail or waterborne transport by 2030 and 50% by 2050; this equates to 3 times as much rail freight by 2030 and 4 times as much by 2050. Accommodating this shift will require far greater utilisation of the existing infrastructure, and periods to maintain the railway will be severely reduced

Based on the strategy and available resources, the maintenance policy and programmes are formulated, including detailed maintenance planning, scheduling and implementation activities. These activities and the infrastructure condition reports are collected for analysis and improvement by the maintenance information system.

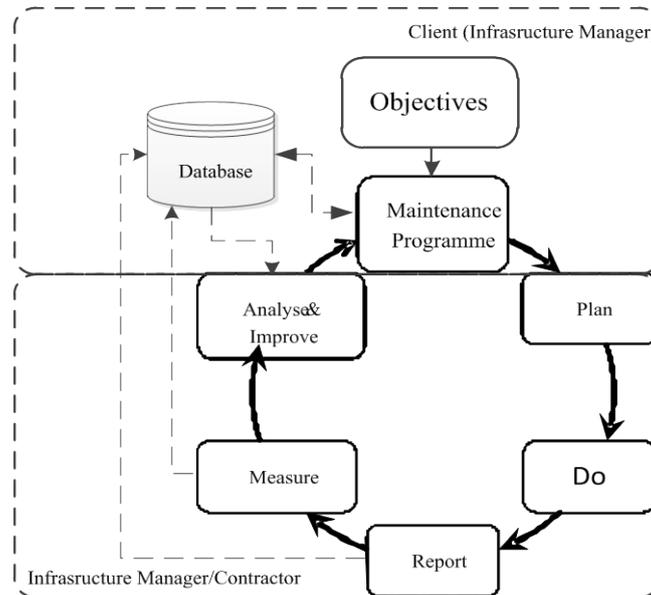


Figure 1: Maintenance process for continuous improvement

A maintenance strategy used can either be preventive or corrective; see Figure 2. Preventive maintenance is conducted “before a detected fault” and corrective is “after a detected fault”. Preventive maintenance is divided into condition based and predetermined maintenance. Condition based maintenance includes a combination of monitoring and/or inspections and/or testing, analysis and the ensuing actions. Predetermined maintenance is carried out at predetermined intervals (time or tonnage based) according to prescribed criteria. It is intended to reduce the probability of failure or degradation of an item’s functioning.

Note: If an inspection in the condition based maintenance category leads to a suggestion that action (repair or replacement) should be carried out immediately, it is reported as a corrective maintenance.

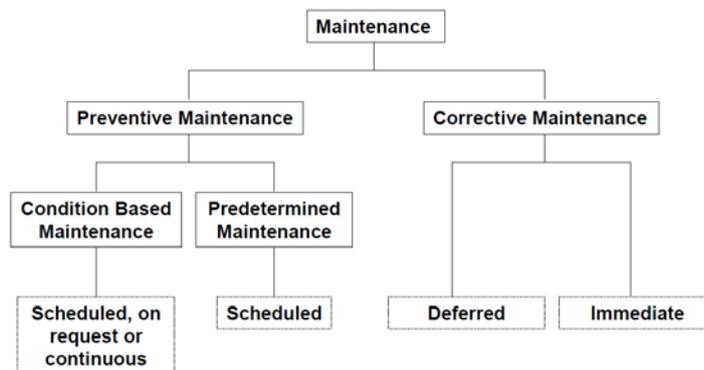


Figure 2: Maintenance strategy

The performance of the railway infrastructure is measured by Performance indicators (PIs). A PI compares actual conditions with a specific set of reference conditions (requirements) by measuring the distance between the

current environmental situation and the desired situation (target), the so-called ‘distance to target’ assessment (1). Typical railway PIs are punctuality to measure availability, number of asset failures to measure reliability, maintenance time for maintainability and number of accidents for safety. Other PIs in use are e.g. train path quality, total train kilometres, age of infrastructure, condition and passenger modal transfer quality. Currently there are very few PIs that measure capacity and possession time.

The typical planning process for the railway track maintenance process is shown in Figure 3. As shown in the block diagram, the maintenance requirements, such as decreasing the life cycle cost through increased quality of maintenance and minimised down time, are considered in the maintenance strategy formulation. In the next phase, based on the formulated strategy, the maintenance frequency and possession time is planned. In this activity, the length and frequency of track possession time for maintenance are planned based on the formulated maintenance policy. After possession time planning, the resources are planned (i.e. man, machine, materials and methods), followed by the logistics and scheduling activities. These activities include the transportation of logistics for machines and resources, as well as the information flow required to make the resources available at the right time, at the right place, in the right quantity etc. The next phase, “act in possession,” constitutes maintenance implementation, including grinding, tamping and replacing modular S&Cs are undertaken. This is followed by after-work activities like machine withdrawal, safety clearance and control. The final phase is “documentation,” the evaluation of the maintenance activities through documentation, reporting, feedback, analysis etc.

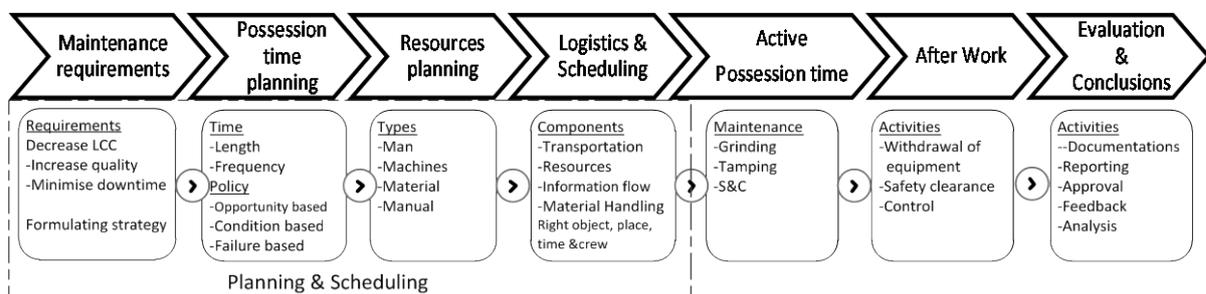


Figure 3: Maintenance flow process diagram

In WP1, a detailed study of the IM maintenance process was undertaken using process mapping, workshops and a questionnaire. Bottlenecks, performance killers and other related factors were discussed for the maintenance activities, like grinding and tamping. Functional and capacity requirements for planning and scheduling faster inspection and reduced maintenance possession time were identified and developed (D1.1). However, the performance killers and drivers were of general description and not all could be used for this particular deliverable. For example, as D1.1 mentions, almost all IMs are searching for better support for planning maintenance activities and possession planning. Many already have existing tools, but they are outdated or have problems in handling the necessary large amount of data.

Objectives and strategies differ between IMs, making it difficult to describe a common current railway maintenance process and to suggest improvements for more effective and efficient maintenance. It was extremely difficult to find common problems and eliminate concerns that were not important to the process. A

number of brainstorming sessions sought to identify improvements and innovations that would meet AUTOMAIN's objectives.

### 1.1. Objectives

The objectives of this deliverables are:

- To study, identify and assess the innovations that can improve the effectiveness and efficiency of large scale inspection and maintenance processes with a scope for track (grinding and tamping) and maintenance of switches and crossings;
- Further identification and development of key technologies that will drive the development of modular infrastructure design.

These objectives will result in:

- Reducing the benchmarked possession time by up to 25 % for tamping and grinding
- Reducing the benchmarked possession time for installation and inspection during the life of the asset by at least 50 %

The objectives can be translated into innovation goals, as shown in Figure 4.

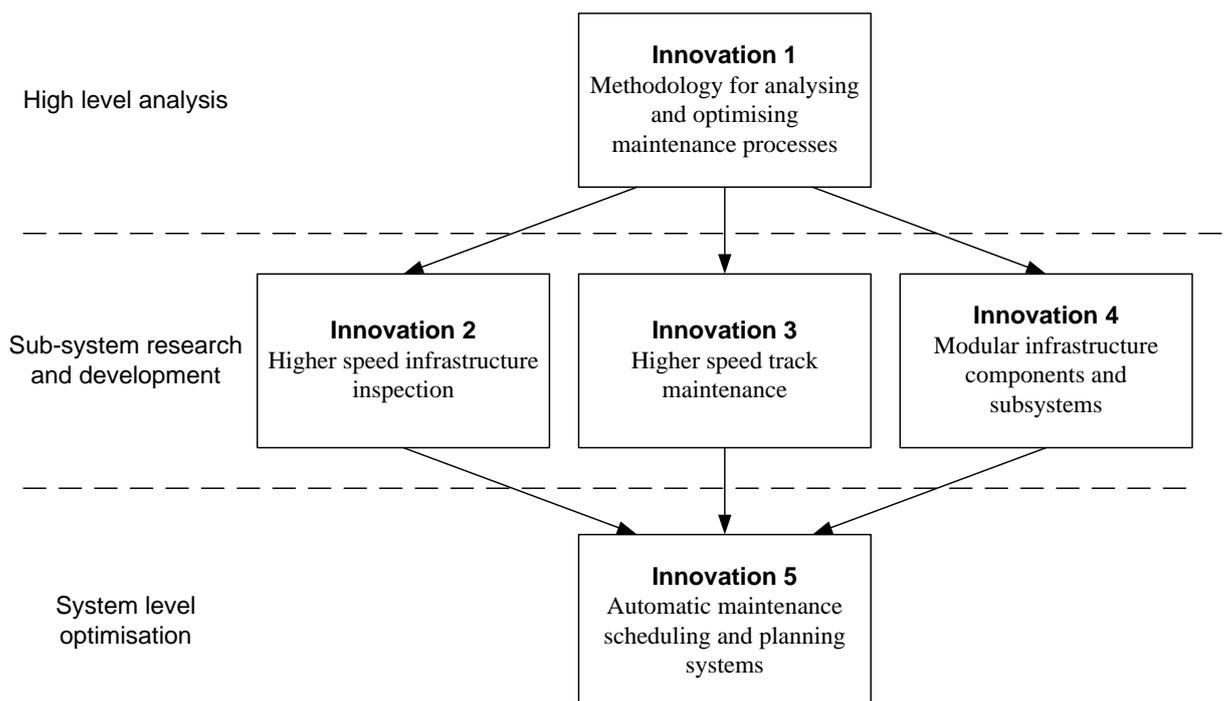


Figure 4: The individual AUTOMAIN innovations result in a system-level step-change.

## 1.2. Methodology and Approach

The workflow starts with inputs from WP1 and WP2, as well as inputs from the lean analysis and Value Streamed Mapping (VSM) workshops conducted for tamping in WP2. See Figure 5.

In order to find the areas for improving current practices of conventional grinding and S&C maintenance, lean analysis and VSM were conducted in WP4. Based on current practices, improvements and innovations were identified for the first level of AUTOMAIN practice. Lean analysis of tamping was conducted in DB, SNCF, ProRail, NR and TRV, grinding in DB, TRV and NR and maintenance of switches and crossings in TRV.

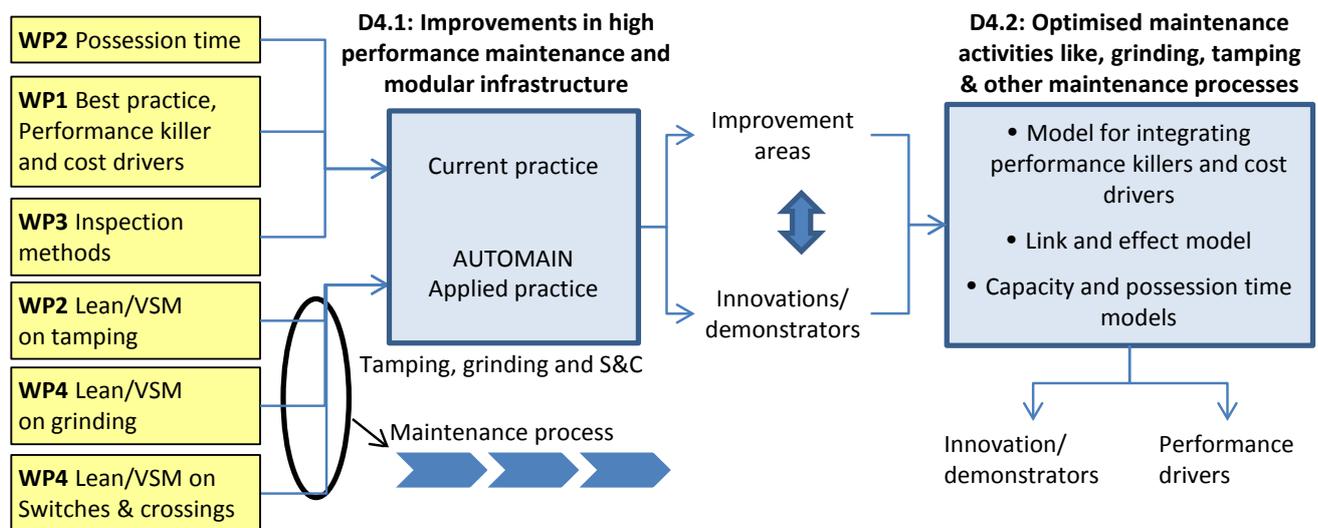


Figure 5: Interrelation of activities and strategies to reach WP4 Goals

Lean thinking uses two methodologies (developed and conducted by KM&T) to describe applied practice (reality):

- Structured Observations: in this case, 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: this paper based exercise maps out processes and procedures; it is used to identify issues and suggest improvements.

The studies resulted in identifying performance killers and opportunities for improvement, i.e. a problem that is easily solved (“low-hanging fruit”).

Performance killers and opportunities were ranked using three criteria: is this our problem, how important is it to solve, and can it be implemented? Criteria were rated according to their positive effect on the maintenance possession time and capacity utilisation. They were ranked high, medium or low. This step indicates the elements to pursue.

The performance killers were linked back to the railway maintenance flow process, as shown in Figure 3. The VSM and lean analysis presented a total approach, including long term planning and identifying “low hanging fruit”.

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To identify innovations, brain storming workshops were conducted; these were followed up during the WP4 meetings. See the list in section 4.

A three-stage approach was planned to increase the availability of freight train tracks; reducing 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.

A link and effect model and a capacity optimisation study are used for validation in D4.2. Following this, new objectives and strategy are suggested in D4.2 to reduce maintenance possession time with suitable KPIs while achieving AUTOMAIN's objectives.

## 2. Current practices

This chapter describes current maintenance practice and current practice for possession time based on Swedish experience. The description of current practices for maintenance is based on the lean analysis of tamping, grinding and maintenance of switches and crossings.

### 2.1. Possession time

The data from WP2 display a clear difference in the time of day that the track is possessed by the various infrastructure managers; e.g. Network Rail and DB mostly have the track at night during train-free periods and only occasionally during the day; SNCF has an even balance of night and daytime possessions. The data also show a significant difference in the typical possession length for SNCF compared to ProRail, Network Rail and DB; the latter typically have longer 3-6hrs possession lengths, whilst SNCF possession periods are shorter with a cluster of up to 2hrs and another cluster around 3-5hrs.

The distribution may also vary significantly due to the very strict safety regulations. Some possession time in the Netherlands will be spent on inspections, whereas other IMs do this between trains. In some countries (e.g. Germany) the policy is to create more track possession for inspections to identify more preventive maintenance.

AUTOMAIN focuses on planned possessions only, as unplanned activities need to be controlled and reduced through effective and improved inspection and planning/scheduling leading to a more reliable network.

#### 2.1.1. Breakdown structure of maintenance possession time in practice.

In principle, all work in and/or beside the track depends on the track being available, i.e. there must be sufficiently long periods between train departures to perform work. The time required depends on the type of work to be done, equipment/vehicle capacity, the amount of resources in the form of personnel and machinery, and safety procedures. Track-going maintenance vehicles (i.e. On Track Machine = OTM, TSI definition EN1403 High Performance machines are track bound and have to travel on the open or closed track) also need to be off the track between train passages.

Increased traffic has a large impact on the conditions for carrying out maintenance; if one extra train is allowed to pass the maintenance site, it can decrease the possession considerably. The priority of the maintenance activities is low in relation to the operation of trains; this means delayed trains also decrease the planned possession.

Preparation and concluding time, as shown in Figure 6, are not dependent on possession time for maintenance but consist mainly of such preparatory measures as packing equipment, preparatory measures on the maintenance site and transporting equipment from the starting point to the part of the track where maintenance is to be performed.

The possession time is often reduced by preparatory track safety work (S1), transportation and set-up time (TS1) at the beginning of the possession and in the end, terminating track safety (S2) and clearance and transportation time (TS2). Such actions/work can reduce the total possession time up to 40 minutes.

The preparatory track safety work before starting maintenance requires the maintenance personnel to communicate with the train control centre and get confirmation to enter the track. The traffic control centre gives the starting time. The starting time is adapted to the present situation on the track site; the situation may

differ from the original plan from which the maintenance personnel planned the work. If the promised starting time expires, traffic management again has to confirm that it is okay to enter the track.

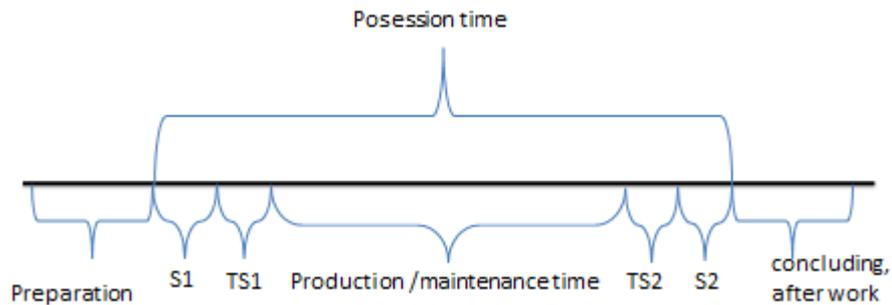


Figure 6: Details of possession, preparation and concluding time

After the maintenance personnel are allowed to enter the track, connectors must be applied to the track to short-circuit the rail. This prevents electricity from going through the track lines and signals the traffic control centre that the track site is occupied. Next, “obstacle-signs” are placed before and after the site to signal to other rail operators that the track is occupied. All this is done by a special train supervisor, who must be in place at every maintenance activity.

Depending on the actual planned maintenance activities and the machines that are used, track circuits like axle counters or switches at level crossings may have to be removed.

At the end of the possession time, the actions are performed in reverse order. The terminating track safety activities will include inspection of the track before it can be reopened to traffic.

Different types of work are associated with the different security measures. However, generally speaking, the preparatory precautions occupy about 10 minutes of possession time, while measures for reopening the track take about 15 minutes. The difference is mainly due to the nature of the inspection that must be performed after finishing the work.

### 2.1.2. Transportation and setup time

When access to the track is secured and required safety actions taken, the actual maintenance work preparation begins. As Figure 6 shows, the transport and set-up times can be divided into two main time-consuming steps: transportation of the machines to be used to where the maintenance will be performed and any other steps required before work can begin e.g. setup time for the maintenance vehicle.

Track work is mostly performed using rail-going vehicles/equipment. The first part of the working time must be used to get the rail-going vehicle/equipment in place. Transportation of rail-going vehicles and machines can only be initiated at specific entrances designed for the purpose; at this point, the machine must be driven to the workplace. The time for this varies depending on the distance from the ramp to the workplace, machine speed capacity, etc. The machine may also arrive at the workplace and take more time than expected for start-up and adjustment.

### 2.1.3. Maintenance on the track

After transporting and preparing the machine, the actual work on the track can start. This also includes certain preparatory activities and takes time.

Before the maintenance work can begin on the track, certain tasks must be performed. For example, the rail temperature needs to be checked/measured or road crossings removed. After completing the maintenance, the ballast needs to be restored. Moreover, the place must be cleaned and the maintenance activities documented. As mentioned earlier, the track is inspected again, this time to ensure that trains can run safely and securely. All this must be done during the possession time. This type of work cannot be interrupted.

### 2.1.4. Maintenance between trains

If an extraordinary train passage takes place in the middle of maintenance, the track will not be available for work for a couple of minutes, leading to shortened possession time; in fact, it may be impossible to use the resulting possession time for any maintenance at all; see Figure 7.

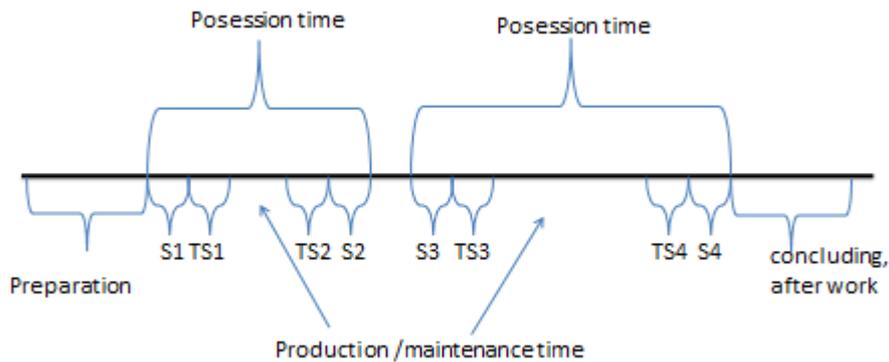


Figure 7: Details of possession between trains

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## **2.2. Grinding**

Conventional grinding typically involves taking an initial measurement of the rail head condition to determine what material removal is required. The maintenance actions are based on the results of track recording car data on rail corrugation, Non Destructing Testing (NDT) and visual inspection for Rolling Contact Fatigue (RCF), such as head checks, spalling or squads.

Hand grinding or corrective machining may also be required to correct such track defects as Rolling Contact Fatigue (RCF) or severe corrugation; depending upon the severity, these must be corrected within a short time frame, and unless a track possession is planned, they must be corrected by manual interventions. For more severe rectifications of the rail, a milling machine can be used for greater material removal rate per pass with a positive impact on both LCC and track possession time.

Grinding and milling (rail machining) are conducted for safety, economy, comfort and noise and vibration reduction reasons. Traffic degrades the rail over the time, and rail machining is a common method to restore the rail head and remove defects from the rail surface. The defects to be removed include Rolling Contact Fatigue and rail head corrugations; maintaining the rail profile is necessary to give the right wheel and rail contact band. There are five rail grinding and milling categories: initial, corrective, symptomatic, preventive and cyclic. In most cases, cyclic grinding is included in preventive machining.

Milling is most frequently used for corrective maintenance, is effective if larger quantities of material must be removed and the rail head needs to be restored from fatigue damage or profile issues. With a working speed of 600 to 800 m/h, milling is much slower than grinding, but the material removal rate is significantly greater per passage, typically up to 1,8 mm on a continuous basis.

Advantages of milling are:

- Re-profiling of rail in one pass.
- High accuracy of track profile.
- No removal of track circuits like axle counters is necessary.
- No flying sparks.

Disadvantages are:

- Milling is not possible in switches and crossings.
- Milling is not possible in tight curves with side wear.
- Only one working direction.
- Only one rail profile per activity.

For more information see Appendix B.

Note that this project deals with preventive grinding and excludes other categories.

Grinding methods include conventional grinding and high speed grinding. This project only deals with the principle of grinding, but covers both methods.

The amount of material that can be removed in one pass of a grinding train depends on the particular machine, but is typically limited to fractions of a millimeter; usually several passes are required to complete the maintenance required. Milling typically removes several millimeters on the rail head.

### **2.2.1. Strategies and objectives**

Grinding is done for the following reasons (INNTRACK 2008):

- Corrugation
- Rolling Contact Fatigue (RCF)
- Re-profiling for vehicle stability (Equivalent Conicity)

Maintenance grinding can be either a preventive or a corrective strategy. In corrective maintenance, the rail defects are measurable and a greater material removal rate is necessary to rectify the problem. A preventive maintenance strategy aims to keep the rail head surface in good condition and prevent the appearance of defects. This has a positive impact on the LCC and decreases the risk of rail flaws. The optimal preventive strategy and its parameters have previously been discussed. A general view is that cyclic grinding based on MGT of traffic, steel grade and radii of curves and post measurement to verify the status is well established even if it would be possible to adjust the grinding interval on more factors the logistic to achieve a more flexible plan is remains challenging.

#### ***One pass grinding***

One pass grinding (OPG) is a special preventive grinding strategy where the grinding machine re-profiles the rail head in one pass. Up to 0.3 mm of material is removed. Due to the high working speed of the grinding machine OPG requires the rail surface to be in a good and homogeneous condition.

#### **Specifications of OPG**

- Working speed of machine between 8 and 10 km/h
- One pass is necessary to re-profile the rail
- Material removal approximately 0,3 mm
- Grinding performance between 7.000 and 8.000 m per hour
- Length of grinding sections per shift between 30 and 40 km
- Use of big grinding machines with at least 48 stones
- Documentation of quality with installed measurement systems
- Disruption of track possession possible

#### ***Two pass grinding***

Two pass grinding (TPG) is a special preventive grinding strategy where the grinding machine re-profiles the rail head in two passes. Due to the high working speed of the grinding machine, TPG requires that the rail surface be in a good condition of the rail surface. TPG procedure is used, for example, at DB with good results.

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## Specifications of TPG

- Working speed between 8 and 10 km/h
- Two passes to re-profile the rail
- Material removal approximately 0,3 mm
- Grinding performance between 3.500 and 4.000 m per hour
- Length of grinding sections per shift between 10 and 20 km
- Use of big grinding machines with at least 48 stones
- Documentation of quality with installed measurement systems
- Disruption of track possession impossible

### ***High speed grinding (HSG)***

The existence of this method was not known at the start of AUTOMAIN; HSG is there for classified as Best Practice. For more information, see Section 3.1.1.

#### **2.2.2. Measuring systems**

Consecutive monitoring is done by Non Destructive Testing (NDT) methods and close visual inspections to establish the need for grinding. NDT methods include ultrasonic testing, eddy current testing, rail profile measurements and visual inspections. In INNTRACK, more methods are described in deliverable D4.4.1. Most of these methods are not useful to determine grinding intervals because when a crack is large enough to be seen by ultrasonic measurements or is visible on the surface, it could be uneconomic to machine it away. Corrective grinding can be used to ensure that the situation is not getting worse or milling trains can be used to fully remove the defects. Leaving cracks in the rail head after grinding without entirely removing them (so-called head check seeds) has been proven to have a negative impact on the LCC of the rail, since any remaining cracks are likely to grow faster and at a steeper angle.

The most important method to avoid rail breakage is the ultrasonic train measurement, typically done 0,3 – 24 times per year depending on national regulations. For cracks to be detected by ultrasonic measurement they must have developed a depth above 5 mm, which is too large to apply preventive grinding strategies.

Eddy Current measurement has been introduced by multiple central rail administrations to find cracks at an early growing stage of 03 mm depth, a good ground depth for an optimal grinding strategy. Rail profile measurements are executed to confirm the transactional and longitudinal target profile and can also be used to calculate the equivalent conicity. Close visual inspection is used to find severe problems before a safety issue arises; it is also used to complement NDT by finding other types of failures (e.g. wheel burns).

Actual grinding machines also have the capability to measure the rail profile.

#### **2.2.3. Grinding methods**

Conventional grinding on main lines is often executed by means of a conventional 48 stone grinding machine with rotating grinding stones that can operate at a speed of 8-12 km/h. In each passage, this machine can remove 0.1 mm material; it typically needs 2-4 passages to re-profile a rail. Alternatively, grinding can be done

by a 64 stone machine which can operate at a velocity of 7.5-15 km/h. A conventional grinding machine can be used both for preventive and corrective measures.

The grinding stones consist of a material that becomes extremely hot and sparks can cause the vegetation on the embankment to ignite. Hence, grinding should not be performed on hot dry days. For firefighting purposes, grinding machines often have tanks filled with water.

Another issue is the steel dust from conventional grinding. It can be caught in the mudguard of the grinding stone and form bigger pieces (slag). If these fall out onto the track, they can come between the switch blades, bridge an isolated joint or make the ballast conductive. For safety reasons these slags must be collected and removed from the track; see Figure 8.



Figure 8: Slag on track have to be removed, b) Slag collected from the track.

High Speed Grinding (HSG) is an innovative preventive rail grinding concept developed by Vossloh. Because it has a grinding speed of up to 80 km/h, the train can use a regular train path for grinding. A HSG train is equipped with 384 passively propelled stones (96 stones are continuously grinding) and need three passages to remove a minimum 0.1mm material. By tilting the grinding stones, the HSG can control or influence the cross sectional profile over time. Finally, the machine generates an acoustically optimised grinding result, free of facets.

A comparison of the different methods is presented in Table 1.

Table 1: Different grinding methods.

Machine type	Speed	Material removal rate	General pros	General cons
<p><b>Conventional Grinding</b></p> <p>48pcs of stones (24pcs per rail)</p> <p>Rotating actively propelled grinding stones</p>	up to 10 km/h	up to 0,1mm per pass	<ul style="list-style-type: none"> <li>• Versatile in terms of preventive, corrective and grinding.</li> <li>• Re-profiling of rail possible.</li> <li>• Basic track condition irrelevant</li> <li>• Suitable for two-pass grinding with up to 20km grinded rail per shift</li> <li>• Suitable for one-pass grinding with up to 40km grinded rail per shift</li> <li>• Documentation of quality due to integrated measurement systems</li> </ul>	<ul style="list-style-type: none"> <li>• Requires track possession time</li> <li>• Removal of track installations necessary</li> <li>• Removal of some concrete panels in level crossings necessary</li> <li>• Generates periodically longitudinal facets due to horizontal rotating grinding stones in case of wrong machine set up or bad state of machine</li> <li>• Cross profile facets</li> <li>• Just grinding stone dust is collected, metal dust parts remain on track</li> <li>• Slag picking part of process Fire hazard</li> <li>• Desires people in track</li> <li>• Cannot machine switches and crossings</li> <li>• Must use special equipment for tunnel work</li> <li>• High notice level during operation</li> </ul>
<p><b>Conventional Grinding</b></p> <p>64pcs of stones (xx pcs per rail)</p> <p>Rotating actively propelled grinding stones</p>	Up to 15 km/h	up to 0.2 mm per pass	<ul style="list-style-type: none"> <li>• Versatile in terms of preventive, corrective</li> <li>• Re-profiling of rail possible</li> <li>• Basic track condition irrelevant</li> <li>• Suitable for two-pass grinding with up to 20km grinded rail per shift</li> <li>• Suitable for one-pass grinding with up to 40km grinded rail per shift</li> <li>• Documentation of quality due to integrated measurement systems</li> <li>• New improvements of machine allows grinding without dismounting of axle counter</li> </ul>	
<p><b>High Speed Grinding</b></p> <p>96pcs (48pcs per rail (12pcs per unit))</p> <p>Rotating passively propelled grinding stones</p>	up to 80 km/h	0,035mm per pass	<ul style="list-style-type: none"> <li>• The preventive performance of up to 100km per shift</li> <li>• Does not require track possession time</li> <li>• Acoustically optimised result</li> <li>• Facet free</li> <li>• No dismantling of track installations</li> <li>• Can grind level crossings without removal of concrete panels</li> <li>• No slag collection needed</li> <li>• No people in track</li> <li>• High operational flexibility</li> <li>• Differentiated grinding to adjust to different track conditions (e.g. on tangents and curves)</li> <li>• Applicable for tunnel work, collecting grinding and metal dust</li> <li>• No environmental noise disturbance during work</li> <li>• Suitable also for adhesive and leave film removal</li> <li>• Easy homologation due to use of locally approved traction</li> </ul>	<ul style="list-style-type: none"> <li>• Only actively adjusts cross profile sectional over time, no conventional cross sectional re-profiling</li> <li>• Fire hazard</li> <li>• If grinding within traffic: needs railway stations or turnout rails with suitable interval</li> <li>• Separate measurements must currently take place</li> <li>• Cannot machine switches and crossings</li> <li>• Not optimised for corrective rectifications</li> <li>• Locomotive needed</li> </ul>

### 2.2.4. Workflow

The workflow differs between different countries and regions, but in general, it starts with maintenance requirements before long term planning is worked out. The time horizon for long term planning is typically 18-24 months. The next step is medium term planning, often called “resource planning”; the typical time span for this is 18-6 months before maintenance. Planning logistics and scheduling starts around 6 months prior to implementation and execution of grinding. After the execution is completed, the after work phase begins, including conclusions that are implemented in the next planning cycle. The general workflow for grinding is shown in Figure 9.



Figure 9: The overall workflow for grinding activities including all stages of planning and execution

The implementation (execution) of conventional grinding has 16 different steps; see Figure 9. Due to the high safety demands and the high use of the track, the work is divided into these steps. They can differ among infrastructure administrators, but are generally the same. Conventional grinding typically follows the workflow shown in Figure 10.

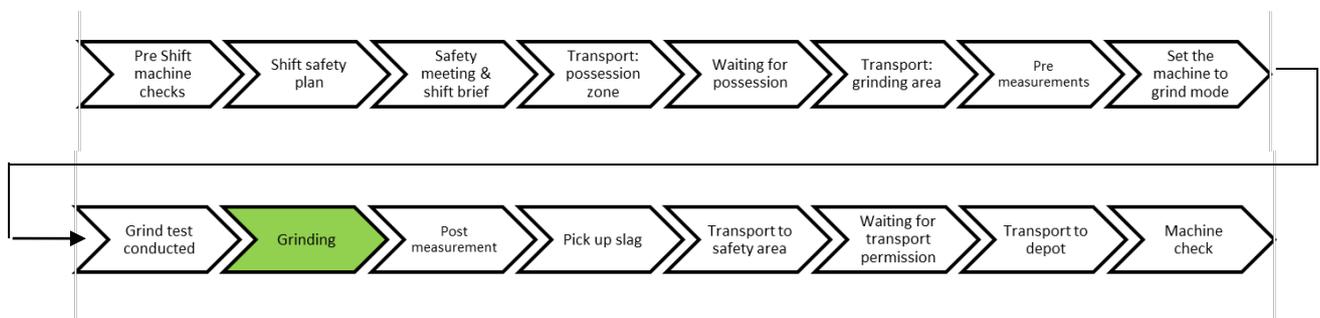


Figure 10: The workflow for conducting conventional grinding.

This project concentrates only on plain line track grinding, and switches and crossings are therefore excluded. Curved tracks might need grinding more often than tangent tracks. The grinding strategy varies between different central rail administrations, and this strategy determines the frequency and material removal rate. Tracks with heavier axle loads and greater speed limits typically need more attention than ordinary mixed traffic tracks.

### 2.2.5. Findings of lean analysis

Lean analysis for grinding has been conducted in Germany, Sweden and UK. The results are presented in APENDIX C” T4.2 High Performance Grinding – Lean Analysis of Current Process”. A summary of key concerns and opportunities is presented below.

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A high proportion of a typical conventional grinding shift is spent on non-value added activities. Thus, it may be possible to:

- Reduce the time spent travelling to the worksite;
- Reduce the time spent traversing the track possession to maintain several small worksites;
- Remove the need for the manual collection of slag;
- Remove the time spent for pre and post-maintenance measurement runs.

In contrast to the tamping shifts where machine checks are typically performed on-site, conventional grinding machine checks are done before and after the core of the maintenance shift.

Key concerns/findings are:

- Strategy and priority to maintain, the relative merits of reactive (corrective) versus preventive grinding warrant further investigation.
- KPIs need to be re-thought to better reflect and incentivise the value of the work undertaken.
- Robust infrastructure database and data systems to predict track degradation need to be developed. Structured geometry data collection should be based on maintenance needs.
- Maintenance should be minimised in fire sensitive areas during high risk times of the year; possibly provide a water train where this is not possible.
- Robust training systems should outline best practices to ensure all employees and contractors are trained to an equally high level.
- Structured communication procedures should be implemented.
- Structured work sequence Standard Operating Procedures (SOPs) should be developed.
- Systems to accurately align relevant skill set crew to machine type should be created.
- Systematic selection and allocation processes should ensure the selection of the most flexible, effective machines and resources, along with the best stabling points and most efficient route to the track possession zone. Involve rail officials in the creation of the plans to help create a sense of responsibility and accountability.

Machine manufacturers, IMs and researchers should be encouraged to investigate and develop a number of potential improvements:

- Modify machine design so that manual slag collection is no longer necessary;
- Improve on-board measurement equipment so that manual on-track measurements are no longer required;
- Develop a system to evaluate the effectiveness of each grinding pass and use this to optimise the following one;
- Increase metal removal rates to enable machines to work at higher speeds or remove more material in a single pass;
- Automate the production of post-maintenance reports and the uploading of these to the central database, possibly making use of modern internet based approaches such as cloud computing ;
- Create a whole life cost / benefit model or for a conceptually advanced design.

### 2.3. Tamping

The action of rail traffic causes the track to degrade over time; tamping is the most common method of restoring vertical and lateral track geometry. It typically involves making an initial measurement of the existing track geometry to determine what lifts and slews are required along a given length of track (i.e. vertical and lateral corrections). The tamper moves relatively slowly along the track (slow walking pace). According to Selig (1) and Waters (1994), the sequence of tamping is the following (Figure 11):

- (A) The tamping machine positions itself over the sleeper to be tamped.
- (B) The lifting rollers raise the sleeper to be tamped to the target level, creating a space under the sleeper.
- (C) The tamping tines are inserted into the ballast on either side of the sleeper.
- (D) The tamping tines squeeze the ballast into the empty space beneath the sleeper, retaining the sleeper in this raised position.
- (E) The tamping tines are withdrawn from the ballast; the lifting rollers lower the track, and the tamper moves forward to the next sleeper.

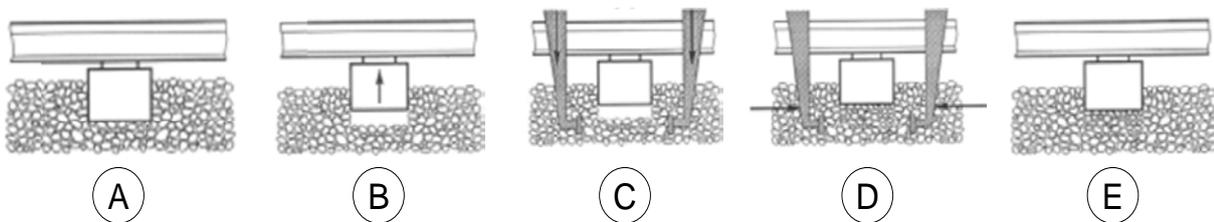


Figure 11: Sequence of Tamping (Selig and Waters, 1994)

Tamping affects the ballast structure and causes “instability” in the ballast bed which means that the ballast needs to be stabilised and consolidated after tamping. Therefore, some safety regulations are called for, including reducing the traffic speed to 70 km/h until 100 MGT have passed. Another method is to operate a dynamic track stabiliser with units for applying vertical load on the ballast bed or directly after tamping.

Tamping is not allowed if the rail temperature is above a defined limit because at high temperatures, the risk for track buckling increases noticeably. At temperatures below zero, the risk of frozen ballast and rail breaks increases. Thus, tamping is not suitable for or allowed at low temperatures. This temperature limit varies across countries.

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.

An alternative process called stone blowing is used in the UK, along with tamping. While similar to tamping in many ways, instead of squeezing the existing ballast, a measured quantity of fresh stones is blown underneath each sleeper to effect a change in track height. However, stone blowing is considered an established practice to improve the recovery of track, especially towards the end of its life, and to extend its remaining useful life. This method is described in PENDIX D “Task 4.3 Supplement Report on the use, benefits and limitations of stone blowing”.

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### 2.3.1. Strategies and objectives

Different tamping strategies fulfill the technical and economical requirements under given boundary conditions.

In general **corrective tamping** is based on the standards and regulations of the various railway companies; defined thresholds and limits indicate the need for maintenance in the short term. Additional safety limits are defined and if the amplitude of a track geometry defect is above this limit, speed reductions or track closure are the consequences. Therefore, corrective maintenance is planned and carried out when the maintenance limit is reached. The resulting short-term planning of tamping activities leads to inefficiency in the planning and tamping process itself (see also the results of Lean Analysis). The use of big tamping machines requires track possession, thereby reducing the availability of the track. Because of the low priority of the maintenance in relation to operation, the time slots for maintenance must fit into the timetable of the trains. The unknown availability of the different types of tamping machines also influences the efficiency of the maintenance activity.

To reduce these problems, the proportion of **preventive tamping** has grown in recent years. The main advantage of preventive tamping is better planning of the tamping activity. Long-term planning enables longer shifts and the use of adequate tamping machines, dramatically increasing the efficiency of the maintenance activity. But the decision-making process, the selection and grouping of reasonable sections for preventive tamping, requires more knowledge and effort, especially when changing from corrective to preventive tamping.

The track sections for preventive tamping can be defined by setting mean intervals which depend on track and operational parameters or by predicting track deterioration.

### 2.3.2. Measuring systems

The track geometry is measured by track recording cars. There are two different measurement systems. First, the cord based measurement system measures the track geometry at three points. The transfer function is not constant over the wavelength of the track geometry defects and must be corrected for a more reliable measurement. Second, the inertial measurement system uses a gyroscopic platform as a reference plane and is therefore able to measure longer wavelengths than the cord based system.

If the amplitude of deviation is near or above a threshold, track tamping is necessary. The thresholds, which are maintenance or safety related, depend on operating conditions and vary for the different European railways.

To remove track geometry defects with longer wavelengths, it is necessary to take a pre-measurement in relation to fixed points. This initial measurement is used to determine the lifts and lateral movements of the sleepers which are necessary to restore the required track geometry. Modern laser-based measurement systems like EM-SAT directly generate the data for the tamping machines.

### 2.3.3. Tamping methods

Tamping can be carried out manually or by tamping machines. The construction of the machines differs for plain lines and S&C. Table 2 gives an overview of typical tamping machines and their related parameters.

Table 2: tamping machines and related parameters

Line Tamper						Universal (Both Line and Switch Tampers)					
	Lift	0-30mm	30-60mm	60-80mm			Lift	0-30mm	30-60mm	60-80mm	
Type	Sleepers	1x	2x	3x	Insertions	Type	Sleepers	1x	2x	3x	Insertions
09-16	1x	800	600	300	m/h	Unimat 08-475-4S	1x	500	300	150	m/h
09-32	2x	1100	800	400	m/h	Unimat 09-16-4S	1x	800	600	300	m/h
09-3x	3x	1500	1100	800	m/h	Unimat 09-32-4S	2x	1100	800	400	m/h
09-4x	4x	2000	1600	1300	m/h	Normal sleeper distance = 600mm					
Normal sleeper distance = 580-620mm											

Manually tamping will often be done to restore the track geometry in critical situations if the time required for planning and conducting machine-based maintenance is not available. Machine-based maintenance will often be carried out later on.

### 2.3.4. Workflow

The workflow for tamping can be read in detail in report D2.2 Lean Analysis of Track Maintenance Process.

### 2.3.5. Findings of lean analysis

Lean analysis of tamping has been conducted in France, the Netherlands, Germany, Sweden and the UK. The results appear in D2.2 Lean Analysis of Track Maintenance Process. A summary of key concerns and opportunities identified is presented below.

Lean analysis of tamping indicates there is scope to improve the effectiveness of maintenance possession time by investigating the following:

- Travelling to and traversing the work site;
- Increasing capacities of the equipment used;
- Reducing the overall non-value-adding procedures.

There is also a scope for the following:

- Reduce the number of maintenance shifts cancelled or curtailed;
- Optimise allocation of manpower and machinery;
- Optimise use of track geometry and condition data.

From these inputs and after workshop and brainstorming sessions, the following performance indicators were identified as relevant:

- Transportation time
- Non-value adding (NVA) time: preparation, confirmation, communication, waiting and lost time
- Active maintenance time

The following suggestions are relevant for further work:

- Tamping varies between IMs; therefore, an optimised tamping strategy should be developed.
- Track geometry measurement frequency for optimal trend tracking merits further study.



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- Tamping design could be improved in the following areas: increased flexibility (e.g. for both high output plain lines and switches), reduced time and human intervention to set up, ability to warm up during transit, record work in either direction, and potentially drive on and off the tracks at suitable locations.
  - The use of geotags to automatically transfer track data to the tamper in preparation for maintenance should be investigated.
  - Standard Operating Procedures should be adopted to drive correct behaviour and support error proof process.
  - Improved planning of manpower and machinery could provide significant benefit; this is already done in other areas such as crew rostering software for Train Operating Companies.
  - Requirements for stabilisation of maintenance machinery need to be considered by and incorporated into route utilisation strategies, if not already done.

## 2.4. Switches and crossings

Switches and Crossings need more maintenance than the normal track, as they are more complex and have movable parts. Many track failures causes train delays, and these are more frequent in S&C than in normal track if calculated by track length. The INNOTRACK project aimed to reduce life cycle costs of railway maintenance by 30% and as part of this project D1.4.6 prioritised maintenance activities with the biggest impact on maintenance costs. Three of these concerned switches and crossings:

- S&C – wear in switches
- S&C – Cracked manganese crossings
- S&C – Geometry maintenance

The action of rail traffic causes track to degrade over time; this includes Switches & Crossings (S&C) which are a key component of the overall time and cost required to maintain and run a railway network. One of the key areas of wear is at the crossing where the wheel transfers load from one section of rail to the next. This is a high impact zone that is typically cast from special high strength steels for longevity. Such crossings suffer from wear, metal flow (lipping) and Rolling Contact Fatigue (RCF) and are inspected at regular intervals. If the crossing is found to be in poor condition, one of two possible approaches is used to rectify the situation:

- Surface build up welding (i.e. repair).
- Crossing replacement.

The decision to repair or replace a crossing follows a series of inspections, including visual and ultrasonic inspections. Surface build up welding is used if it is deemed at the inspection stage that the degradation is not severe enough to warrant a complete replacement. The surface of the crossing is prepared (ground back). Additional metal is then welded to the crossing, building up the damaged wing rail and crossing nose using manual metal arc welding. The additional welded material is then ground back to the required profile.

Occasionally, when the metal is ground back, the condition of the underlying material is found to be poor (a problem made worse by the challenge of inspecting manganese crossings with ultrasonic techniques, which tend to perform poorly due to the large cast grain size of manganese steel). A temporary repair must be made before arranging replacement of the crossing at a later date.

In the case of a crossing replacement, it is necessary to cut the adjacent rails at four points, remove and replace the crossing, and weld in the new crossing using alumino-thermic welding. The welds must be re-profiled by stripping and grinding, and the stress free temperature should be checked and within limits.



Figure 12: Preparation of an Alumino-thermic Weld

In the case of both repair and replacement, the grinding is done manually using powered manual grinders such as the Robel grinder shown below. The process and the quality of the finish depend on the skill and expertise of the person doing the grinding.



Figure 13: Manual Grinding

Surface build-up welding for deep cracks > 10mm requires longer possession times than crossing replacement; the typical time for a build-up welding repair is 6 to 8 hours, whereas a crossing replacement might typically take 4 to 6 hours.

#### **2.4.1. Strategies and objectives**

Maintenance activities in S&C are mainly carried out as corrective maintenance. The purpose of the corrective action is to:

- Reshape surfaces in order to be within geometrical tolerances.
- Repair component due to broken material (cracks etc.).

The most critical components are in the crossing panel. The crossing is most important since it has the largest irregularity in the wheel transfer zone; the check rail comes second and glued insulated joints (GIJ) and switch blades are third. The corrective actions are basically done by welding and grinding or by replacing the component if the wear/damage is considered too big.

#### **2.4.2. Measuring systems**

To check the geometrical characteristics of S&C, a number of measuring tools are used:

- A SOLA measuring device is used to measure track gauge, control width and track cant.
- Different types of templates are used to check geometric shapes of the wheel transfer zones between the point of the crossing and the wing rails.
- When a suspected crack is discovered, penetrant fluids are used to determine if it is a crack. Non Destructing Testing (NDT) is used with penetrant fluids. The full NDT-system consists of three different fluids which are sprayed on the area where the suspected crack is located. First the area is sprayed with “dye penetrant”, which is often red. This fluid creeps into the cracks. After a few minutes, a “cleaner” is

sprayed on so that the dye penetrant can be removed. The dye penetrant which has gone into the cracks will not be removed. Finally, a white “developer” is sprayed on. If there is a crack, the dye penetrant is clearly seen against the colour of the developer.

### 2.4.3. Methods

Two methods are used as corrective maintenance:

- Repair by build-up welding.
- Replacement of the component.

#### Repair by build-up welding

Repair by build-up welding mainly uses the MMA-method (Manual Metal Arc), with a hand-held electrode. The type of crossing, manganese crossing (Mn) or rail crossing, specifies what specific welding process has to be used.

In a Mn-crossing, the material is not allowed to go over 2000C due to the risk of transformation of the material structure. No pre-heating is used, and during the welding, the welding strings must be kept very short to minimise the heat. Therefore, the actual welding operation takes a long time.

If the crossing is rail steel, the area to be welded must be pre-heated to ensure good penetration into and adhesion to the base material. The temperature is raised up to around 3500C and kept there during the whole repair. The size of the areas is important; it must be kept at a good working temperature during welding, without any added heating. The pre-heating can use flames or electrical heating covers. After the welding, the surface is ground to correct the shape. The same templates are used for working on the point and wing rail as for identifying the need of build-up welding.

#### Replacing component

When a component is replaced, the rails are cut. A crossing requires four cuts, a glued insulated joint needs two, and a switch blade takes one cut. The cutting is normally made with an electrical cutter, but can also be done with a torch. In the latter case, it is more difficult to have a well-shaped cut. Where to cut is decided by the length of new component plus adding 25 mm at each weld joint for welding material. The most common method of welding joints is alumina thermic welding. MMA and electric flash butt welding can be used, but they are very rare. After welding, the excess welding material is cut away with a hydraulic tool followed by grinding. The most important areas of the rail are the head at top of rail and the running edge.

### 2.4.4. Workflow

The workflow of the maintenance planning period begins with the initial track inspection and ends with the re-opening of the track. Basically the simpler a processes is, the more reactive it tends to be. By contrast, with greater complexity, reaction times to emerging issues begin to slow down, often failing to seek resolution in a timely manner. The overall planning process for the maintenance of crossings is summarised as follows:

- Crossing inspection conducted.
- Decision on type of maintenance made.

- Maintenance suggestions sent to Track Master.
- Maintenance activity added to high level plan (i.e. master plan).
- High level plan presented to Contract Manager.
- Dates and times negotiated with train operator.
- Requests for maintenance approved or rejected.

Track inspections are undertaken according to the schedule outlined in Table 3 below. These inspections determine whether the crossing is to be repaired or replaced, noting the limitation of ultrasonic inspection techniques on manganese type crossings as discussed previously.

Table 3: Inspection Schedule

Inspection type	Conducted by	When
Overall inspection	Trained welder	3 years prior to maintenance
Manual inspection		3 months prior (but carried out once a year)
Visual inspection	Contract manager	3 months prior to maintenance
Visual inspection	Contract manager	2 weeks prior to maintenance

The planning processes for build-up welding repairs and crossing replacement follow the same steps until two weeks before the activity is to take place. At that time, a work area inspection is carried out, and the Contract Manager, Safety Manager and welder assigned to complete the repair decide on the scope of work required.

The planning time frame to obtain track access depends on the length of time required to repair or replace the crossing. Table 4 indicates the time frames typically needed to request track access.

Table 4: Possession Request Time frames

Requested Possession time	Requested time frame	Time of the day activity takes place	Detail
3 Hours	14 Weeks	Day and Night	Easier and cheaper to secure
4 Hours	15 Weeks	Day and Night	Time of day dependent on white time availability
6 Hours	16 Weeks	Night	Will require a reroute, carrying additional costs
8 Hours	17 Weeks	Night	Will require a reroute, carrying additional costs
12 Hours	18 Weeks	Night	Very expensive and less likely to be agreed due to budget constraints
48 Hours	16 Months	Weekends	Extremely expensive & disrupting requiring replacement services by road

The table shows that for white time possessions (from 20 minutes to about 6 hours depending on traffic), the maintenance plan needs to be submitted 14 weeks in advance. At this stage, it is usually possible to extend white time possessions by 1 to 2 hours without incurring major additional costs, typically between 1 000 and 10 000 € per hour depending on how it affects traffic. Possessions that are significantly longer than the available white time will incur additional costs for re-routing traffic, for example.

Where a weekend possession is required, this needs to be presented in February of the year before (i.e. 16 months prior) so that it can be incorporated into the working timetable. Such possessions tend to involve major disruption and cost, requiring replacement bus and truck services.

In the run-up to the possession, the Contract Manager carries out the following tasks (see Table 5) to ensure that all materials and equipment are confirmed prior to the maintenance activity.

Table 5: Activities of contract manager

Order of Sequence	Activity	Time frame
1	All necessary material ordered	4 weeks prior to maintenance
2	Crew and light machinery confirmed	4 weeks prior to maintenance
3	Train path booked for light machinery	2 weeks prior to maintenance
4	Confirmation of crossing replacement made to train dispatcher	1 week prior to maintenance

In the above table, “light machinery” includes the excavator and welding train as described previously. Note that provisional maintenance windows (i.e. possessions) are routinely booked into the long-term maintenance plan without knowing exactly what work will be required.

The workflow for the maintenance action on the track differs depending on whether build-up welding or replacement is done, as well as who is performing the action if non-standard procedures are used.

#### 2.4.5. Findings of Lean analysis

Lean analysis for S&C has been conducted in Sweden. The results appear in APPENDIX E “T4.4 S&C Maintenance – Lean Analysis of Current Process”.

The planning stage was included in the S&C work to elicit planning or process related issues that could impact the overall effectiveness of the maintenance undertaken. The Value Stream Mapping (VSM) workshop identified three distinct areas:

- Maintenance planning.
- Surface build-up welding (i.e. crossing repair).
- Crossing replacement.

Attendees at the workshop raised concerns about each of the work steps; these were documented by KM&T. They then suggested ideas or opportunities for improvement to address the concerns highlighted. This information was subsequently used to generate a prioritised list of concerns and opportunities.

The concerns were grouped as below, and are listed in priority, with the first causing the most concern:

- Standards and procedures (52 % of all concern).
- Communication (13%).
- Skill and knowledge (9%).

- 
- Safety (9%).
  - Resources and equipment (9%).
  - Data systems (4%).
  - Budget management (4%).

The following list shows the highest priority concerns:

1. Low utilisation of track possession.
2. Lack of standard operating procedures.
3. Need for better equipment.
4. Weather sensitivity, fire, buckling.
5. Poor target setting.

A number of ideas or opportunities were mentioned during the workshops relating to improvements that could achieve significant cost and time savings. Again, those at the planning stage tended to be common for both build-up welding repair and crossing replacement.

Planning:

- If it were possible to develop the means by which all maintenance activities could be completed in 3 hours, this would enable planning to be completed in 5 to 9 weeks with a subsequent reduction in overall costs.
- During 2011/2012 there were 100 maintenance activities of all types that were planned during the 16 month planning window, but 864 maintenance activities were carried out (i.e. 764 unplanned activities); this suggests there is significant scope to improve the inspection and early detection systems.

Build-Up Welding Repair:

- Using a water spray to cool welded areas before grinding would significantly reduce the cooling time of the rail, which, in turn, would reduce the amount of track time.
- The use of a manual milling machine instead of a manual grinder would streamline the re-profiling of the crossing, as the desired rail profile is built into the milling head. This would ultimately save time on the track, and could potentially result in a higher quality of profile / finish.
- Large amounts of time on the track could be saved if a plasma cutter were used instead of a manual grinder to initially remove material from the fault zone.

Crossing Replacement:

- The addition of a second crew member cutting the rail in parallel would halve the time taken to cut the crossing.
- The preparation of the next mould while the alumina-thermic welding is in progress would streamline the welding process and potentially give a 30% improvement in time.
- Investment in duplicate tools and equipment would allow many tasks to be conducted in parallel, saving significant time.

- 
- Following the alumino-thermic welding, a large amount of excess material has to be cut from the rail, and this is currently done once all 4 welds are complete. If additional crew members started material removal shortly after each weld was completed, the overall time required would be reduced.

### 3. Improvements, Innovations and Best Practice

Based on the findings from the lean analysis and brainstorming sessions, a number of options (innovations, improvements and best practice) were identified. The option “Best Practice” is used to classify already existing methods identified during the work and considered as solutions for decreasing the possession time by delivering increased effective and efficient maintenance. These options have a high potential to decrease the possession time and have been simulated in D4.2. Some innovations can be developed over the long term, as for example, blue sky options, e.g. grinding trolley. The underscored text below indicates the short name/title of the option; see also Table 1-3 in D4.2. The lists below also indicate Best Practices and the performance of simulations.

#### Grinding:

- High Speed Grinding (HSG); Best Practice and simulated.
- Improve grinding speed without jeopardising the quality outcome (new grinding stones, cooling).
- Improving material removal rate, reduce number of pass for same material removed; simulated.
- Reduce time spent on traversing unground section; simulated.
- Automated slag collector; Best Practice and simulated.
- Adaptable Grinding machine ; AUTOMAIN practice.
- Grinding trolley; blue sky.
- AUTOMAIN Speed up production by combining two machines; simulated.
- AUTOMAIN Grinding Strategy; simulated.

#### Tamping:

- High performance tamping machine, Best Practice and simulated.
- Special single failure tamping machine.
- Use of track recording measurement directly for tamping machine.
- Automated control of tamping machine depending on tamping parameters.
- Identify the root cause and removal of reason for single failure tamping machine.
- High priority of maintenance through tamping.
- Combination of maintenance activities in meaningful order.
- Use of track recording measurements directly for tamping machines.
- Improvement of existing or development of special single failure tamping machine for short.
- Pre and Post measurements of track quality.

#### S & Cs:

- Increase the skills of inspector; Best Practice.
- Grinding of the built-up welding; innovation.
- Water cooling equipment for manganese S&C; Best Practice.
- Replacement strategy (Modular concept) instead of built-up welding: Best Practice.
- On-line measurement through camera from OH; innovation.

- Modular concept (Panel replacement); innovation.
- Extended rail parts; Best Practice.
- Create standard work; Best Practice and simulated.
- Implement strategy for stock and non-standard material; Best Practice.
- Display contact information for train dispatchers on the IM's web site; Best Practice.
- Working inside maintenance shed; Best Practice.

The following were common for tamping, grinding and S&C:

- Possibility of using lean analysis as a tool for continuous improvement, but it needs to be applied for the railway maintenance process; see Section 3.4. Best Practice in other industries.
- Development of a robust system which integrates inspection data, maintenance data and other relevant location data (e-maintenance). AUTOMAIN database/software for handling decision data e.g. pre- and post-measurement, asset information, so it becomes easy to access, easy to handle, reliable, able to share amongst all partners involved; see Section 3.5
- Standard operating procedures.
- Training, education and increasing the skills of the personnel.

### **3.1. Best Practice for Grinding**

#### **3.1.1. High Speed Grinding**

High Speed Grinding (HSG) is a preventive cyclic/periodic grinding concept developed by Vossloh Rail Services. An HSG train operates at speeds of 60 - 80 km/h and therefore does not require an engineering possession time. Furthermore, the process does not require the removal of any track equipment (such as signalling devices); it can be safely operated over S&C, and the grinding result is free from facets. This means that HSG trains are planned as normal trains in a normal train slot. Since the HSG machine is a wagon (not a self-propelled machine) it needs an approved locomotive during transport, shunting and operation. The grinding procedure of passive (non-propelled) grinding stones by means of forward motion of the vehicle and the typical grinding pattern are shown in Figure 14.

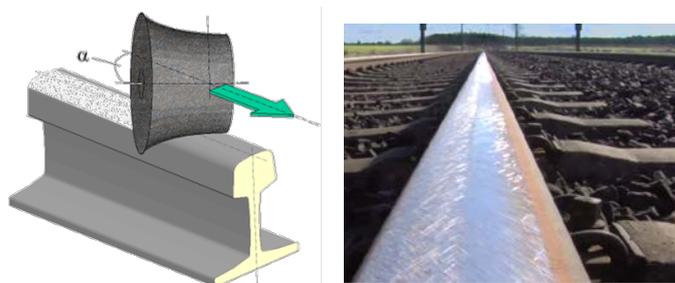


Figure 14: Passive grinding stones and typical grinding pattern (3)

### Theoretical background of High Speed Grinding

An objective of HSG is to continuously and cyclically prevent rolling contact fatigue by removing the very thin, hardened rail head surface. This layer develops from strain hardening as contact forces of the rolling wheel (weight, traction) continue to work the surface. It acts as the breeding ground for cracks that develop in multiple forms, primarily those near the corner gauge that are known as Head Checks. These cracks are the main reason for rail maintenance and can considerably reduce the life span of a rail. The hardened rail head surface is shown in Figure 15 as well as the cracking of the hardened layer which leads to crack initiation in the main material. The figure shows the 0.1 layer of hardened rail head surface (Martensite).

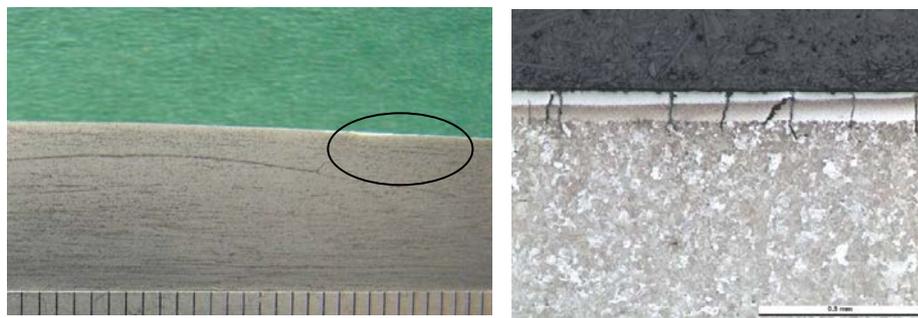


Figure 15: Left side shows the 0.1 layer of hardened rail; right side shows how the hardened layer cracks (3)

The hardened layer is typically less than 0.1 mm thick; therefore, if preventive machining is executed at the right time, only 0.1 mm must be removed to stop cracks from forming in the natural steel of the rail head. For the same reason, the rail must be somewhat free from cracks and rail head defects before entering a preventive machining process. Hence, by removing 0.1 mm on a continuous basis, the rail life cycle can be extended to its maximum. A typical mono HSG is shown in Figure 16



Figure 16: Mono HSG train from Vossloh High Speed Grinding GmbH (3).

A mono HSG train guarantees the rail material removal of a minimum 0.1 mm in three passes. Figure 17 shows rail material removal for HSG preventive grinding, conventional preventive grinding and corrective grinding.

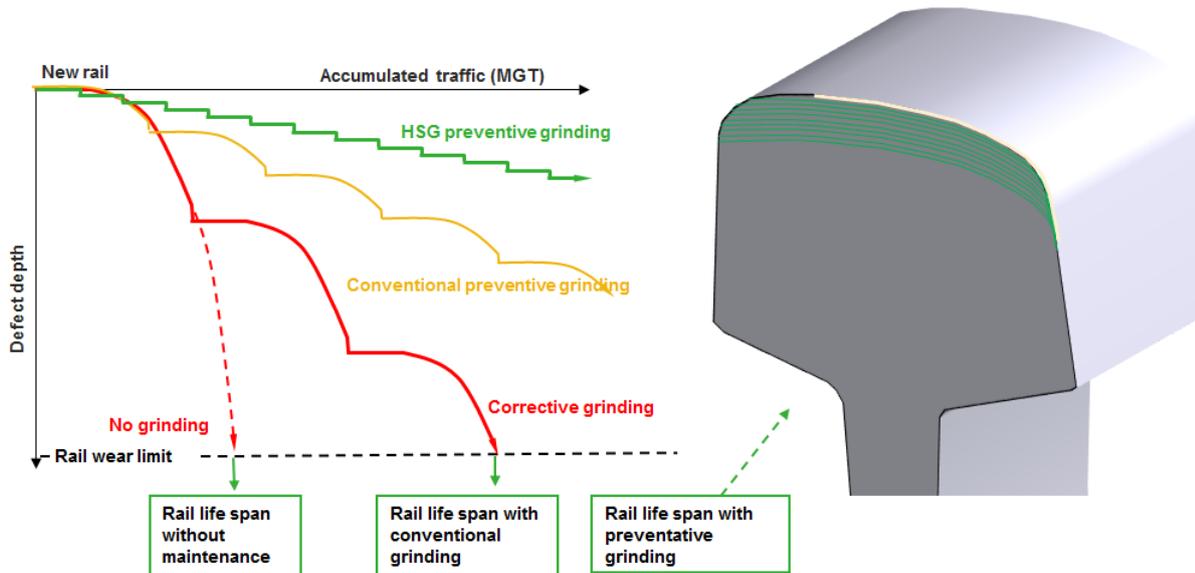


Figure 17: Material removal for different grinding strategies (3)

Another reason to attack the problems of rolling contact fatigue in an early stage is its non-linear development. The longer one waits, the more difficult the rectification becomes, both in terms of necessary material removal and from an economical point of view.

The graph in Figure 18 shows the relationship of MGT and critical defect depth (3).

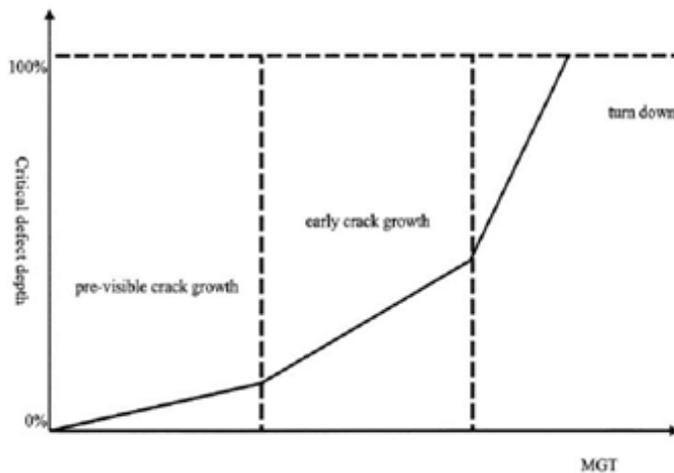


Figure 18: Critical defect depth (4).

### Operation

During operating, a HSG train is grinding with 384 stones (96 at a time) which adapt to the existing rail profile during grinding. The grinding units can be pivoted; thus, over time it is possible to actively influence the cross sectional rail profile and achieve e.g. stress relief of the gauge corner.

During High Speed Grinding, there is no need to have people working on the track for e.g. slag collection. Also the stone exchange process is safely conducted on board the train with no need to go out onto the track.

The HSG trains are equipped with an innovative spark capturing system which ensures that the machine does not interfere with track installations. The HSG trains are used for grinding work in tunnels and on bridges.

### Acoustic performance

Since the set of 12 pcs of grinding stones are fixed to a rigid bar, the grinding result is exceptional in terms of longitudinal profile, which has the naturally positive effect of acoustically optimising the rail head surface during grinding. Since 2012, the HSG process has been approved by the Deutsche Bahn to grind specially monitored tracks (BÜG – Besondere Überwachtes Gleis) in Germany. The principal grinding difference between a conventional grinding train and an HSG is shown in Figure 19. The rigid grinding bar of HSG has a positive effect on the longitudinal waviness.

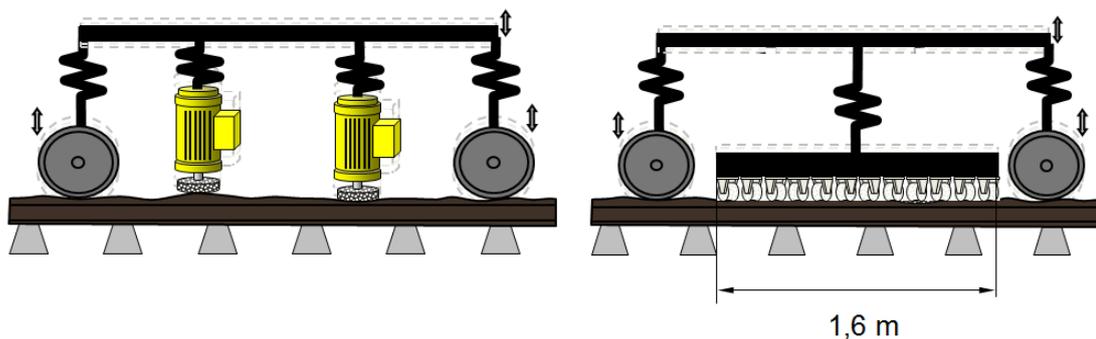


Figure 19: Grinding difference between conventional and HSG (3).

### Capacity – traffic or grinding optimisation

Depending on the interests of the track owner, an HSG train can be operated in a way that has no impact on the traffic; this normally results in a capacity of 35 ground kilometres per normal 8 hour shift and a material removal rate of a minimum 0.1 mm. If, on the other hand, the track owner focuses on getting the most spark time out of each shift, the grinding process roughly covers as much as 100 ground kilometres of 0.1 mm removal per normal 9 hour shift. An optimised shift cycle typically means 1 hour and 30 minutes, 45 minutes of grinding and 45 minutes of locomotive shunting and stone exchanging.

#### 3.1.2. Automated slag collector

A fast slag collector is manufactured by a Canadian company Protec MIV (see Figure 20). It can collect slag at more than 10 km/h and also extinguish line side fires. It collects slag with a speed up to 20 km/h. The speed of the collector has to be higher than the grinding speed so that it manages to collect the slag in between the grinding passes.

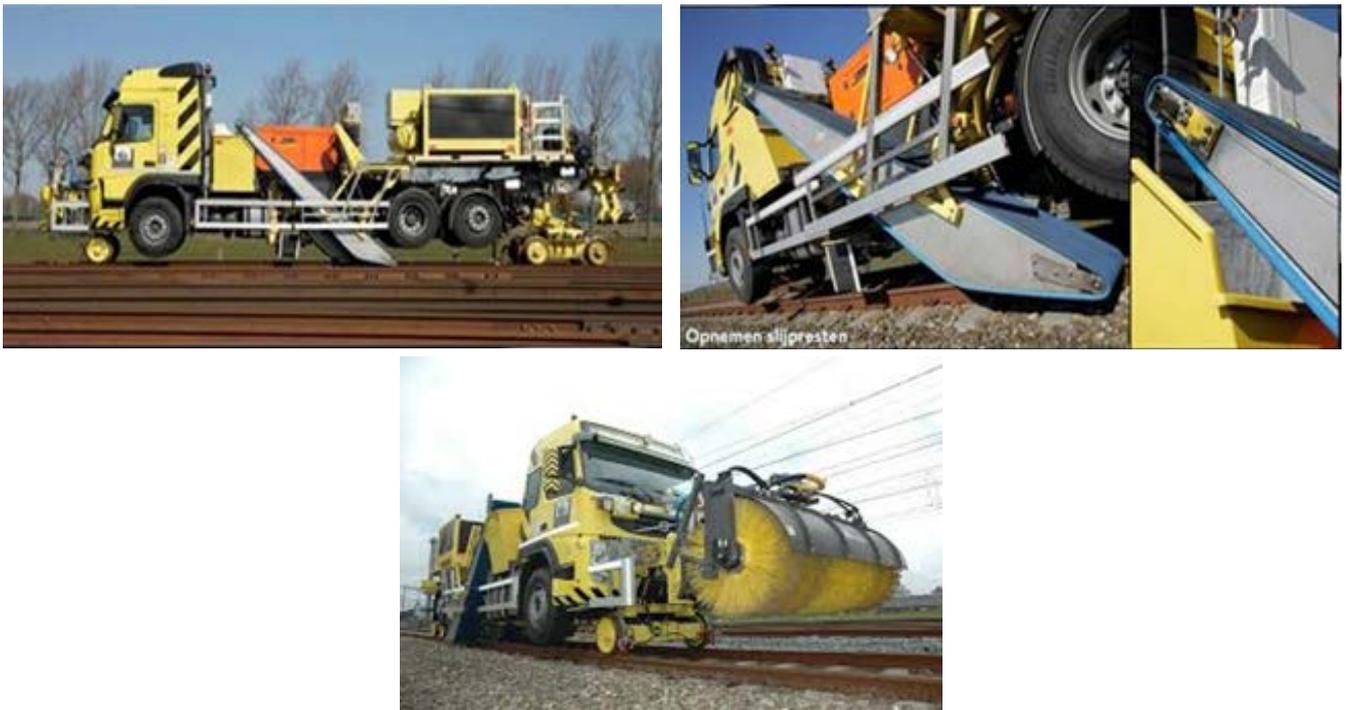


Figure 20: Automatic slag collection machine

### 3.1.1. Pre and post measurements

Actual grinding machines used for preventive grinding are equipped with measurement devices which are able to continuously measure and record the rail profile and the rail surface. At DB, the measurements are part of the documentation of delivered grinding quality.

In the case of two pass grinding, a metal removal of at least 0.2 mm is necessary; therefore, this is part of the contract between IMs and outside companies. If the metal removal cannot be measured by onboard devices, the rail height must be measured with a device that is manually put on the rail at a marked position. One measurement has to be carried out before the grinding and one measurement after the grinding at the same place. However, this procedure reduces the time available for grinding and does not give good control over the metal removal. Continuous measurement of rail height with onboard devices is a better option for controlling the quality and reducing non-productive time.

### 3.1.2. Maintenance strategy

The AUTOMAIN maintenance strategy for grinding is divided into three stages; the AUTOMAIN grinding strategy, the improved grinding strategy and the innovative grinding strategy. Stage one, the AUTOMAIN grinding strategy, is conventional grinding using a grinder with 48 stones and a grinding speed of 10 km/h. Stage two, the improved grinding strategy, uses a high speed grinder with 96 stones and a grinding speed of 80 km/h. Simulations have been done with a 64 stone regular grinding machine and a twin HSG grinder. This machine can remove 0,2 mm of material in one passage, thus reducing the number of passages and track possession time. It even has automatic slag picking for saving possession time. This grinder is currently used in the UK and will soon be adopted in Germany. Stage three, the innovative grinding strategy, uses the innovations presented in this report; note that no simulation are presented because more information and work are required for trustworthy

results. The simulations of the maintenance strategy are done in D4.2 with the stage one and stage two of the AUTOMAIN grinding strategy. Table 6 shows the grinding strategies.

Table 6: AUTOMAIN grinding strategy.

	<b>AUTOMAIN grinding strategy</b>	<b>Improved AUTOMAIN grinding strategy I</b>	<b>Improved AUTOMAIN grinding strategy II</b>
<b>FREQUENCY</b>	25 tonnes axle load 800 < R < 2500 m Tangents – 40 MGT Curves 20 MGT	25 tonnes axle load 800 < R < 2500 m Tangents – 40 MGT Curves 20 MGT	25 tonnes axle load Curves 800 < R < 2500 m 15 MGT Tangents – 15 MGT
<b>Machine</b>	48 stones	64 stones	96 stones
<b>Rail quality</b>	260	260	260
<b>Grinding speed/passes</b>	10 km/h 2 passes	7,5 km/h 1 passage	80 km/h 3 passes
<b>MINIMUM METAL REMOVAL</b>	0,2 mm	0,2 mm	0,1 mm
<b>TARGET PROFILE</b>	In general – 60E1 High rails with pronounced HC – 60E1	In general – 60E1 High rails with pronounced HC – 60E1	A worn rail profile close to the 60E1
<b>TOLERANCE</b>	+/- 0,5 mm	+/- 0,5 mm	+/- 0,5 mm
<b>SURFACE ROUGHNESS</b>	$R_a \leq 10 \mu\text{m}$	$R_a \leq 10 \mu\text{m}$	$R_a \leq 10 \mu\text{m}$
<b>FINISH</b>	No blueing	No blueing	No blueing

### 3.1.3. Adopted grinding machine

Basing on the requirements of DB, the grinding company LORAM has developed a grinding machine with 64 stones which is able to grind the rail, including re-profiling, without dismantling the axle counter or other equipment installed in the track. This saves time and guarantees a homogenous rail surface and rail profile. The use of standard machines makes dismantling of the devices necessary.

### 3.1.4. Grinding trolley

#### Introduction

The conventional machining procedures require track possession time which reduces the inherent capacity of the railway network. Grinding is performed by expensive and specially constructed grinding trains. A suggested innovation is combining the actions to reduce the total cost. In this case, the maintenance action of grinding is combined with normal train operation. A schematic diagram of the rolling stock based grinding trolley is shown in Figure 21.

## Rolling stock based grinding

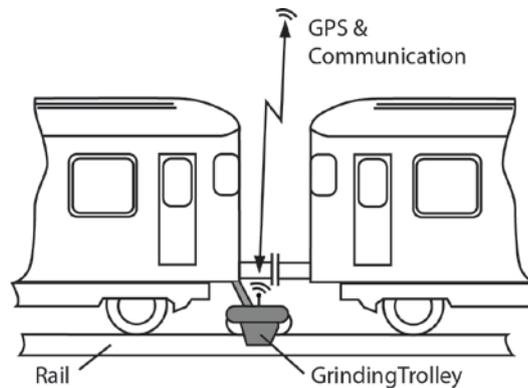


Figure 21: Rolling stock based grinding trolley. Innovation Level1

**Innovation level 1:** In the first level, the grinding procedure is performed by small stand-alone grinding trolleys. Each rolling stock operator must be able to carry a grinding trolley upon request by the infrastructure manager. The trolley system should be designed to work and follow trains across borders and networks. By removing smaller portions each time and repeating the procedure more frequently, crack initiations will be removed before the crack propagation rate accelerates. The trolley consists of three parts:

1. **Measurement:** This part of the trolley measures the condition of the rail to feed the grinding strategy.
2. **Communication:** The communication and positioning system is used to facilitate the download and execution of the grinding instructions and to locate and manage the trolley fleet. Communications are powered by an energy harvesting system.
3. **Grinding:** The grinding process is powered by the train speed and performs the grinding based on the GPS position and downloaded grinding commands or information from the measurement part.

**Innovation level 2:** The trolley will be developed and refined to replace a single wheel set of a locomotive. This implementation will be a standard module for future trains.

### Effect of the innovation

- Reduced track possession time for grinding
- Expensive grinding vehicles will be replaced by many small and cheap grinding trolleys
- Increased rail life length due to “constant” removal of small crack initiations
- Management systems, maintenance actions and spare part logistics of the trolleys are required

### 3.1.5. Speed up production by combining two or more machines

Operating an HSG machine does not require track closure or impact traffic. Its capacity varies between 35 ground kilometres per 8 hour shift and 100 ground kilometres for a 9 hour shift. It is anticipated that with further development and improvement, it will be possible to couple two normal HSG trains together to create an HSG Twin Train and increase the capacity. Combining two HSG machines can decrease the track possession time for grinding. The efficiency in terms of reduction of track possession time as well as economic implications

have been simulated in this project, although the quality output on rail condition is not confirmed in this report. The results of the simulations on a twin HSG are given in D4.2. The anticipated HSG is shown in Figure 22.



Figure 22: High Speed Grinding – Twin train which can remove 0.1mm in one pass (3)

### **3.2. Innovations for Tamping**

To identify possible innovations which reduce or minimise the possession time for tamping, several analyses and tests were carried out and observations made. Beside the reduction of possession time by increasing maintenance efficiency (higher working speed, less preparation time) a higher quality of maintenance can reduce the overall possession time during the lifetime of an asset. The issue of quality versus speed was therefore also investigated for this deliverable.

The following sections describe the results of the investigations and point out possible starting points for an optimisation of tamping parameters, techniques and strategies. The achieved results demonstrate that optimisation and a noticeable reduction of possession time are possible.

The following innovations and improvement areas were identified to minimise possession time:

- Optimisation of tamping parameters (minimum lifting of sleepers, squeeze time, single or double intrusion of tines).
- Automatic adjustment of machine parameter with respect to tamping requirements (lift height of sleepers, number of intrusion, squeeze time).
- Recording and transfer of all maintenance relevant parameters together with GPS coordinates by the tamping machine in digital format.
- Improvement of existing machine or development of special single failure tamping machine for sections up to 100 m.
- Removal of root causes for single failures (if possible from economic point of view).
- Combination of maintenance activities like tamping and grinding.
- Direct use of track recording measurements for tamping, avoidance of EM-Sat measurements.
- Higher priority of maintenance activity.
- Optimised tamping strategy.

Most of the identified innovations need further investigation and improved technologies and processes. Therefore, an analysis of the TRL (Technology Readiness Level) and feasibility studies are necessary to identify the next steps in the short-, mid- and long-term.

#### **3.2.1. Quality versus speed**

Beside the lean analysis of one tamping shift with the focus on the process, tests with a four sleeper tamping machine 09-4x were conducted in 2012. These tests should identify the impact of tamping parameters and techniques on the quality and sustainability of the track geometry and answer the following question:

*Is it possible to increase the sustainability of tamping in such a way that the resulting speed reduction is compensated?*

To this end, the following techniques were analysed:

- Higher minimum lifting of sleepers.
- Tamping twice, moving two sleepers forward.
- Tamping twice, moving four sleepers forward.

According to the tamping techniques and the lift of the sleepers, parameters like tamping time (time of intrusion of tamping tines) have to be adjusted to avoid ballast damage and to increase the homogeneity of tamped ballast structure.

The tests were carried out on line 5830 between Passau and Traubling over a total length of more than 30 km. Figure 23 illustrates the techniques tested in one shift. The diagram shows the lift of the sleepers. The black line marks the standard technique where the sleepers were lifted twice for lifts greater than 25 mm. In the three sections tamped with this standard technique, the working speed is between 1844 and 2047 m/h and the proportion of twice tamping is between 7.5 and 19%.

The red line marks the section where the machine moves two sleepers forward; this means all sleepers are tamped twice. The working speed slows to 1509 m/h which is still quite fast.

The blue line marks the section where the machine tamps each sleeper twice but moves four sleepers forward. In this case, the working speed slows to 1333m/h.

It could be expected that in the last two cases, the working speed will noticeably increase if the machine operators have more experience.

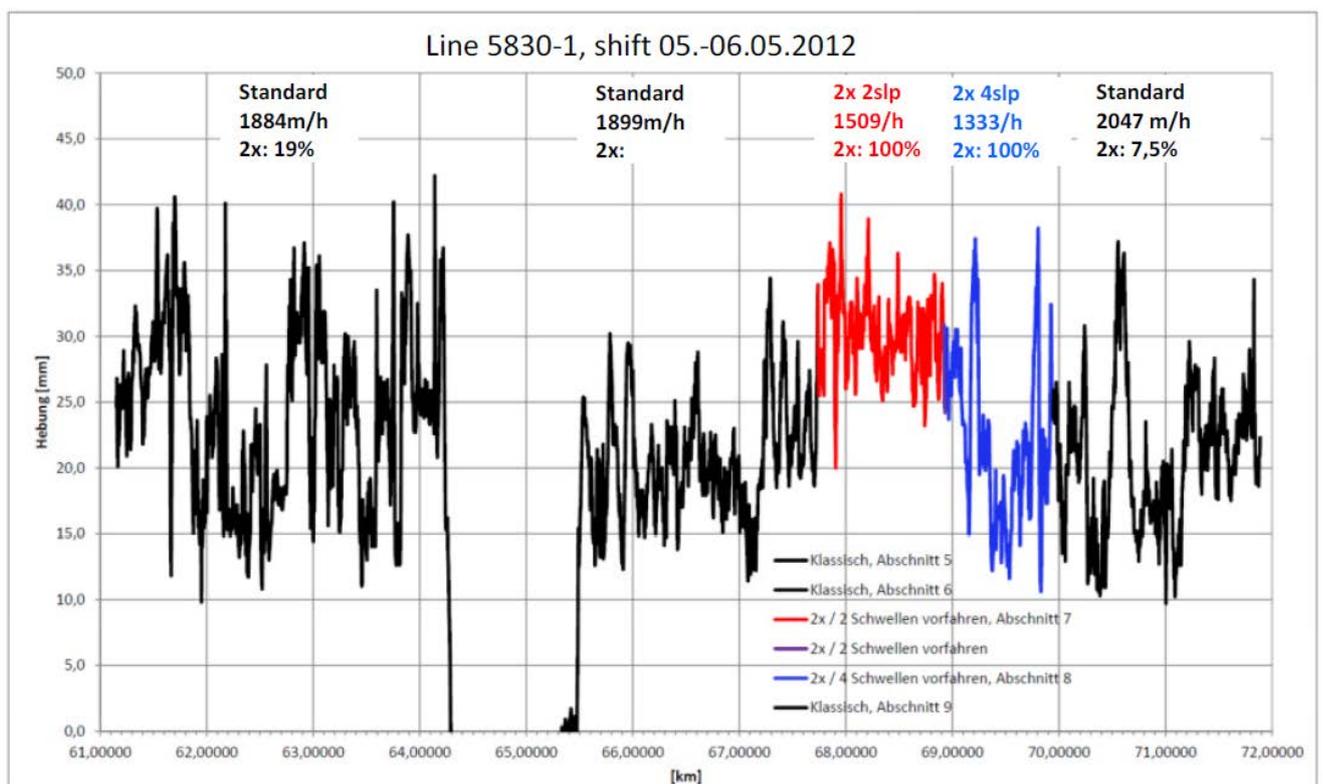


Figure 23: Lift of sleepers for different tamping techniques

The following ranges of working speeds are achieved in all sections and shifts for each method:

- ➔ Standard method, app. 1600 - 2050 m/h
- ➔ Twice tamping, 2 sleeper movement, app. 1350 - 1550m/h
- ➔ Twice tamping, 4 sleeper movement, app. 1050 – 1400 m/h

Clearly, the real working speed of the four sleeper tamping machine depends not only on the tamping technique but also on boundaries like track homogeneity (e.g. sleeper distance) and the actual power of the operator. The experience of the operator has a big impact on the working speed and quality.

The working speed also slows because the operator has to adjust machine parameters like tamping time manually. This means if the tamping time depends on the amplitude of lifting of the sleepers and the number of tamping times (once or twice), the operator has to adjust the parameter for each change of amplitude/number of intrusions. If the tamping machine could control this and other parameters automatically, the operator would not be burdened with this task, and the error rate would decrease.

### **3.2.2. Automatic adjustment of machine parameters for tamping requirements (Improvement)**

The comparison of the track geometry after nearly one year of operation shows only small differences in long-term behaviour. In the sections where the tamping machine tamps twice moving four sleepers forward, there is a slightly better track geometry. But one year of operation does not allow a definitive conclusion. Therefore, further analysis of track geometry will be carried out to quantify the quality improvement.

### **3.2.3. Further Investigation and analysis of track geometry for different tamping techniques**

To analyse the impact of tamping parameters on the sustainability of the track geometry, it would be very helpful if the tamping machine could record and store important data in a digital form. Using GPS, track geometry and machine parameters could be transferred directly after or during maintenance into a web-based data base (maintenance cloud). This would allow a statistical assessment of the tamping parameters and the effect of the maintenance activity on sustainability. It would also solve an issue in SAP whereby maintenance is not correlated to the exact place.

### **3.2.4. Improvement of recording and transfer of all maintenance relevant parameters together with GPS coordinates**

Other important results of the analysis are listed below and are described in the following sections.

- The removal of single failures with special tamping machines or the removal of the root causes for the single failures will reduce the possession time dramatically.
- Pre-measurement of track geometry with EM-Sat takes more time than tamping. To reduce or avoid possession time, new measurement techniques are necessary; for example, it should be possible to use the measurements from the track recording car directly on the tamping machine.

### **3.2.5. Root cause analysis of single failure**

Detailed analysis of the deterioration of the track geometry finds that maintenance activities are often triggered by single failures. This means the track geometry deteriorates very quickly in short sections. Figures 24 and 25 show typical measurements of the vertical track geometry for the left and right rail. Between the “spots”, no maintenance is required, and the change of track geometry is very slow. The distance between the single spots which need to be maintained varies from track to track.

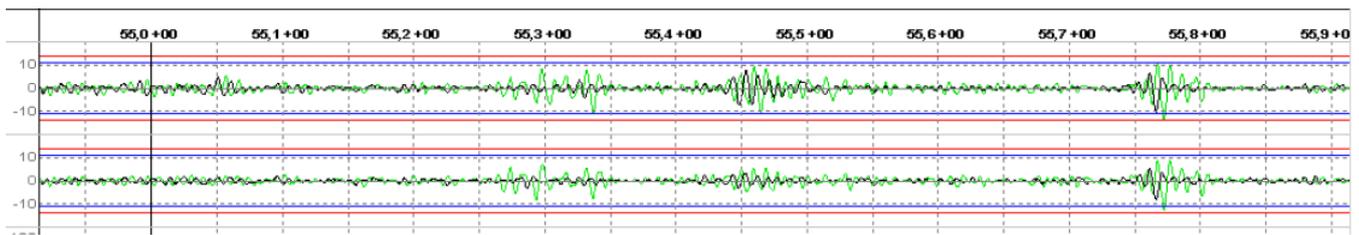


Figure 24: Typical measurement of vertical track geometry left and right rail; short sections trigger maintenance

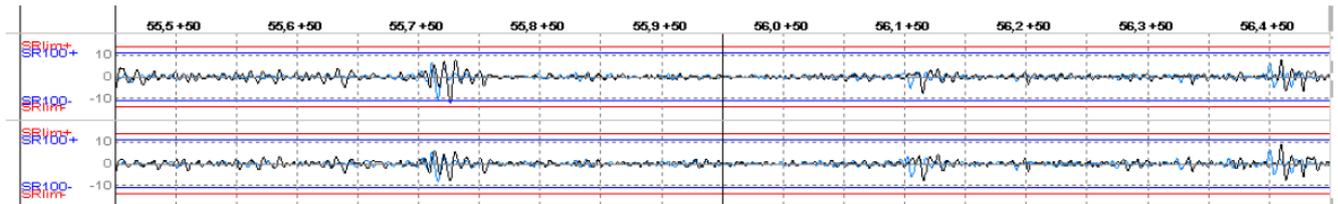


Figure 25: Typical measurement of vertical track geometry left and right rail; short sections trigger maintenance

Besides switches and crossings or expansion joint disturbances in the track geometry, other reasons for spots with bad track geometry include track stiffness or other track parameters (homogeneity) like bad welded joints, local defects in the rail surface, transition zones, wet spots in soil or bad drainage. For further information on root cause analysis of single spot failure, a cause and effect diagram which can facilitate elimination of spot failure is presented in milestone 6 report. Depending on the distances between the single spots, the use of big tamping machines for plain lines like 09-3x or 09-4x may not be an economically or technically sound decision.

To minimise possession time, it is necessary to identify and remove the root causes for the single failures. If it were possible to remove the root causes at reasonable cost, the maintenance intervals would increase dramatically and the use of high-performance tamping machines for the whole section would result in minimised possession time. The track quality and the life time of the asset would also increase. In the case of installation of new tracks, individual track components like under sleeper pads should be used to increase the homogeneity of the track and thus avoid or minimise the structural reasons for single failures.

Combining the maintenance activities will also increase the reliability of the track geometry. Grinding the rails directly after tamping will remove the disturbances in the rail surface which are responsible for local track settlement. The maintenance of welded joints is necessary after tamping too.

### 3.2.6. Combination of maintenance activities in order of importance

If the removal of the root causes cannot be done at a reasonable cost, the use of improved single-failure tamping machines will reduce the possession time. In existing tamping single failure machines like Unimat Sprinter, improvements are necessary to increase the length of the section to be tamped. A new generation of tamping machines with short preparation times and laser based measurement systems used to define the tamping parameters, like the lift of sleepers, will improve the tamping process and reduce the possession time.

### 3.2.7. Improvement of existing tamping machines or development of special single failure tamping machines for sections up to 100 m (Innovation)

Tamping machines should be able to record the geometry of track sections before and after tamping and to store these values together with the tamping parameters, like lift of sleepers or tamping time, in a digital

format. These data can be used to optimise the tamping process and to assess the sustainability of the maintenance activity.

### 3.2.8. Use of track recording measurements directly for tamping machines

The distribution of possession time for the subtasks of ballast delivering, pre-measurement with EM-Sat and tamping (part of the tamping activity on line 5830) shows great potential to reduce track possession time.

Table 7 summarises the time and number of shifts needed for the mentioned subtasks to maintain approximately 40 km of track.

Table 7: Needed time and number of shifts for the sub tasks.

Task	Time [h]	Number of shifts	Remarks
Pre measurements with EM-Sat	≈ 32	5.6	Possession during night
Ballast delivering	≈ 6	Na	Possession during day
Tamping	≈ 35	5	Possession during night

The delivery of additional ballast, which was necessary before the actual tamping activity, can be divided into short time frames and can therefore be carried out in “natural” train-free periods.

It is interesting that the pre-measurements, which are mandatory for certain line categories, take nearly as much time as the tamping itself. Therefore, this is a very important point for optimisation.

The possession time could be reduced dramatically (about 40%) on certain lines if, for example, the measurements of track recording cars can substitute the pre-measurements with EM-Sat. At the moment, this is not possible because at least two important technical issues have to be solved:

1. Recorded position is not accurate enough.
2. Measurements cannot be transferred from relative to absolute coordinate system.

The Japanese Railway (JR East) uses active RFIDs to improve the accuracy of location. The tags can be read-out with a car that is driving up to 300km/h. DB will cooperate with JR East and install devices to test the possibility of improving the accuracy of the location.

The transfer of the measurement data needs improvement on the measurement car and on the tamping machine. One possibility is to use the fixed points installed on overhead line masts along the track to correlate the measurements and detailed tamping parameters.

Due to the potential for improvement and the interest of infrastructure managers, this topic will be addressed in upcoming projects, including Capacity4Rail (C4R) or projects in Shift2Rail (S2R)

### 3.2.9. Higher priority of maintenance

The lean analysis and observations made during several shifts point out the issue of late trains. Delayed passenger or freight trains can reduce track possession time and increase the risk that planned maintenance will not be finished. This causes higher costs, and additional shifts are necessary to maintain the track. But this is a low priority compared to operation. To solve this problem in an economical way, critical maintenance tasks with high follow-up costs or high additional possession time as a result of a delayed start of maintenance should get

higher priority. This means that the planning process has to take into account risks and follow-up consequences in case of incomplete work within a planned shift.

### 3.2.10. Optimised tamping strategy

Prognostic tamping is based on the prediction of the track deterioration. The prediction takes into account existing measurements by track recording cars and estimates the individual deterioration rates for each location on the track. From the actual state of the track at each location, it is possible to predict the remaining time to maintenance – defined as the time until the track geometry deteriorates to the maintenance limit.

Figure 26 shows the predicted standard deviation of the vertical track geometry over place (x-axis) and time (y-axis) for a section of a line. The colour (z-axis) marks the amplitude. In this case, the prediction starts after the section was tamped. The track geometry shows growth at different speeds, depending on the local deterioration rate. The grouping of the sections to be tamped should balance technical needs with economic aspects.

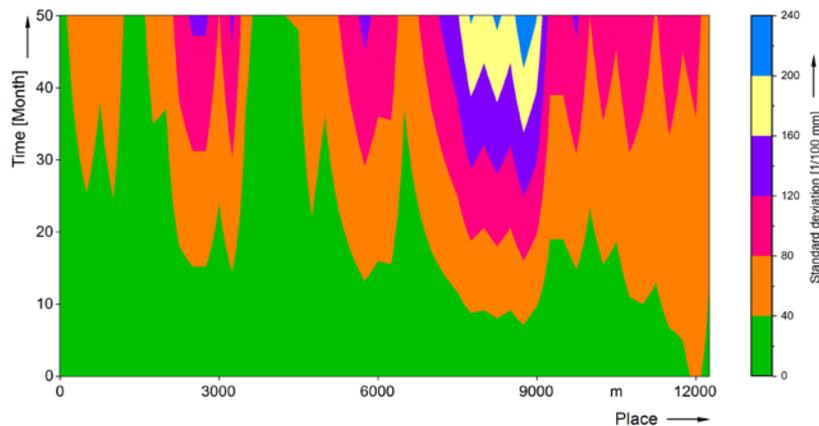


Figure 26: Deterioration of track geometry over time (y-axis) for a track section of 12 km, standard deviation over 250 m

The quality and validity of the predicted track geometry depend on the quality of the data. The correlation of the different runs of the measurement car and the identification of measurement errors and maintenance activities are especially important to reliably predict the deterioration and, thus, the need for maintenance.

A life cycle cost analysis (LCC) was done to identify the economic effects of different tamping strategies, considering the following strategies:

#### Corrective maintenance:

Short-term planning and maintenance due to current failures of track geometry.

#### Preventive maintenance:

Long-term planning and maintenance in specified time based intervals.

#### Prognostic maintenance

Middle- and long-term planning due to prognosis of track geometry and maintenance in *variable* time intervals.

The in and out-frame in Figure 27 shows the parts which were included in or excluded from the LCC analysis. In the case of migration it was assumed that a new strategy requires migration at the beginning. The cost for the

migration in the event of additional tamping was included in the analysis. The cost to migrate to a system level, including developing IT-systems, changing standards and training infrastructure managers was not included.

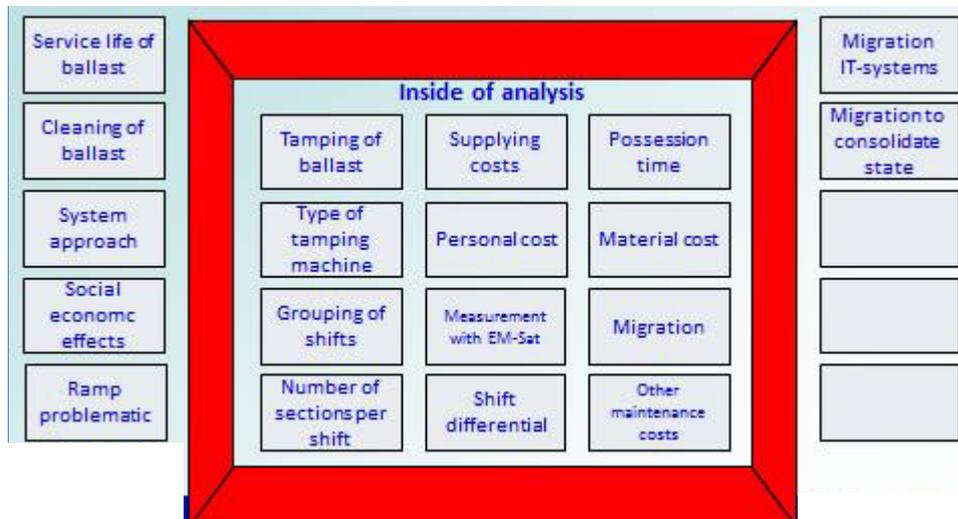


Figure 27: In- and out-frame for LCC analysis

Figure 28 shows the cost break-down structure (CBS) used in the LCC model. To analyse different views of the strategy and identify important cost items, the CBSs of the LCC model implemented a high level of detailing.



Figure 28: Cost break-down structure for LCC analysis

Costs for investment, operation, non-availability and social economic effects were omitted. Note that availability will increase with preventive and prognostic maintenance because of the higher efficiency of the activity.

Besides economical parameters, the LCC model allows the selection of technical parameters, including type of tamping machine, shift performance indicators, and loss of time due to multiple tamping sections (see Figure 29).

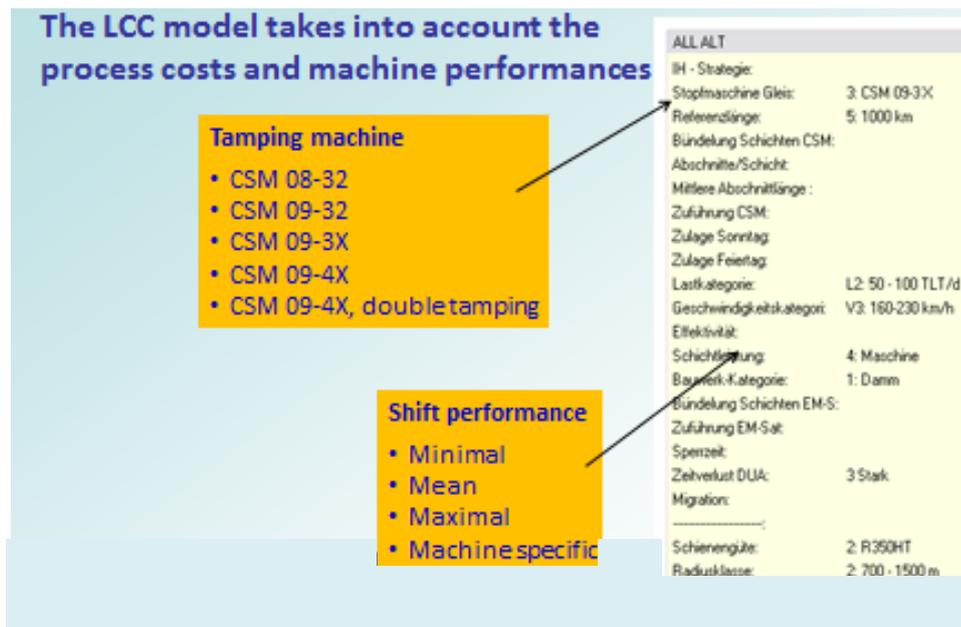


Figure 29: Parameters of LCC model

Tables 8 and 9 summarise important technical parameters and boundaries for the various maintenance strategies. The LCC calculations used a discount rate of 8% (DB value) and an inflation rate of 2 %, with a time horizon of 20 years.

Table 8: Technical parameters and boundary condition of the different strategies – part 1

Parameter	Reference case corrective maintenance	Variant 1 Preventive maintenance	Variant 2 Prognostic maintenance
Maintenance strategy	Corrective	Preventive	Prognostic
Grouping of shifts	No	5	5
Number of sections	1-2	1-...2	1-2
Possession time	3	5	5
Effectively of strategy	100%	85-95%	80-6-90%
<b>General assumptions for all cases</b>			
<b>Nominal discounting rate</b>	<b>8%</b>		
<b>Inflation rate</b>	<b>2%</b>		
<b>Effective discount rate</b>	<b>5%</b>		
<b>Time horizon</b>	<b>20 years</b>		

Table 9: Technical parameters and boundary condition of the different strategies – part 1

Parameter	Reference case Corrective maintenance	Variant 1 Preventive maintenance	Variant 2 Prognostic maintenance
Mitigation	No	yes	yes
Mean supply length tamping machine	150-200 km	50-100 km	50-100 km
Mean supply length EM-SAT	150-200 km	50-100 km	50-100 km
Shift grouping EM- SAT	1	5	5
Increase of long- term behaviour	no	yes	yes
Part of shift differential	High	low	idle

Figure 30 shows the distribution of the annual leveling cost for the strategies for the next 20 years. The initial migration cost for the new strategies leads to increasing cost in the first three years. Apart from the first three years, the corrective maintenance (red line) results in the highest maintenance cost per year, followed by the preventive maintenance (green line). The blue line marks the prognostic maintenance, representing the lowest maintenance costs.

In all strategies, the long-term behaviour of the track was taken into account. It was assumed that preventive and prognostic maintenance would increase the maintenance interval because a more optimal date was set for maintenance.

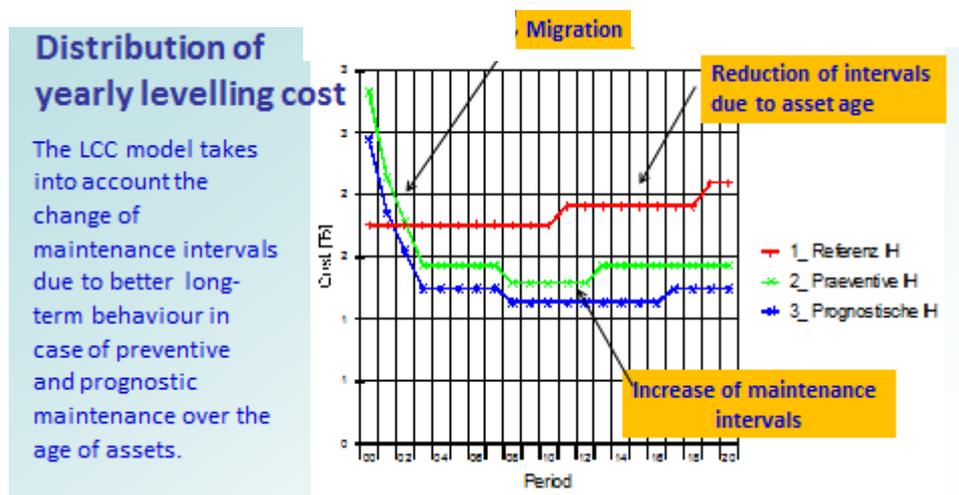


Figure 30: Distribution of yearly leveling cost for different strategies

Finally, Figure 31 shows the cumulated levelling cost for a period of 20 years.

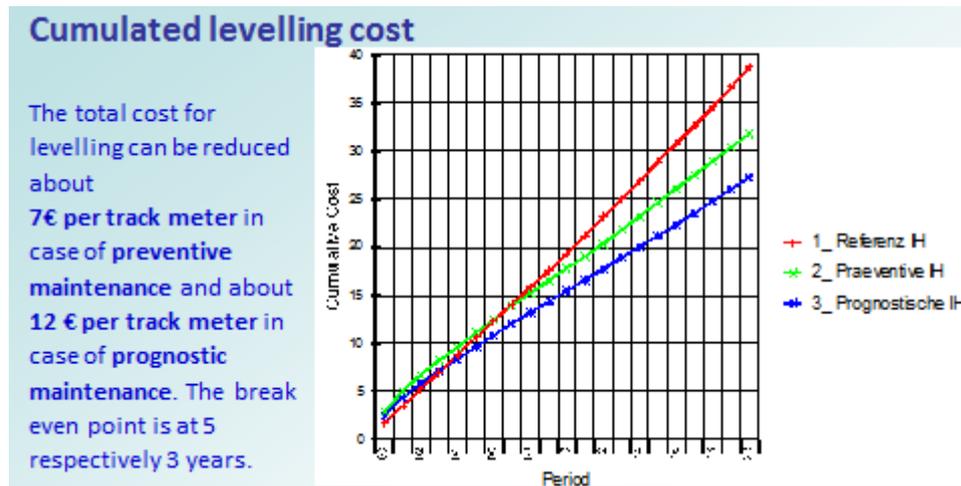


Figure 31: Cumulated levelling cost for different strategies

As before, the prognostic maintenance strategy (blue line) shows the best economic performance, followed by the preventive strategy. A cost reduction of 7 € and 12 € respectively per track metre is possible by changing the strategy.

Additional advantages are the increased lifetime of ballast; because cost reduction is related to a reduction in the number of shifts required, availability will increase with preventive or prognostic maintenance. The real increase of availability depends on the boundary conditions and the definition of availability.

Under the given boundaries, a reduction of track possession time of 18% is possible if the infrastructure manager changes the maintenance strategy from corrective to preventive. In the case of prognostic maintenance, a reduction of track possession time of 30% seems achievable. Difficulties such as incorrect predictions, grouping of sections or machine unavailability may decrease the benefit, but the results of the analysis strongly suggest changing the strategy.

### **3.3. Switches and Crossings**

#### **3.3.1. Increase inspectors' skill**

Today, inspectors merely make observations; they do not specify what action should be taken. Therefore, a trained welder frequently has to go out a second time to observe the same thing. If the skills of the inspectors were improved, one visit to the track would identify the problem and determine the actions to be taken. This would lead to reduced possession time and shorter lead time from inspection to repair.

#### **3.3.2. Grinding of built up welding**

Maintenance activities on S&C are done as corrective actions; basically, as repair and build-up welding. The most common components to require build-up welding are the point and the wing rails of crossing. After the welding, the weld has to be ground down. Today this is done manually, and the result depends on the skills of the person doing the grinding. Another issue is that the grinding generates noise and vibrations which are not good for the person doing the grinding. Combining the programmable part of mechanised welding equipment with a small milling machine will be faster, healthier and achieve the same or a better result.

#### **3.3.3. Water cooling equipment for build-up welding**

When doing build-up welding on manganese crossings, it is important not to exceed 200°C for the crossing, or there will be changes in the structure of the material. This is currently solved during welding by waiting and letting the crossing cool down by itself; sometimes the flange of the crossing is filled with water to speed up the cooling. Water cooling equipment can be developed to keep the temperature below 200°C in the welding area, thereby reducing the welding time.

#### **3.3.4. Replacement strategy (modular concept) instead of repair and build-up welding on track**

Maintenance activities in S&C are corrective actions, basically repair and build-up welding. One of the problems with welding is that the total process takes a long time. The first reason is the material; manganese-steel must be kept cold, while rail steel has to be kept hot. The second reason is that a weld must ground, and that takes time.

Wear and cracks in manganese crossings are the most common reasons for repair. When repairing manganese crossings with cracks for which the depth or width is unknown, the repair begins by grinding away the crack. This operation reveals the depth and width. Often the crack is too deep or too wide to repair; if this is the case, it undergoes a temporary repair and the crossing is replaced later. This causes wasted time for planning, repair and temporary repair. Sometimes safety is jeopardised due to when a temporary repair is not technically good enough.

Another common problem that is that the time to repair may exceed the possession time means a second visit to finish the repair work. This is not just a waste of time; it sometimes jeopardises safety.

A replacement strategy means that repair work is done in a workshop, not on the track. There are many advantages to this:

- With a standard crossing replacement, the necessary time for replacement can be less than four hours.
- A quick replacement process means fewer people on the track.

- A repair done off the track have better quality due to better conditions.

### 3.3.5. On-line measurement through camera from Overhead (OH) line

S&C inspections are normally done by people on the track using different measuring tools. This system is inefficient and unsafe in several aspects.

By using a camera, which can be considered a monitoring system in its simplest form, all disadvantages can be reduced or even eliminated. The camera allows an instant view of the S&C; it is just a click away, and nobody needs to be on the track. This is very safe and efficient in all S&C, especially those far away, in tunnels or in areas with a lot of traffic. The overhead (OH) camera for S&C monitoring developed in AUTOMAIN WP3.2. is shown in Figure 32.



Figure 32: On-line camera from OH-line for measurements

An inspection can be a preventive action, with high resolution pictures measuring track gauge, flange ways and wear. The inspection can also be a corrective action, for example, to check for obstacles in the moving parts of the S&C, especially in winter when snow and ice can fall from trains. This can indicate what skills the person handling the problem must have. To cite one example, during winter, the function of the heating system can easily be seen.

To summarise, an On-line camera on the OH-line is much safer and more efficient than a manual system, as it does not require people on the track.

### 3.3.6. Modular concept

Modularization is a term both in construction and in maintenance of an asset. A modularized asset is easier to install and maintain than an asset built without modules. The term can be used for showing the possibility to replace larger unit instead of components. The larger unit can be repaired at the workshop where the condition for repair is better than in the field. The term is also used to separate expensive components (which have a low failure rate) from inexpensive components that have a higher failure rate.

For S&Cs modularization has been used in building point machines with several repairable units that in field is replaced and repaired in work shop. Modularization of the crossing has also been discussed where the crossing can be replaced with or without the sleepers so the surface welding can be done in workshop instead of the field. When replacing sleepers a restoration of the track geometry is also possible.

Switches & crossings are built up with different components and subcomponents. The basic components are the different steel parts (switch blades, stockrails, crossings, checkrail, baseplates, slide chairs etc.), sleepers and point machines. S&Cs also includes sub components such as detection devices, heating system etc. Instead of

handle S&Cs in separate components in aspects of installation, inspection and maintenance they shall be seen as modules. These modules are defined as follows:

- Distinct parts (mouldes)
- A clear specification of WHAT is to be done in terms of repair and maintenance (standard work).
- A clear specification of HOW repair and maintenance is to be done (standard work).

A study of the maintenance process at Trafikverket “Maintenance and replacement of Switches & crossings within Trafikverket” (6) found that there are no fixed rules or standards on how to manage or carry out maintenance. Normally, the S&Cs are checked regularly; the frequency is based upon the type of track, traffic load and speed. When the result of the inspection is outside specifications, someone must decide what maintenance should be done. If every component and sub-component which has been degraded is renewed during the maintenance activity, the curve of the technical status would look like Figure 33 below.

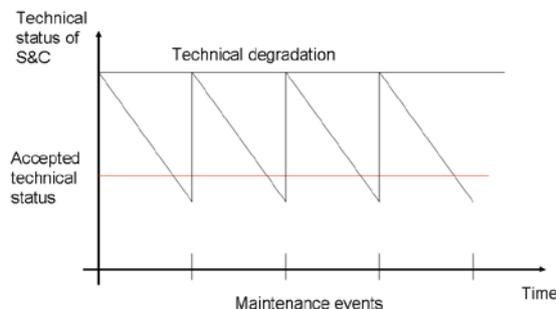


Figure 33: Theoretical technical status when everything degraded is renewed by maintenance.

Figure 33 shows regular degradation; the timing of the next maintenance activity is easy to predict, since it will come at a regular interval.

This is not the case in reality, however. Normally, inspection personnel do the measuring and compare the result to the existing standard. In this comparison, a certain wear can usually be noticed. Often this wear is still within stated tolerance levels; therefore, it is not necessary to do anything. Nevertheless, it is a degradation which affects other components in the global S&C system.

In the switch part, the most replaced steel part is the curved switchblade. The crossing part is a little more complex since there is a direct relation between the checkrail and the crossing when it comes to safety and both components show wear. The need of a good transfer or wheel requires the crossing to have good geometry and a good profile. The root cause of problems in crossings is high vertical and lateral forces in combination with bad contact geometry. It is very important that maintenance has good results.

The most common maintenance activities in the crossing area are adjusting the checkrail with shims for better safety and welding the crossing for optimal geometry. Aspects like correct over-all geometry or good track quality when it comes to levelness and stiffness not concerns in this process. Due to the gap between what is really degraded and what is renewed during a maintenance event, the curve of the technical status will be as shown in Figure 34.

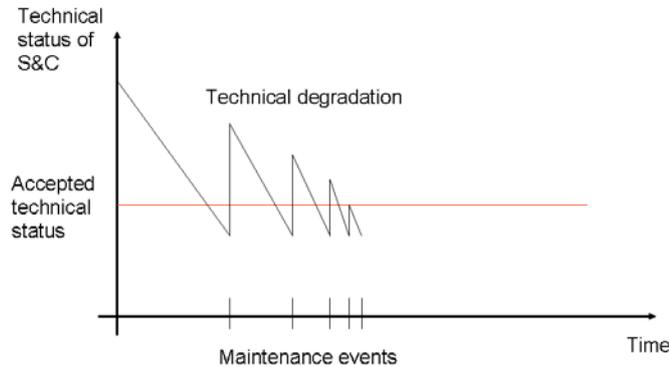


Figure 34: The degradation of the technical status when only some parts of the S&C are renewed during maintenance event.

When only some parts of the S&C are renewed, a negative degradation trend begins, because after maintenance, the S&C is not at the same high technical level as when it was new. A big part of the S&C system has not been renewed at all and in some parts not to the same level as when new. The output from the renewal activity is at a lower technical level for each maintenance event; at the same time, the events become more frequent.

“Guidelines for modularisation of S&C” (7) recommended the establishment of function structures by reducing the number of sub-functions and combining several sub-functions into a single module. This is supported by the service contractors; in general, they prefer large modules.

By defining modules, create standard work for *what* to be done and *how* there will be a number of improvements:

- Knowledge of what to do
- Knowledge of how to do it
- Knowledge of how long it will take
- Knowledge of the technical result
- Higher technical result
- Less total time in track for installation, inspection, decision/planning of actions and maintenance

### 3.3.7. Extended rail parts

When a component is welded in the track, the width of the weld joint is approximately 30 mm. When this component is removed and replaced, the rail has to be cut. Normally these cuts are made so that the welding joints are also removed. This means that the new component is too short for the “gap” in the track. To solve this, the spare parts can be made with extended rail parts.

### 3.3.8. Create standard work

Many concerns were noted during the observation of a crossing replacement. Among the top 23 concerns rated as having the highest impact on track possession, efficiency, standards and procedures stand topmost; see Figure 35.

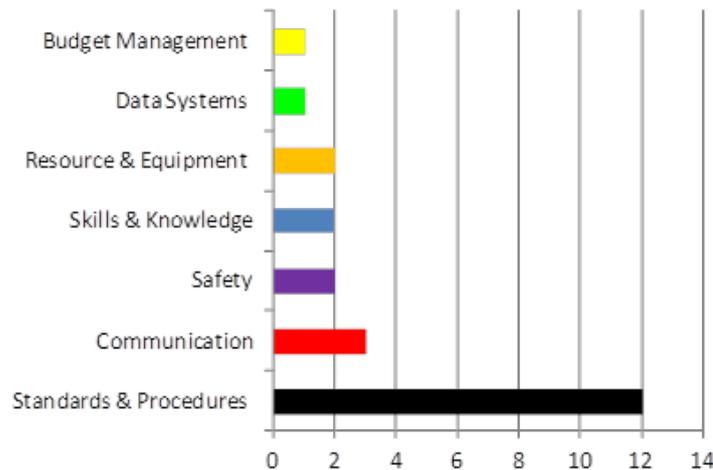


Figure 35: Categorisations of High Impact Concerns

Standardised procedures will give several positive effects:

- Technical results of work will be known.
- Time taken will be known, making work easier to plan.
- Cost of work is much easier to calculate.

Simulations have been done on a case study of a crossing replacement using an improved process. This is presented in deliverable 4.2.

### 3.3.9. Implement strategy for stock of non-standard material

The need to replace a worn out or broken component is the same for standard and non-standard materials, but the delivery of non-standard materials often takes much longer. This can lead to temporary repairs and sometimes jeopardise safety, depending on the technical condition of the component.

In order to avoid this, a strategy should be implemented whereby an S&C on tracks with over a certain number of trains or tonnes, and/or in strategic positions should always have available spare parts if the S&C has non-standard material.

### 3.3.10. Display contact information for train dispatchers on the IM's web-site

There contractors often have problems getting the correct contact information to the train dispatcher. This causes loss of valuable possession time. If all contact information required by the train dispatchers is displayed on the IM's web-site, access would improve.

### 3.3.11. Work inside a maintenance shed

During the VSM workshop, several concerns were raised about safety and equipment availability, e.g. the adjacent track was open and operating with high speed traffic; ice from passing trains can break off, putting the crew at risk of serious injury; welders must walk fairly long distances to collect different pieces of equipment, tools and material.

A best practice was used by a ProRails contractor. A mobile maintenance shed (see Figure 36) was used to increase safety while working on a double track, protect personnel from harsh weather and improve lighting during night shifts. At the same time, it increased the availability of machines and tools and decreased setup and close down time.



Figure 36: Maintenance vehicle providing protection from harsh weather conditions

### **3.4. Lean thinking approach**

Lean analysis technique was used to observe and evaluate current maintenance practices and compare the approaches. It also helped to identify root causes/areas of differences in lengths of track possession and to understand the current situation. Two methods were used to evaluate and compare current practice, namely:

- Structured Observations: an actual tamping shift was observed in detail for each railway administration
- Value Stream Mapping (VSM) workshops: a paper-based exercise that maps out the process and is used to identify issues and suggest improvements.

The approach has 8 steps. Specification and opportunities (for more information see D2.2 Outline for lean process):

1. Planning.
2. Process observation.
3. Value stream map; work steps.
4. VSM; Idea generation.
5. Hand-off diagram.
6. Collection and evaluation.
7. Stratification of improvement actions.
8. Definition of high level project work stream.

It was too difficult and time consuming to make observations for directly comparable maintenance shifts across the railway administrations, so a decision was made to observe broadly similar track possessions, accepting that there were differences in the type of machines used, as well as the aims and objectives of possession. This led to great differences in the observed number of steps during the possession time, as there were differences in:

- Density of traffic.
- Chosen strategy.

- Funding.
- Resources allocated.

The definition of Non Value Added actions needs to consider the requirements of rigid safety regulations and the need for trained and certified workers to perform welding and cutting and to work on signal and electrical assets.

During the work in AUTOMAIN, the approach was slightly changed by the VSM results. Structured observations, in some cases, were too general and needed to be linked back to the Railway Maintenance Process. They also required analysis and ranking based on priorities and possibilities for solution. The aim was to identify the most effective solutions of those issues of highest concern by:

1. Scoring each concern in terms of priority.
2. Developing and then prioritising a list of potential solutions and/or mitigations, drawing on the work of the VSM workshops and any other ideas suggested during the exercise.
3. Combining the priority score from the concerns and the potential solutions to identify the most attractive option.

### ***3.5. Robust infrastructure database and data system***

Many concerns were raised during the lean analysis of grinding, tamping and modular S&C, including the following:

- Inaccurate data on track condition.
- Automate the production of post-maintenance reports and uploading of these to the central database.
- Improve on-board measurement equipment, so that manual on-track measurements are no longer required.
- Better use of track geometry and condition data.
- No history of earlier performed maintenance.

A blue sky, “single central system” solution is presented in Figure 37. A robust on-line database and data system can provide the necessary data and the decision support to all parties involved in the railway maintenance process. The core modules include a number of central databases with analysis and reporting tools. These databases store and provide data such as maintenance history, e.g. what kind of maintenance has been performed, where and when. Another database stores pre-measurement data combined with inspection data i.e. to support trending of the degradation from the designed position of the track. This is necessary as a control measure, because if the track moves from its designed position with stress-free rail temperature, the inbuilt track forces will increase and the risk of sun buckling and rail cracks will increase. All maintenance vehicles will be tagged with RFID (Radio Frequency Identifications) containing information on the type and capacity of the vehicle. They will also have GPS-equipment that can provide information on their position. Before the maintenance activity can start, the maintenance operator must push a button and insert the type of maintenance to be performed (preventive or corrective), and if the vehicle is on a station, insert the track number. As soon as this information has been inserted, a panel in the vehicle will receive information e.g. deviations from pre-measurement data, measured quality, and earlier conducted maintenance on this spot. The maintenance activity can then start; when finished, the operator pushes the “off” button, and the system will send maintenance data back to the central system, including the quality of the performed maintenance. The central system will then calculate the expected degradation and plan the next maintenance.

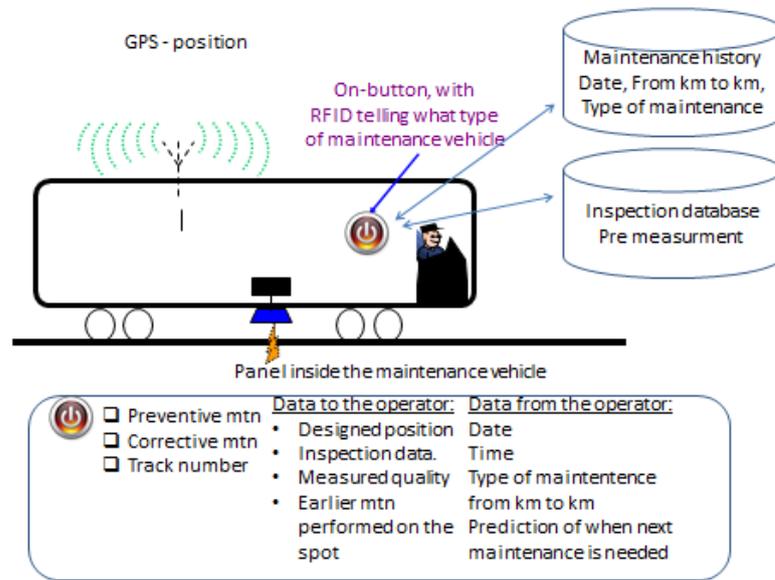


Figure 37: Single central system for maintenance decision support

## 4. Conclusions, Key findings, and Recommendations

### 4.1. General Observation

The objectives of this deliverables are to identify, study, and assess innovations that can improve the effectiveness and efficiency of large scale inspection and maintenance processes for track grinding and tamping, and the maintenance of switches and crossings. It also identifies and develops key technologies to drive the development of modular infrastructure design. It seeks to reduce the benchmarked track possession time by up to 25% for tamping and grinding and to reduce the track possession time for installation and inspection during the life of the asset by at least 50%.

A three-stage approach was planned and applied to increase the availability of freight train tracks, including the following: reducing 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. The focus was on reducing the possession time for maintenance by improving the planning process and the scheduling of activities.

Current objectives and strategies differ between IMs, making it difficult to describe a common railway maintenance process and suggest improvement possibilities leading to more effective and efficient maintenance. In some cases, the chosen strategy is even corrective, e.g. maintenance of S&C; in such cases, the LCC cost increases at least three times while the technical life length decreases. There are also big differences in how KPIs and PIs are used; currently, very few PIs to measure capacity and possession time.

At the present time, very few documents show how maintenance is actually done. In addition, there is a need to identify various types of useful knowledge, and address relevant issues which are useful to achieve the objectives of this project; examples of such are :

- Need of pre-measurements
- Need to add and re-profile the ballast before tamping
- Weather and temperature effects (too warm and not able to tamp, too cold and not able to weld etc. )
- Low priority for track maintenance, delayed trains have higher priority,
- Need to demount assets that can be damaged by maintenance
- Lack of multi-skilled personnel (traffic, electric); certified personnel required for maintaining signaling and electrical assets, welding, rail cutting, vehicle operations etc.

AUTOMAIN innovations to be considered according to DOW are: (1) adapting best practice from other industries in maintenance optimization to reduce the benchmarked possession time up to 50%; (2) carrying out faster track maintenance to reduce possession time by 25%; and (3) creating modular infrastructure to reduce possession time by 50%. This requires doing the work in less time within the current timetable, breaking the maintenance into bigger chunks and splitting the work into smaller blocks that fit into the planned timetable.

Lean thinking should be used as a tool to improve the railway maintenance process; RAMS and LCC methodologies are best practices from other industries and would be beneficial here as well. The lean thinking proved highly effective; a number of clear and interesting differences were noted between different railway IMs, as well as many common issues and suggestions for improvement. However, lean thinking cannot yet be

used as a benchmarking tool, as further harmonisation/normalisation is needed. Lean thinking has been used in AUTOMAIN to find areas for improvement and an attempt was made to describe the current maintenance practices and processes throughout the railway industry. But as many of the non-added value components are caused by regulations, demands on safety, environment and reliability, it is not advisable to make conclusions on the incidental practices and processes of different IMs given in the report.

#### **4.2. Key findings for AUTOMAIN innovation 2 and 3**

Best practices in terms of existing methods, techniques and approach have been identified within the railway system. The adoption and implementation of these practices will enhance the effectiveness of the maintenance activities under consideration: tamping, grinding, and S&C maintenance. This, in turn, will improve the allocation and utilisation of track possession time. The best practices for tamping, grinding and S&C maintenance include;

- High Speed Grinding (HSG).
- Grinding with reduced number of pass but same material removal.
- Adaptable Grinding machine.
- Utilisation of maintenance shed to give suitable working condition.
- Further investigation and analysis of track geometry for different tamping techniques.
- Enhanced recording and transfer of all maintenance relevant parameters together with GPS coordinates.
- Extended rail parts on switches and crossing.
- Skill upgrades of S&C inspectors.
- Replacement strategy (modular concept) instead of build-up welding.
- Standard working procedure for switches & crossings.

The second category in the analysis for high performance maintenance is the improvement of existing practices and methods. These are intended to improve the condition and maintainability of the track system and its supportability. These improvements cover the aspects of maintenance procedures, logistics, human factors and machine conditions. They include;

- Adopt Standard Operating Procedures (SOPs) to drive correct behaviour and support error-proof processes
- Improve grinding speed without jeopardising the quality outcome by using new grinding stones and cooling procedures
- Reduce time spent on traversing unground section by optimising all actions during a shift
- Prioritise and combine maintenance activities in meaningful order
- Carry out structured root causes analysis of isolated geometry defects (single failures)
- Use track recording measurements directly on tamping machines
- Make automatic adjustment of machine parameters for tamping requirements
- Acquire water cooling equipment for manganese S&C

- Implement optimum strategy for stock and non-standard material
- Display contact information for train dispatchers on the IM's web site; best practice

The improvement analysis for high performance maintenance has also highlighted some innovations to be developed over the long term. These include mechanised systems which will require detailed product design and development. Others are innovative reasoning, projection and methodology which require field validation and verification besides the simulation carried out in Report D4.2. The innovative ideas for the maintenance activities considered in this project are given below:

- Grinding trolley.
- AUTOMAIN production speed-up by combining two machines.
- Simulation based grinding strategy.
- Automated slag collector.
- Prognostic tamping strategy.
- Development of special single failure tamping machine for sections up to 100 m.
- On-line measurement with a camera from OH.
- Modular concept for switches & crossings.
- Panel replacement (modular concept) for switches & crossings.
- Robust infrastructure database and data system.

### **4.3. Recommendations**

The identified best practices, improvements and innovations for the three maintenance activities under consideration can be modeled and simulated after suitable modifications (i.e. those relevant to the individual IMs) to ascertain the possibilities for achieving the anticipated reduction (25%, 40% or 50%- depending on the case)-in maintenance possession time. Report D4.2 gives some of aspects of the modeling and simulation, along with some additional considerations and procedures which will facilitate the achievement of AUTOMAIN's goals. Some of the suggested innovations require further development and engineering analysis to give detailed and specific design specifications, which is not covered in this report.

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## Appendix A: Glossary and Acronyms

DOW	Description of Work
EM-Sat	Track quality measurement vehicle/system
Geotags	is the process of adding geographical identification metadata to various media.
GIJ	Glued Insulated Joints
HSG	High speed grinding
KPI	Key Performance Indicators- The actual indicators used to quantitatively assess performance against the critical success factors. A KPI is a PI of special importance comprising individual or aggregated measures.
MMA	Manual Metal Arc (MMA) is an arc welding method using covered electrodes,
NDT	Non Destruction Testing
OPG	One Pass Grinding
OTM	On Track Machines. TSI definition EN1403 High Performance machines are track bound and have to travel on the open or closed track) also needs to be off the track between the train passages
PI	Performance Indicator. Parameters (measurable factor) useful for determining the degree to which an organisation has achieved its goals or numerical or quantitative indicators that show how well each objective is being met.
RCF	Rolling Contact Fatigue
RFID	Radio Frequency Identifications
Slag	Steel dust form grinding that has sintered in the mudguard of the grinding stone and form bigger pieces (slag)
SOLA	measuring device is a commonly used hand held tool for checking track gauge, canting and flange ways between check rail and rail.
SAP	Business management software solution
SOP	Standard Operating procedures
TPG	Two Pass Grinding
TSI	Technical Specifications of Interoperability

## Appendix B: Milling.

Rail milling is a process used to restore the rail head profile and to remove defects in the rail head. This involves cutting the rail head using shaped cutting blades, as opposed to abrasion as used in grinding. Milling is very effective in terms of material removal, and is typically employed where a significant depth of cut needs to be made, for example to:

- Remove defects that are quite deep
- Restore rail head profile
- Introduce an entirely new rail head profile



*Figure 1: Milling train conducting work.*

The work process is slower than conventional grinding in terms of working speed (typically around 800 m/h), but a greater amount of material can be removed in a single pass. The surface finish also tends to be better than conventional grinding as the profile is contained in the cutting head and fine ground by longitudinally operating fine grinding stones.

Milling can be viewed as an alternative to conventional grinding, or as a complementary process, as it is more effective when the depth of material to be removed is more than about 1mm. It also has certain operational advantages when compared to grinding, with significantly less risk of causing line side fires, and greatly reduced contamination. As such, it may offer advantages in tunnels or high fire risk areas; it can also be used alongside tracks that remain open to traffic, and there is no need for manual slag collection or removal of signaling equipment.

## Operation

A milling train is typically equipped with one to three milling wheels and one to two fine grinding units respectively per rail. The milling wheels remove up to 2mm of material per pass while the fine grinding units merely remove facets from the milling wheels and polish the surface.

Because of the great material removal rate, the milling wheels are ramped up over a stretch of about 10 metres to reach the desired work depth. Upon several passes, a new ramp is normally conducted outside the previous ramp to even out the transition.

Due to the walking pace operational speed, it is possible to collect all types of necessary measurement data, such as profiles and material removal rate, during the milling process itself. Most milling trains are also equipped with an Eddy Current measuring system to confirm a rail head is free from defects.

The milling knives become worn during operation, but can easily be changed by changing a cartridge with the specific knife in question or simply the whole milling wheel to a new one with fresh knives. Depending on the steel grade of the rail, different knife quality can be used.

A milling train is typically self-propelled and can operate at a speed of 80Km/h during movements.

The process of milling does not suffer from dust or diesel emissions or sparks, making the process highly suitable for tunnel and bridge work.

Table 1: Description of milling operation with general pros and cons

Machine type	Velocity	Material removal rate	General pros	General cons
<p><b>Milling</b></p> <p>4 + 4 (2 + 2 per rail)</p> <p>Actively propelled milling wheels and fine grinding stones</p>	up to 800 m/h	up to 2mm per pass	<ul style="list-style-type: none"> <li>- The corrective and re-profiling performance with removal rate of up to 2mm per pass</li> <li>- 'As good as new outcome' completely free from rail flaws</li> <li>- Dust and emission friendly process suitable for tunnel work</li> <li>- Facet free</li> <li>- No dismantling of track installations</li> <li>- Can mill level crossings without removal of concrete panels</li> <li>- No slag collection</li> <li>- No fire hazard</li> <li>- Machines normally equipped with measurement system</li> <li>- Can machine greater part of switches and crossings</li> <li>- Fixed milling wheel profile - accurate outcome</li> <li>- Rail measuring does not affect the machine performance</li> <li>- Low noise level during operation</li> </ul>	<ul style="list-style-type: none"> <li>- Requires track possession time</li> <li>- Low relative working speed upon small material removal</li> <li>- Minimum removal rate of app. 0.4mm</li> <li>- Cost ineffective for low material removal rate operations - not optimised for preventive maintenance</li> <li>- Has to stop upon changing milling wheels</li> <li>- Desires people in track</li> <li>- Risk of patch work outcome due to work in track possession</li> <li>- Fixed milling wheel profile - investment necessary to change to unique profile</li> </ul>

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## Appendix C: High Performance Grinding – Lean Analysis of Current Processes

### Executive Summary

This document contributes to Deliverable D4.2 of AUTOMAIN, an EU-funded project aimed at reducing the possession time required for railway maintenance in order to increase overall network capacity for rail freight. The work primarily involved using Lean Analysis techniques to observe and evaluate current maintenance practices in relation to rail grinding, and to compare the approaches taken by a number of railway administrations participating in AUTOMAIN. This work follows on from a previous deliverable focussing on tamping, and as with the previous exercise, two methods were used to evaluate and compare current practices, namely:

- Structured Observations – where an actual grinding shift was observed in detail for each railway administration
- 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

This report details the Structured Observations and VSM workshops, provides analysis and commentary of key aspects such as timings and the proportion of value added activities, and acts as a means of collecting and collating concerns and suggestions from front line staff. The main findings were as follows:

- a high proportion of a typical grinding shift is spent on non value adding activities, and there is scope to reduce overall possession times by reducing “waste” as defined by the principles of lean including:
  - the development of automatic slag collection technology
  - improved on-board measurement equipment to the point that manual on-track verification measurements are no longer required
  - developing machines that have the ability to undertake measurement (both pre and post maintenance) as well as grind in a single pass, ideally using this to evaluate the effectiveness of each grinding pass optimise the next
  - automate the production of maintenance reports and the uploading of these to a central database
  - the introduction of Standard Operating Procedures to reduce errors and drive efficient work practices
- the way maintenance is planned can impact the efficiency and effectiveness of maintenance, and large differences were noted between the planning processes of different administrations – there appears to be scope to improve and refine the planning process by:
  - making better use of the ultrasonic inspection data that is already gathered to generate efficient maintenance plans, ideally integrating this with track geometry information recorded by existing inspection vehicles

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- optimising grinding plans according to the actual volume and type of traffic on a given route
  - ensuring that those responsible for planning grinding activities fully appreciate key factors that influence the success of maintenance possessions as a result of issues including track quality, provision of pre-maintenance site data, possession size and the location of S&C
  - there are a number of technological innovations that would further reduce waste by assisting the planning process:
    - using service vehicles to undertake pre-maintenance inspection of track condition
    - improving the methods to measure, quantify and predict RCF so that a more targeted approach can be taken
  - incentives and performance measures need to be carefully considered in order to minimise overall maintenance and / or drive the efficient use of available possession time:
    - encourage the use of track friendly vehicle designs by introducing differential track access charging to reduce the problem “at source”
    - set maintenance targets that incorporate the quality and longevity of the maintenance undertaken
    - align performance indicators to minimise overall possession time and maximise maintenance effectiveness and longevity
    - ensure that maintenance targets do not result in overly aggressive grinding practices that damage the railhead

There are a number of further developments such as preventative grinding where new technology enables grinding to take place between regular train services, and the increased use of rail milling. While these warrant further consideration, it was not possible to establish the effectiveness of these within the scope of this study. But overall, there does appear to be significant scope to improve current equipment and processes to reduce the impact possession time related to railhead grinding activities.

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## 1. Introduction

The key objective of the AUTOMAIN project is to look at ways of reducing what are predominantly night-time maintenance track closures that impact negatively on rail freight capacity. A preceding work package (reported in Deliverable 2.1) identified tamping and grinding to be the maintenance activities with the greatest impact on longer duration possessions, and tamping was initially selected for further evaluation using Lean Analysis techniques. Following the success of this work, a further piece of work was commissioned to evaluate grinding to looking for best-practice maintenance technologies and procedures, as well as highlighting areas and opportunities for improvement for the future.

The consultancy company KM&T was commissioned to undertake the analysis of a number of typical grinding possessions for three railway administrations, Network Rail (UK), Deutsche Bahn (Germany) and Trafikverket (Sweden). This involved KM&T undertaking a Structured Observation of a grinding shift in each country, along with an office based Value Stream Mapping (VSM) workshop. At the time of writing, only the Deutsche Bahn Structured Observation has been performed, but VSM workshops have been completed for all three railway administrations involved.

As with tamping, the analysis of grinding proved worthwhile, and there were a number of interesting differences noted between railway administrations, as well as a good number of common issues. A comparison with the earlier tamping study also highlighted some interesting points. However, the single Structured Observation does limit the comparison of the relative merits of the practices and processes of different administrations. It is suggested that further observations need to be undertaken to obtain full value from this aspect of the work.

As with the tamping study, the direct output from the Lean Analysis was produced by KM&T, with the University of Birmingham providing support to produce this report, which forms a key contribution to Deliverable 4.2.

## 2. Background Information

### 2.1 The AUTOMAIN Project

The core objective of the AUTOMAIN project is to improve the efficiency of track maintenance to increase the availability of the network for freight traffic<sup>1</sup>. The proposed time horizon for widespread implementation of the proposed changes is in a number of stages, the first of which is 2026 (i.e. fourteen years from now).

### 2.2 The Grinding Process

The action of rail traffic causes track to degrade over time and grinding is the most common method of restoring rail head condition. In the case of corrective grinding, it is commonly used to tackle problems such as Rolling Contact Fatigue (RCF) and rail head corrugations, or to restore the profile of a rail head that has worn to an undesirable or unacceptable shape. It typically involves making an initial measurement of the rail head condition to determine what material removal is required. A number of rotating grinding stones are arranged to remove defects and restore the required profile to the head of the rail through abrasion. The process is both energy intensive and slow – traditional grinding techniques require that the grinding train moves along the track at a slow walking pace (i.e. 6 to 10 km/h). The amount of material that can be removed depends on the particular machine, but it is typically limited to fractions of a millimetre, and several passes may be required to complete the maintenance required.

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<sup>1</sup> A full description of the project and its objectives can be found in the introduction to Work Package 1, Deliverable 1.1



Figure 1 – Rail Grinder in Action (wikimedia)

The grinding stones have a finite lifespan, although they tend to last longer than a typical maintenance shift unless they fail prematurely and need to be replaced manually on-site. The grinding action produces both a significant volume of grinding dust and a large number of sparks, potentially resulting in lineside fires. To combat this, grinders are equipped with water sprays / jets used to dampen down the lineside to reduce the risk of fire, or to extinguish any fires that are started.

Special grinding machines are used on switches and crossings, but this study concentrates only on the grinding of plain line track. On plain line, grinding is done for a number of reasons, typically to improve or maintain the overall quality of the rail head, or remove small imperfections that could result in Rolling Contact Fatigue for example. Other reasons for grinding are to improve or maintain curving performance, or reduce noise emitted from the wheel rail interface commonly by removing corrugations from the railhead (a shallow pattern of unevenness in the height of the railhead that causes noise).

There are generally accepted to be five grinding categories<sup>2</sup>:

- Initial Grinding – This is the grinding of new rails to remove mill scale or defects as a result of the installation process, and it offers an opportunity to correct irregularities at welds for example. The newly installed rails therefore start in as good a condition as possible, thereby delaying the onset of rail head deterioration.
- Corrective Grinding – This is used to remove observed rail surface defects such as corrugation, lipping (i.e. plastic deformation) or fatigue cracks, and it can involve removal of a significant amount of material depending on the defect concerned.
- Symptomatic Grinding – This is where grinding is undertaken as a result of breaching an intervention level for defect size, or as a result of excessive measured noise and vibration, commonly as a result of corrugation developing on the rail head.
- Preventative Grinding – This is where the rail head is maintained regularly in order to prevent railhead issues from developing, and is typically planned in advanced based on tonnage or traffic levels. It typically involves only small amounts of material removal.
- Cyclic Grinding – This is a form of preventative grinding where grinding takes place at fixed intervals identified through experience.

<sup>2</sup> Wheel-Rail Best Practice Handbook, F Schmid, 2010

Alternative grinding techniques are used by certain administrations where, for example, instead of rotating grinding stones, the rail is abraded by stones that oscillate forwards and backwards. This produces a fine surface finish, but only removes a very small depth of material, and cannot be used for rail re-profiling. Its main application is to remove rail head corrugation, particularly in noise sensitive areas.

A further alternative is so-called High Speed Grinding (HSG). Developed by Vossloh, this novel approach has been in commercial use since 2008, and involves unpowered grinding stones set at an angle to the railhead that rotate due the forward motion of the vehicle. This method focuses on preventative, cyclic grinding where the objective is to remove the very thin, hardened rail head surface on a regular basis before cracks or corrugation can initiate. The HSG train runs at speeds of up to 80 km/h, does not require an engineering possession or the removal of track equipment, and can be safely operated over S&C.

### **2.3 Rail Milling & Planing**

Rail milling is another process used to restore rail head profile. This involves cutting the rail head using shaped cutting blades, as opposed to abrasion as used in grinding. Milling is very effective a metal removal, and is typically employed where a significant depth of cut needs to be made for example to:

- remove defects that are quite deep
- restore rail head profile that has suffered significant plastic flow (lipping)
- introduce an entirely new rail head profile.

The process is slower than grinding in terms of working speed (typically around 1.2 km/h), but a greater amount of material can be removed in a single pass. The surface finish also tends to be better than conventional grinding as the profile is contained in the cutting head.

Milling can be viewed as an alternative to grinding, or as a complimentary process, being more effective where the depth of material to be removed is more than about 1mm. It also has certain operational advantages when compared to grinding, with significantly less risk of causing lineside fires, and greatly reduced contamination (unlike grinding, the process generally recovers about 98% of the swarf generated). As such, it may offer advantages in tunnels or high fire risk areas, it can be used alongside tracks that remain open to traffic, and there is no need for manual slag collection or removal of signalling equipment.

Rail planing is also be used, particularly where heavy re-profiling is required. A number of cuts made by special planing “knives” are used to achieve the required profile for the running edges or running surfaces. As with milling, the process produces swarf rather than dust, and there are no sparks to lineside fires.

### **2.4 Lean Techniques and Analysis**

Lean is a proven business improvement methodology that originated from the automotive industry in Japan in the early 1940s. It is essentially a number of simple and robust tools and techniques based around a way of thinking way for ‘continuous improvement’ in order to meet or exceed ever increasing customer expectations. It empowers all levels of a business or organisation to work in an efficient manner, whilst focussing on five key areas of a business: People, Safety, Quality, Cost and Delivery. Within this, a key focus of the lean methodology includes the ongoing identification and elimination of “waste” within an activity, process or organisation which is defined as “anything that the customer is not prepared to pay for”. This can come in several different guises:

	WASTE TYPE	RAIL INFRASTRUCTURE - EXAMPLES
T	Transportation	Excessive movement of raw materials
R	Resources	Lack of employee involvement
I	Inventory	Excessive stock piles of raw materials
M	Motion	Walking from machine to machine
W	Waiting	Waiting for raw materials or permissions
O	Over Processing	Over engineering (making better than it needs to be)
O	Over Production	Excessive finished goods (making too many)
D	Defects	Reworking a product or plan due to error

Figure 2 – The Different Forms of Waste

There are a large number of analysis tools available from the “lean toolbox” that assist with the identification of waste. From these, three core approaches were selected:

- Structured Observations of the maintenance process from an independent third party perspective, noting key parameters such as the timing of key activities and opportunities to reduce waste
- mapping out both the maintenance and planning processes during as series of Value Stream Mapping (VSM) workshops, including the quantification of key parameters wherever possible such as the duration of the task, the manpower required etc.
- production of a Hand Off Diagram which records the roles involved in undertaking the activity and the communication between them

This approach has previously proven successful in a diverse range of companies and organisations, highlighting scope for significant improvement in processes and procedures. It also provides a means and opportunity to re-connect an organisation’s management with what is happening at ground level, and it provides staff with a means of communicating ideas for improvement back up the through the organisation.

## 2.5 KM&T

KM&T is a UK based consultancy firm that specialises in applying lean processes to services, manufacturing and operations in numerous industries. KM&T have helped to improve working processes for some of the world’s largest organisations and identify efficiency savings worth millions of pounds a year. Toyota is regarded as the world’s foremost developer and users of lean principles and methodologies, and KM&T was set up to apply this approach and techniques to other companies and industries. A large proportion of KM&T consultants are ex-Toyota employees with first-hand experience of lean approaches.

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### 3. Summary of Work Undertaken

The Lean Analysis for grinding was undertaken by KM&T, starting in February 2012, and involved the following railway administrations:

- Deutsche Bahn in Germany
- Network Rail in the UK
- Trafikverket in Sweden

Value Stream Mapping was undertaken for all three administrations, and Structured Observations have (or are shortly to be) completed for Deutsche Bahn and Network Rail. Due to political issues in Sweden, it was not possible to undertake a Structured Observation for Trafikverket.

#### 3.1 Structured Observations

Structured Observations were undertaken for a single maintenance possession with each event attended by KM&T representatives observing the full maintenance shift, from initial safety briefing through to handing back of the line. Key timings and observations were recorded, and the utilisation of time was subsequently broken down into 3 generic categories:

- value added activities
- necessary non value added activities
- non value added activities

This information was then presented in graphical format, along with a summary of the observations made during the course of the visit.

It is important to note that Structured Observations are usually done for very similar or notionally identical tasks which share common aims and objectives. It would have been difficult and time consuming to arrange observations for directly comparable grinding shifts across railway administrations. So a decision was taken to observe broadly similar possessions, accepting that there would be differences in the type of grinding machine used, the aims and objectives for the possession etc.

#### 3.2 Value Stream Mapping (VSM) Workshops

A VSM workshop was undertaken either prior to or shortly after the Structured Observation sessions, attended by experienced machine operators and maintenance planners, hosted and directed by representatives from KM&T. Each workshop followed a standard pattern:

- the various steps involved were mapped out through discussion amongst attendees
- key parameters such as process times were estimated based on the experiences of those present
- concerns and ideas for improvement were elicited from those present, supported by observations made by KM&T from their Structured Observations

As stated previously, the objective of AUTOMAIN is to increase the efficiency of track maintenance in order to increase track availability. While this could potentially be viewed purely as relating to the actual grinding process, in terms of the overall availability of track, the planning process is also widely considered to be important. For example, the maintenance needs to be carefully planned to avoid waste, ensuring that the right machine and staff are sent to the right location at the right time, supplied with appropriate background information / data and objectives.

It was therefore considered important to map out not only a typically maintenance possession, but also the planning process leading up to that possession. The mapping process itself was undertaken by placing “Post-It Notes” on a large roll of backing paper on the wall of the room as shown in the photograph below:



*Figure 3 – Example Value Stream Mapping Workshop (Network Rail VSM)*

Each vertical line of Post-It Notes represents a different step in the process, with pink notes being used for non value added activities and green notes for value added activities. Beneath the description of each step in pink / green are further notes which was used to gather estimates for key parameters including:

- cycle time for each step (how many hours it take to complete a particular step)
- manpower required
- operation frequency (how many times a particularly task is undertaken for a particular process)

Beneath these are further rows of notes to record concerns and ideas for improvement. Ideas generated that were not specific to a particular step were recorded in a separate area.

Following this analysis, a Hand-Off Diagram was produced to detail the communications that takes place between different roles during the planning and execution stages. This was used to demonstrate the complexity of interactions between those involved. An example diagram is shown below:

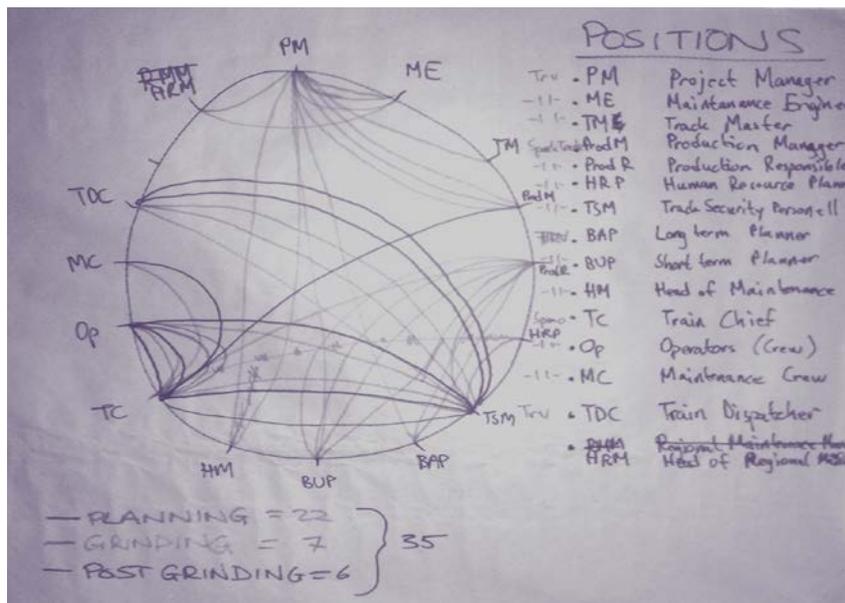


Figure 4 – Typical Hand-Off Diagram (Trafikverket VSM)

#### 4. Findings – Structured Observations

Only a single Structured Observation was undertaken for Deutsche Bahn due to difficulties with making suitable arrangements with other railway administrations. Comparisons were however drawn between the observed grinding shift and tamping shifts observed previously as part of Work Package 2. Comparisons are made below as appropriate.

##### 4.1 DB Structured Observation

The DB grinding shift took place on the 8<sup>th</sup> February 2012 between Mündling and Otting-Weilheim, part of the original mainline north from München to Nürnberg which carries a mix of passenger and freight. The shift was undertaken at night and had a planned duration of 480 minutes (8 hours) with the work to be undertaken within a possession lasting 405 minutes (6¾ hours). The maintenance was being undertaken for preventative reasons, and several grinding passes were made. It involved a Speno 48 stone grinder with a 10 km/h maximum grinding speed and a 100 km/h maximum transit speed, operated by a crew of 12:

- 2 drivers – responsible for train movements
- 2 operators – responsible for monitoring and controlling the operation of the grinding stones
- 1 supervisor – accountable for meeting shift targets and responsible for taking decisions on-site as a result of unexpected issues or problems
- 4 slag collectors – responsible for collecting the lumps of grinding dust that can build up on the machine and then break loose sporadically and fall on to the track
- 3 safety representatives – primarily responsible for those working on the track

A detailed breakdown of the work steps observed is contained in Appendix A, and is summarised in the pie chart shown in Figure 5. According to the definitions of waste as defined by the principles of lean analysis, activities were categorised as value added (green), necessary non value added (yellow), and non value added (red).

Although machine checks were done, these occurred prior to and then following the maintenance shift, and did not limit or impact on the amount of grinding that could be achieved within the shift. They have therefore been excluded from the figures presented.

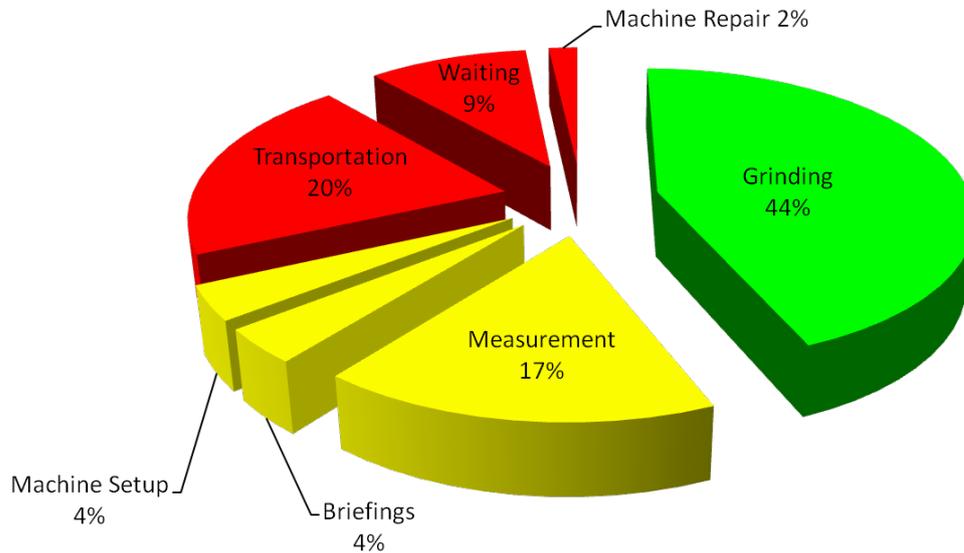


Figure 5 – Breakdown of DB Grinding Shift

Only a limited proportion of the overall time available was actually spent on the primary value added activity of grinding (44%). The remainder was taken up by various necessary non-value added activities such as measurement runs, briefings and machine set up, accounting for 25% of the overall shift, and non value-added activities for the remaining 31%, including transportation to, from and within the worksite, time spent waiting and as a result of a mechanical failure.

It was also noted that there was significant contingency, with the grinding completed in 305 minutes, i.e. 100 minutes less than 405 minute possession time allowed for (6¾ hours).

## 5. Findings – VSM Workshops

The Value Stream Mapping (VSM) workshops were used to map out both the planning stage and a typical maintenance possession. As with the previous tamping VSMs, it was felt important to include the planning stage to elicit planning or process related issues that could impact on the overall effectiveness of the maintenance undertaken.

### 5.1 Proportion of Value Added Steps

Similar to the previous tamping study, the overall proportion of value added activities was low. Averaged across the three administrations, there were only 1 or 2 value added steps out of a total of 35 for planning and undertaking a typical grinding shift. This suggests that there is scope to simplify the process, potentially reducing errors and the amount of time taken.

### 5.2 Overall Planning Complexity

There was a large variation between administrations in the number of work steps involved in planning a maintenance shift, from 7 at NR, to 18 for DB and TRV. A degree of variation would be expected due to

differences in network size or traffic density for example, and it is noted that for Step 4 of the Network Rail VSM relating to the booking of possessions states that there was “lots of to and fro – simple system not in place”. Yet this is recorded as a single step. But even accounting for these, the scale of variation suggests that there are fundamental differences in approach between administrations.

This variation could be as a result of the tendency for processes to become more complex over time. It is interesting to note that grinding was only recently re-introduced on NR following the derailment at Hatfield in October 2000. It is also possible that the relatively recent re-introduction of grinding on NR may have provided an opportunity for a ‘clean sheet’ approach to develop efficient and simpler processes and procedures.

A further observation made was that the overall number of work steps involved in planning a grinding shift (an average of 14) was lower than that for tamping (an average of 24). A degree of difference would be expected according to the detail with which the workshops were conducted. But even accounting for this, it would appear that grinding is simpler to plan than tamping. Possible reasons for this could be that tamping involves a higher degree of intervention in the track and supporting ballast than grinding. Tamping also requires a greater degree of coordination with other aspects such as pre-measurements, the provision of additional ballast and the re-profiling of that ballast for example, each of which need to be individually planned.

### ***5.3 The Planning Period / Lead Time***

There was also a surprising difference between administrations in the lead time for planning grinding possessions, with TRV at one extreme at 12 months, and NR at the other extreme at 48 months. This would initially appear to contradict the findings of Section 5.2 where NR have significantly fewer planning steps. One possible explanation suggested for this is that NR may have a simpler planning process that can be undertaken well in advance, but this does warrant further investigation.

### ***5.4 Cycle Time***

The total cycle time (i.e. the total amount of time spent on planning and undertaking maintenance) was estimated from the information collected, and this varied significantly from approximately 500 minutes for both NR and TRV, to 3 000 minutes for DB. This is again a wide variation, which suggests a much simpler approach is currently being adopted by NR and TRV.

### ***5.5 Resource Levels***

There were quite different levels of resources between administrations, with 44 roles involved with DB, and 19 for NR and 18 for TRV, again suggesting a very different approach is taken between administrations with quite different organisational structures.

### ***5.6 Hand-Off Analysis***

The analysis of the number of hand-offs supported the view that the processes and procedures used by DB are quite different with 58 hand-offs versus TRV with 35 and NR with just 20. There tends to be a strong correlation between the level of resources and the number of hand-offs as is the case here.

### ***5.7 Statistical Analysis of Concerns***

Each workshop prompted attendees to raise concerns relating to each of the work steps, each of which was then documented by KM&T. This was followed by the generation of ideas or opportunities for improvement to help address the concerns highlighted.

The number of concerns raised was generally lower than that for tamping, with between 11 and 25 concerns raised at each grinding workshop, rather than 40 or 50 for tamping. These were split according to whether they

related to the planning stage, the maintenance shift, or to activities that occur following maintenance. An assessment was also undertaken of the number of concerns that have the potential to impact on possession efficiency as shown in Figure 6.

Rail Company	Planning Concerns	Impact on Possession	Grinding Concerns	Impact on Possession	Post Concerns	Impact on Possession
Deutsche-Bahn	13	8	12	11	2	1
Trafikverket	5	1	6	6	3	0
Network Rail	13	4	5	5	6	2

Figure 6 – Number of concerns raised at VSM Workshops

As expected, the largest number of concerns related to the actual possession itself, but there were almost as many relating to the planning stages. This supports the view that planning is a key component in ensuring possession efficiency. A second categorisation was then done, breaking down the concerns into one of eight categories, which was then filtered to select only those concerns considered to have a large impact on the efficiency of the possession according to the likelihood of their occurring, and the impact that they would have. The results are shown in Figure 7.

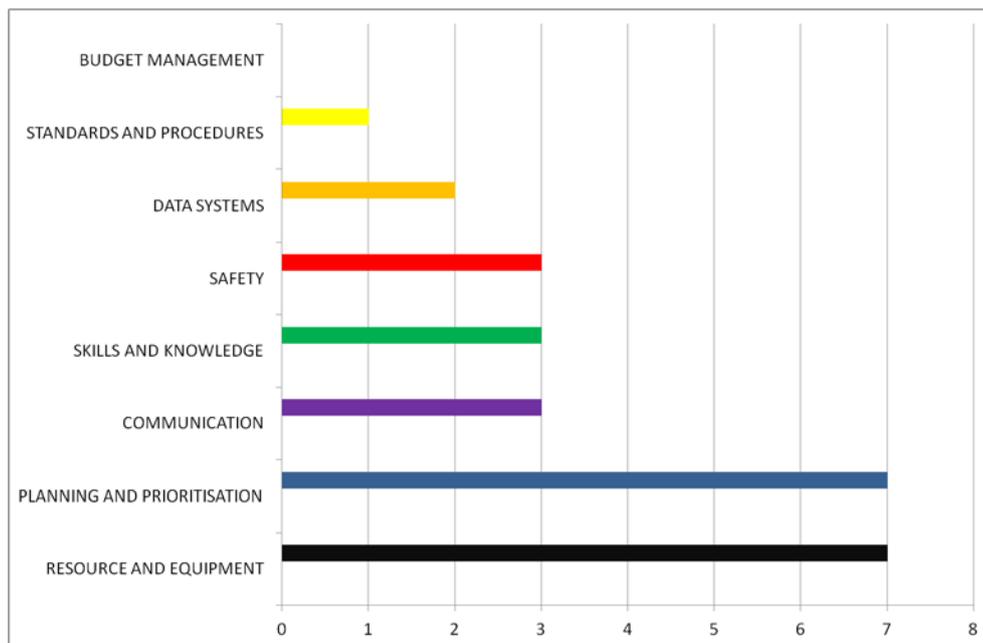


Figure 7 – Categorisation of Concerns from VSM Workshops

Categorised and filtered in this way, there greatest number of significant concerns related to planning and prioritisation of maintenance and also to resources and equipment.

### 5.8 Specific Concerns

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Looking at specific concerns raised during the workshops, there were a good number relating to the planning stage which have the potential to impact on the amount or efficiency of maintenance undertaken. These are summarised below, with the key issues common across administrations summarised in Section 1.1.6:

- there seems to be a lack of appreciation by planners that certain activities at the planning stage can impact the efficiency of a given maintenance possession – these factors can include the quality of track data available to the grinding crew, the impact that machine and crew selection can have on productivity, and the implications of possession size and route planning
- there is a degree of variation in the understanding and interpretation of track maintenance standards, which in turn increases the risk of items being missed or tasks being performed incorrectly
- sometimes less track is ground during a possession than the machine and crew are capable of due to budgetary / financial restrictions where a contractor is paid according to the length of track that is maintained
- insufficient asset knowledge about specific track locations occasionally results in sub-optimum maintenance plans and / or safety plans being developed, resulting in poor productivity
- inaccurate data on track condition can result in poor decision making as to where and how much to grind
- the lack of availability of appropriate machines, crews and machine stabling can result in plans having to be re-worked which can reduce overall maintenance efficiency and productivity
- there are issues relating to the approach taken to maintenance that crosses zonal boundaries which mean that maintenance is not planned as efficiently and effectively as it could be
- asset management systems do not track the benefits of the grinding that is undertaken – if they were to do so, this information could be used to better inform future maintenance requirements and plan more effectively
- the data currently collected and used to plan grinding activities tends to be insufficient and often inaccurate, and quite often needs to be supplemented by time consuming track visits

In terms of the maintenance possession and grinding activity, concerns raised included the following:

- delays in entering or leaving a possession can be caused by poor communication between rail operators, safety controllers and maintenance staff
- maintenance activities are often given only low priority, and there is a lack of follow-up or consequences where delays are caused to maintenance due to issues with late running train services
- the response of rail operators to requests made by the grinding crew can be very slow, hindering the amount of work that can be undertaken
- the unavailability of crew can have significant impact on the safety and quality of the work undertaken
- there is a lack of understanding of the importance of maximising the value added activities within a shift, due at least in part to a “this is how we have always done it” mindset, bolstered by a questionable stance that the duration of certain activities cannot be curtailed due to safety reasons

- the low visibility of standard operating procedures can result in variation in how maintenance is performed (for example where crew members operate the grinding machine in a different way), which in turn increases the risk that things are missed or done incorrectly
- it is suggested that there is a sub-optimum balance between time and quality, where time is prioritised at the expense of future maintenance requirements – for example, conventional grinding trains are sometimes used at higher production rates than they are designed for – this can take one of two forms:
  - an overly aggressive depth of cut is used where material is removed at too high a rate
  - the forward speed of the grinder is too high, regardless of the depth of cut
- this can damage the head of the rail either through the formation of brittle Martensite due to the generation of excessive heat, and / or as result in poor surface finish in terms of rail head roughness and a less accurate ground profile
- the above practices tend to be due at least in part to incentives or targets that are based purely on the length of track to be maintained
- the risk of lineside fires and the occasional lack of sufficient water can occasionally curtail a maintenance shift
- a lack of mandated corrective action if grinding fails to meet quality requirements, and no system to check whether repeated grinding cycles achieve the required improvement.
- slag collectors are generally slower than the machine, resulting in delays and reduced productivity
- if a transit slot is missed, only low priority is given to maintenance vehicles and it can be up to an hour to get another slot
- related to the above, grinders frequently have to transit a long distance from their stabling point, leaving little time for the actual grinding within a given possession
- it is not uncommon for access to and from stabling points is blocked by other equipment, trains of maintenance vehicles, reducing the amount of work that can be undertaken
- the quality of the track needs to be to a certain standard in order for grinding to be undertaken effectively, and the checks done to make sure this is the case are insufficient (i.e. sometimes the track is of insufficiently good vertical and lateral alignment to get the best out of grinding)
- the post maintenance paperwork and signing off procedures are not always completed quickly or sufficiently well, which then has a knock-on effect for following shifts – it was suggested that the reporting system need to be improved
- KPIs on certain administrations are based on the number of grinding shifts undertaken, rather than the amount of grinding done, and this can result in a less than optimum or potential maximum being achieved for a given shift

### ***5.9 Specific Opportunities***

There were a number of specific opportunities for improvement generated by the workshops, which have been summarised below according to whether they relate to the planning or grinding stages, or are more general in nature. The key opportunities common across all administrations are summarised in Section 1.1.6.

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### **Planning Related Opportunities**

- better use could be made of the grinding capacity of modern machines if there were more efficient route planning, and short worksites were avoided in particular
- if production targets were better aligned to possession durations, this would make better use of limited resources, noting that if there is insufficient contingency, there is a risk that a second possession might be required
- moving to an increasingly preventative grinding strategy would make the planning of maintenance activities much easier and more efficient, particularly in relation to the coordination of maintenance activities with planned train services
- preventative grinding may be more effective on a Life Cycle Costing basis, removing defects before they require more invasive and disruptive intervention
- monitoring the effectiveness of the maintenance that is undertaken could be used as an input to the planning of future grinding requirements
- on certain administrations, responsibility for maintaining the infrastructure is split into several geographic areas or “zones”, and occasionally track maintenance is only planned and undertaken up to the boundary of that zone, where it might be more efficient to carry on across the zonal boundary up to the next set of S&C for example
- track maintenance that overlaps zonal boundaries could be consolidated into a more efficient single maintenance plan
- having a skills matrix would help ensure that the correct staff are always allocated for a given maintenance activity
- any improvements to the accuracy and frequency of measurement of Rolling Contact Fatigue would help improve the ability to plan effective preventative grinding programmes

### **Maintenance Shift Related Opportunities**

- if better on-board measurement equipment were available on grinding machines that could replace those activities which are currently undertaken manually on-track, this would reduce machine idle time and increase both productivity and safety
- the increased use of (or development of) machines that have the capacity to grind at higher speeds or remove more material in a single pass (ideally double) would also increase productivity – for example, if it were possible to undertake conventional grinding at say 15 km/h this would go a long way to meeting AUTOMAIN’s objectives
- the automation of post grinding reports and their submission to planning and business management software would result in better information upon which to base future maintenance decisions
- having a central database or computing cloud would help ensure that access to required data can be achieved remotely at all times, increasing maintenance efficiency and reducing the number of unexpected issues encountered on-site, thereby reducing contingency and increasing productivity

- the local supervisor could be given greater responsibility for planning and decision making during the possession, but this would be dependent on the local supervisor ensuring that he / she reviews the track information relating to that site in much greater detail prior to arriving on-site
- in the event of machine breakdown, developing a more efficient way of getting spare parts to the machine crew would greatly reduce down time
- it ought to be possible to develop and implement a system that evaluates each grinding cycle and uses this as an input to control the following cycle(s) to optimise the grinding process, thereby potentially requiring fewer passes to achieve the same or satisfactory results

### **General Opportunities**

- although unlikely, if it were possible to increase the availability of machine storage locations, this would help reduce non-value added transit times
- it may be possible to develop wheel profiles that reduce track degradation and suspension systems that help prevent issues such as RCF and corrugations
- high speed grinding has the potential to be used between regular service trains, thereby eliminating the need for possessions – this is the approach advocated by ProRail in particular who increasingly operate high speed grinders at speeds of between 60 – 80 km/h
- on certain administrations, better use could be made of the existing ultrasonic profile data when planning grinding shifts, resulting in a more focussed and efficient grinding plan
- there is scope to better optimise grinding plans on a route by route basis, or according to the type of train fleet that uses that route using enhanced planning software
- having longer term budgets would enable a more strategic and efficient approach to be taken to planning and undertaking maintenance
- enable grinders to operate over axle counters without requiring their prior removal – this would increase productivity (similarly for rail lubrication equipment) or alternatively, only fit them to the rail that is least likely to require grinding (similarly for rail lubrication equipment)

## **6. Summary of Key Concerns & Opportunities**

A review was undertaken of key concerns and opportunities that were common across administrations, split according to a number of categories as shown in Figure 8 below:

Category	Current State	Recommendation	Benefits
Budget Management	Initial budget not always fully allocated resulting in reduced maintenance activities and planning rework.		
Data Systems	Poor quality inaccurate data, affecting clear visibility of track conditions, resulting in wrong decisions being made on where & how much to grind.	Develop Robust Infrastructure database, and data systems to predict track degradation. Structured geometry data collection, based on maintenance needs.	Optimisation of the frequency and accuracy of the data collected has the potential to improve long and short term planning accuracy.
Safety	High risk of track side fires during drier shifts.	Plan to minimise maintenance in fire sensitive areas during high risk times of the year, possibly providing a water train where this is not possible.	Reduction in fire risks and increased productivity.
Skills & Knowledge	Variations in staff skills and knowledge causing performance issues during planning and grinding phases.	Robust training systems outlining best practices to ensure all employees and contractors are trained to a equally high level.	Training helps increase the job knowledge and skills of employees at each level. It helps in understanding and successfully carrying out everyday tasks as well as organisational policies
Communication	Poor communication between track officials and the grinding crew cause delays in entering and leaving possession zones.	Structured communication procedures.	Improved organisational awareness of direction, pace and priorities. Improved alignment towards common goals.
Standards & Procedures	Variation in standards across and within the administrations. These variations shows that some activities are over engineered, lengthy, complicated processes in one region, but a simplified, efficient, effective in another.	Development of structured work sequence Standard Operating Procedures (SOPs).	The development and use of SOPs for the grinding process will minimise variation across the regions and promote quality and efficiency.
Resource & Equipment	Crew and machine selection not always optimised or aligned with shift targets.	Create systems to accurately align relevant skill set crew to machine type.	Most flexible machines and crew are utilised. Higher output achieved in higher % of operations.
Planning and Prioritisation	Logistics, resource, equipment and material are often overlooked during the planning phases, which have the potential to impact on possession efficiencies. Track maintenance is not recognised as a priority by rail officials, causing lengthy delays to possession arrival, entrance, and exit.	Systematic selection and allocation process to ensure that the most flexible, effective machines and resources are selected, along with the best stabling points, and efficient route to the possession zone. Involve rail officials in the creation of the plans to help create a sense of responsibility and accountability.	Ensures that all potential risks to possession efficiency are identified and mitigated. Improved global awareness of direction, pace and priorities. Better understanding of how their role plays a part. Improved alignment towards common goals.

Figure 8 – Summary of Key Concerns & Opportunities

## 7. Conclusions

As with tamping, Lean Analysis techniques have proven helpful in bringing issues and potential solutions relating to grinding to light, and they provide a channel of communication between staff and the management of railway administrations. While the analysis would have benefitted from comparing a greater number of structured observations, it has highlighted interesting differences between tamping and grinding. There are also a number of areas and potential initiatives that warrant further investigation.

### 7.1 Key Findings

The key findings from this study were as follows:

- As with tamping, a high proportion of a typical grinding shift is spent on non value added activities, and there may be scope to:
  - reduce the time spent travelling to the worksite, an issue which is likely to get worse with the tendency to remove lightly used switches and sidings
  - reduce the time spent traversing the possession in order to maintain several small worksites
  - remove the need for the manual collection of slag from the track following the passage of the grinder, which would also potentially remove the need for the safety representatives
  - get rid of the requirement for a separate pre and post-maintenance measurement runs
- For the Structure Observation undertaken, the grinding was completed in significantly less time than planned (i.e. there was a large amount of contingency). It is not clear whether it is normal practice to include large contingencies, or whether there were special circumstances on this occasion. But it does suggest that there may be scope to make better use of the full planned possession time, or reduce the duration of possessions if these contingencies can sensibly be reduced.
- Although the greatest number of concerns raised during the workshops related to resources and equipment, a high proportion related to the planning stages (i.e. all planning activities up to the day of the maintenance shift), suggesting that the planning process has significant potential to impact on the effectiveness and efficiency of the maintenance undertaken. In particular:
  - concerns over the effectiveness of the allocation of manpower and machinery
  - questions over the maintenance strategies and whether alternative grinding strategies would be more effective
- There were unexpectedly large differences observed between administrations in terms of the complexity of the planning process, with one having a much higher cycle time, resource level and number of hand-offs than the others, yet with a relatively short lead time. This suggests that very different approaches are taken by different administrations.
- It is surprising just how few work steps were recorded for the NR planning stages, suggesting that it has the simplest planning process, although it has not been established whether this is also the most effective.
- It is interesting that machine checks were done prior to and subsequent to the core part of the maintenance shift. This is in contrast to the tamping shifts observed previously where machine checks were typically performed on-site.
- The need to collect slag manually and to go on-track to verify and check the accuracy of the grinding undertaken requires a large number of staff and can constrain overall productivity.

Concerns were also raised during the review of this report that damage can be caused to the head as a result of aggressive grinding practices, where excessive working speeds and / or depths of cut are employed. This tends to be as a result of production targets being set according to the number of metres to be ground, or payment according to the length of track maintained, without adequate consideration of the quality of grinding undertaken.

It was also highlighted that the way the track is trafficked can influence the rate of deterioration of the rail head, and therefore grinding frequency. Key factors such as the volume of traffic, axle loads, primary suspension

stiffness and wheel profile / condition can have a large impact, and a proportion of track access charges in the UK for example is set according to predicted level of damage different vehicle types are likely to do.

## **7.2 Recommendations**

### **Equipment, Technology & Machine Operators**

There are a number of possible enhancements to grinding machines or changes to the crews that operate them that would mean better use is made of available possessions time:

- Machine manufacturers should be encouraged to investigate and develop a number of potential improvements including:
  - modify machine design so that manual slag collection is no longer necessary
  - improve on-board measurement equipment so that manual on-track measurements are no longer required
  - related to the above, develop a system to evaluate the effectiveness of each grinding pass and use this to optimise the following one
  - increase metal removal rates to either enable machines to work at higher speeds, or remove more material in a single pass
  - automate the production of post-maintenance reports and the uploading of these to the central database, possibly making use of modern internet based approaches such as cloud computing
- It is likely that the developments suggested above would increase the first cost of the machine, and in order to support this, a whole life cost / benefit model or for a conceptual advanced design ideally needs to be undertaken.
- Investment in modern grinding machines capable of the simultaneous grinding and recording of post ground rail head condition would mean that post maintenance measurement runs are no longer required. Such machines are also capable of simultaneously undertaking detection and measurement of RCF to assist with the planning of future maintenance requirements.
- Develop a means of grinding in areas equipped with axle counters that does not cause damage to them, or install axle counters that are unaffected by grinding. Where possible, fit axle counters to the rail that is least likely to require grinding. Similarly for rail lubrication equipment.
- Considerations should be given to devolving authority and responsibility for planning and decision making during a given possession to the grinding supervisor on site, on condition that he or she make themselves fully aware of relevant background information relating to the possession and the work site(s).
- Although not part of this scope of work, it would be helpful to understand how reliable grinding machines are and how often technical problems in-service affect productivity. Related to this, would be an investigation into which spare parts most often delay repair to machines in service, and the development of plans for either local storage or rapid deployment of these parts to reduce down time in the event of a breakdown.
- The requirements for stabling for maintenance machinery need to be considered and incorporated into route utilisation strategies, if not already done so.

- There may be scope for increased use of road / rail machines such as the ones developed by Speno, Linsinger and Railquip to help address the problems with stabling and lengthy transits to and from work sites.

Although not a direct finding from the VSM workshops or Structured Observation, it is likely that having maintenance crews trained to be multi-skilled could be advantageous. It would potentially increase planning flexibility, reduce the number of shifts cancelled or curtailed due to staff shortages, and potentially release budget and manpower to run additional shifts and / or machinery.

### Planning

There are a number of improvements relating to the planning of grinding possessions:

- Investigate and ideally improve the use that is made of the ultrasonic inspection data that is already gathered.
- Provide improved planning systems (probably software based) that can be used to optimise grinding plans on a route by route basis according to the traffic each is expected to see.
- On administrations where this is not already standard practice, integrate information into the above from ultrasonic inspection vehicles and track geometry recording cars. This improves maintenance planning and helps ensure that track quality (i.e. vertical and lateral alignment) is sufficiently good for grinding to be effective.
- Ensure there is a good level of appreciation amongst those responsible for planning maintenance of the impact of on the efficiency of possessions of key issues like track quality, provision of pre maintenance site data, possession size etc. This could potentially be achieved through training, on-track experience or workshops for example.
- Reduce the number of short work sites either through enhanced planning tools, or the increased use of preventative grinding.
- Improve the alignment of production targets with possession durations, ideally taking into account factors such as fire risk, the quality of vertical and lateral geometry etc.
- Plan possessions according to the location of S&C, and consolidate sections across zonal / geographic boundaries where it makes sense to do so.
- Budgets for grinding need to be set with a longer term view to increase the efficiency and effectiveness with which maintenance can be planned.
- There is a need for improved systems to measure and quantify RCF, as more frequent and accurate measurement would result in better maintenance planning and the more efficient and effective use of resources.
- Where appropriate, the movement of maintenance should be given higher priority, and the introduction of penalties where delays are caused by train services should be considered as one possible incentive for this.

### Strategy & Incentives

- The relative merits of reactive versus preventative grinding warrant further investigation. Preventative grinding has the potential to improve maintenance planning, coordination with train services and more efficient use of possession time to maximise production rates.
- The development of a skills matrix would help ensure that the correct staff are always allocated for a given maintenance task, it would identify skill set development gaps and training needs, and could promote greater flexibility in train crew and machine operators.
- KPIs need to be re-thought by certain administrations to better reflect and incentivise the value of the work undertaken.
- Maintenance targets need to be set that include the quality and longevity of the maintenance undertaken, not just for the overall length of track that is to be maintained within a given time period. Development of additional acceptance criteria may be necessary to prove the quality of maintenance.
- Combining preventative maintenance activities such as tamping and grinding would potentially reduce overall possession time, although this would need to be balanced against the additional planning effort required.

#### **General**

- Further investigation is needed to determine the reasons behind the apparently very different levels of planning complexity and to assess whether there is scope to apply best practice to improve overall efficiency.
- As with tamping, an international exchange of experiences, especially for high output machines, would also increase the knowledge of machine operators, and a system showing the national availability of maintenance resources (both manpower and machinery) would help mitigate the difficulty encountered with aligning resources and maintenance requirements.
- The amount of contingency allocated within a given shift for fire fighting for example could be use reduced depending on seasonal or predicted weather conditions.
- As with tamping, it may be possible to run the grinder as a “slow moving train” in order to simply possession arrangements, effectively eliminating the non productive time spent taking and handing back possessions. Further investigation into whether this is a realistic possibility is needed, acknowledging that companies such as Vossloh already have experience of operating grinding trains between trains services.
- There needs to be increased adoption of Standard Operating Procedures to drive correct behaviour and help error proof the process.
- Using service vehicles to undertake pre-maintenance inspection of track condition prior to a maintenance shift could help optimise the use of the limited time available during possessions, or reduce overall possession time for a given maintenance requirement.

It is also recommended that additional Structured Observations be undertaken so that a more revealing and meaningful comparison can be made between the grinding practices of different administrations, and ideally between different machine types and grinding strategies and methodologies.

## Appendix D: Supplemental Report on the Use, Benefits and Limitations of Stoneblowing

### Executive Summary

This document is a supplemental report commissioned by the AUTOMAIN partners involved in Work Package 4.3 of AUTOMAIN, an EU-funded project aimed at reducing the possession time required for railway maintenance in order to increase overall network capacity for rail freight. The work involved undertaking research into the use, benefits and limitations of stoneblowing, an alternative track maintenance process developed in the UK over the last 30 years.

The objective for this study was to provide an unbiased review of the technology and any potential it may have to assist with meeting the aims and objectives of the AUTOMAIN project. The report is based on a review of published papers, presentations and interviews with those responsible for developing and operating stoneblowers. The main findings were as follows:

- the UK experience of stoneblowing is positive, with the process regarded as a well proven means of achieving stable and durable track geometry
- it has been successfully employed on all categories of UK track (with the exception of HS1), and Network Rail intend to acquire a replacement fleet of stoneblowers when the current machines reach the end of their service life
- it has been used extensively to defer ballast cleaning or renewal at sites with poor ballast condition, is regarded as an effective measure for treating wet spots, and the latest generation of machines are proving popular for the treatment of S&C
- stoneblowing does less damage to ballast than tamping, although this does depend on the strength and quality of the ballast concerned

In terms of meeting the objectives of AUTOMAIN, stoneblowing has the potential to reduce the overall time required to maintain track condition and geometry:

- UK experience is that the geometry of track treated with stoneblowing is typically 2 to 3 times more durable than tamping, although this needs to be balanced against the higher production rates achieved by modern continuous-action tampers
- the reduction in damage to ballast has the potential to extend the interval between disruptive ballast cleaning and track renewals
- stoneblowing offers an effective means of treating problematic areas such as wet spots, and can be used to defer disruptive ballast cleaning at near life-expired sites

Stoneblowing appears to have the potential to help meet the objectives of AUTOMAIN as a complimentary process to tamping, and further study is warranted to quantify the potential savings in terms of overall possession time.

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## Glossary

alignment	Lateral track geometry.
applied lift	The amount the track is lifted during maintenance.
DB	Deutsche Bahn.
DTS	Dynamic Track Stabilisation – a method used to consolidate ballast by vibrating the track to replicate the action of passing traffic.
fines	Small ballast particles and ballast dust that occur as a result of the action of normal traffic over ballasted track, or as a result of maintenance.
formation	The supporting structure beneath the ballast layer that transmits the load from the track to the ground.
lift	The amount by which the track is lifted vertically at a particular location.
MGT	Million Gross Tonnes.
overlift	A process by which the track is lifted higher than desired to account for settlement due to the action of subsequent traffic for tamping, or to enable stone to be injected for stoneblowing.
residual lift	The amount of lift that remains following maintenance.
S&C	Switches & Crossings.
slew	The amount by which the track is moved sideways at a particular location.
tamping bank	A set of metal tines inserted either side of a sleeper in order to effect a change in height by squeezing and vibrating the ballast beneath the sleeper.
tines	The metal “spades” on tamping machines that are inserted into the ballast to vibrate and squeeze ballast beneath the sleepers.
top	Vertical track geometry.
TSR	Temporary Speed Restriction

## 1. Introduction

The key objective of the AUTOMAIN project is to look at ways of reducing what are predominantly night-time maintenance track closures that impact negatively on rail freight capacity. A preceding work package (reported in Deliverable 2.1) identified tamping and grinding to be the maintenance activities with the greatest impact on longer duration possessions, and tamping was initially selected for further evaluation using Lean Analysis techniques, as reported in Deliverable D2.2.

An alternative track maintenance process has been developed in the UK called stoneblowing which has been in widespread use on UK mainlines since 1999. In order to investigate whether this technology could help meet the objectives of the AUTOMAIN project, this supplemental report was commissioned to review the technology, the operational experience gained since its introduction, its potential benefits and limitations.

This research was undertaken by the University of Birmingham, and edited by John Amoore Senior Research Specialist at Network Rail. Research was undertaken during the period of August to November 2012 using the following sources:

- internet searches for published papers
- interviews with those responsible for developing and operating stoneblowers
- a presentation given at the University of Birmingham on the subject in January 2012
- a review of key publications and texts

This initial draft is intended for internal circulation, review and discussion by partners working on Work Package 4 of the AUTOMAIN project.

## 2. Background Information

### 2.1 The AUTOMAIN Project

The core objective of the AUTOMAIN project is to improve the efficiency of track maintenance to increase the availability of the network for freight traffic (a full description of the project and its objectives is contained in the introduction to Work Package 1, Deliverable 1.1). The proposed time horizon for widespread implementation of the suggested changes is in a number of stages, the first of which is by 2026 (i.e. fourteen years from now or earlier if possible).

### 2.2 Track Degradation

The action of rail traffic causes ballasted track to degrade over time. The high dynamic loads cause the track to move and settle, and abrasion between particles of ballast, and ballast and sleepers gradually reduces its ability to interlock and maintain sufficient vertical and lateral resistance. The track has to be lifted and slewed (i.e. moved sideways) at regular intervals to restore the required level of vertical and lateral track quality, typically using tamping machines. In the UK only a stoneblowing process is also available for the restoration of track quality. However, the intervals between track maintenance cycles tend to get shorter the older the track becomes as the ballast gradually becomes less angular and less able to form a strong interlocking structure.

Eventually, the ballast can get to a point where it becomes un-maintainable (sometimes referred to as “un-tampable”) and it has to be cleaned or renewed. In the case of ballast cleaning, a machine equipped with cutting chains typically scrapes out the existing ballast, sieves it to remove the fines, then replaces the larger

ballast particles along with a proportion of fresh stone under the track. This process is then followed by Dynamic Track Stabilisation (i.e. artificially vibrating the track to settle), and then tamping to restore vertical and lateral alignment.

The initial quality of the track and its supporting formation greatly affects the rate of deterioration – high quality track and formations tend to have longer intervals between maintenance, while track that is near to being life expired can require far more frequent attention. It is important to note that the cause(s) of poor track top and alignment can be caused by problems that run deeper than the top ballast layer. Where this is the case, even when the track has been maintained to bring the local geometry back to a good standard, faults can re-appear after a relatively short duration in traffic.

### **2.3 Measured Shovel Packing**

Prior to the introduction of tamping, track in the UK was largely maintained by hand using a technique known as Measured Shovel Packing. This involved attaching sighting boards to sleeper ends and then measuring the vertical deflection of the track as a train passes. The amount of vertical deflection would then be translated into the quantity of fresh stone to be shovelled in underneath each sleeper, bringing the track back to an acceptable vertical geometry. This maintenance practice was capable of producing a good quality, durable track profile, but was time consuming and labour intensive.

### **2.4 Tamping**

Tamping was developed in the 1950s in order to automate and speed up the process of track maintenance. Tamping is the most common method of restoring vertical and lateral track quality. It typically involves making an initial measurement of the existing track geometry to determine what lifts and slews are required along a given length of track (i.e. vertical and lateral corrections). The tamper then moves relatively slowly along the track, applying required lifts and slews by:

- clamping the head of the rail
- lifting the track
- slewing the track as required
- inserting vibrating metal tines either side of each sleeper
- squeezing the ballast underneath each sleeper to effect an increase in track height
- dropping the track back into place before moving on to the next sleeper

The latest generation of machines have a set of tamping banks that shuttle fore and aft as the machine moves steadily forwards, so called continuous-action tampers. This greatly increases production rates, with the best machines achieving over 2000 m/hour<sup>3</sup>. This does, however, require good quality track with a highly consistent sleeper spacing.

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<sup>3</sup> email from Burchard Ripke – 10<sup>th</sup> December 2012



Figure 1 – Plasser & Theurer Continuous-Action Tamper (David Oldroyd, 2012)

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. It is a widely used and well proven process, but there are two particular aspects that resulted in British Rail Research looking into alternatives:

- Immediately following tamping, the vertical track geometry can be greatly improved, only for the vertical profile to return to its pre-maintenance geometry within months as a result of an underlying unresolved problem, and / or the ballast beneath the sleepers settling back to its pre-maintenance orientation – this is often referred to as “ballast memory”
- The forces involved in vibrating and squeezing the ballast beneath the sleepers are high and result in damage to the ballast. Experiments by British Rail Research suggest that each tamping cycle generates 4 kg of fines per sleeper<sup>4</sup>, estimated to reduce the life of ballast by the equivalent of 20 MGT of traffic.

Interestingly, DB have also investigated the second issue and found that damage is sustained by ballast due to tamping, but at a lower level than the study by BR Research<sup>5</sup>. This tends to suggest that factors such as ballast quality may influence the quantity of fines produced. This is supported by a paper published by the Railway Tie Organisation which compared the behaviour of limestone and granite ballast<sup>6</sup>.

Two relevant papers were also submitted to the World Congress for Railway Research in 2011 by SNCF, RFF and other researchers. The first paper<sup>7</sup> adopts a numerical approach based on previous studies and suggests that tamping causes greater wear than normal traffic. By contrast, the physical tests described in the second paper<sup>8</sup> found that although tamping reduced the characteristic size of particles to around 25mm, almost no fines were produced.

<sup>4</sup> “Principles of Stoneblowing and Recent Technical Developments”, presented by Peter McMichael at the University of Birmingham, January 2012

<sup>5</sup> email from Burchard Ripke – 10<sup>th</sup> December 2012

<sup>6</sup> “Effects of Tamping on Ballast Degradation”, Railway Tie Association (no date)

<sup>7</sup> “Modelling of the ballast maintenance expenses” by M. Antoni, WCRR 2011

<sup>8</sup> “On the damaging effects of the ballast tamping operation” by R. Perales, G. Saussine, N. Milesi and Y. Descantes, WCRR 2011

Tamping is still widely used in the UK, although the lack of uniformity of sleeper spacing on many lines means that it is not possible to use the high output continuous-action tampers with three or four banks of tamping tines.

## **2.5 Stoneblowing**

Stoneblowing was developed as an alternative to tamping, the key difference being that instead of squeezing the ballast beneath each sleeper to effect a change in height, a known quantity of fresh stone is injected beneath each sleeper. This has the primary benefit of leaving the consolidated ballast underneath the sleepers undisturbed.



*Figure 2 – Network Rail Stoneblower (Wiki Commons, 2012)*

The behaviour of the track following maintenance with stoneblowing is quite different to that of tamping. Tamping squeezes in and re-orientates existing ballast beneath the sleepers to achieve the desired geometry, resulting in a high quality initial geometry that settles over time as discussed above (i.e. ballast memory). By contrast, for stoneblowing, it is the quantity of stone injected under the sleepers that controls the lift, and the initial track geometry is less impressive as the freshly injected stone takes time to settle to the desired geometry.

Because of this characteristic, it used to be the case that short duration Temporary Speed Restrictions (TSRs) were applied following stoneblowing. But as experience has grown, this is no longer considered necessary for plain line, although TSRs are occasionally still required for S&C depending on factors such as track layout, condition and operator experience<sup>9</sup>.

The operation of the stoneblower is similar to modern tampers with an initial measurement run undertaken by the stoneblower prior to the maintenance run in the reverse direction. The measurements are usually combined with fixed point information provided by the operator for the on-train computer to calculate the optimum lifts, slews and quantity of stone to be injected. However, unlike a typical tamper, the stoneblower operates almost entirely under computer control for the maintenance run, with the machine determining how far to move between sleepers and where / when to insert the injection nozzles.

A higher level of operator skill is required for stoneblowers than for comparable tamper, partly as a result of the increased complexity of the control system (particularly for the multi-purpose machine). But the machine is

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<sup>9</sup> Report review by Andy Key, January 2013

relatively straightforward to set up, with all of the operations required controlled from the cab using CCTV (i.e. the operator does not need to leave the cab), with set up and set down completed in less than five minutes<sup>10</sup>.

The current generation of plain-line stoneblowers treat two sleepers at once, and the production rate is typically between 450 m/hour and 550 m/hour, which is comparable to production rates achieved by mid-range tampers operating in the UK. Similar to tamping, the recently introduced multi-purpose stoneblowers are capable of operating in parallel, with a pair of machines automatically coordinating their actions to enable turnouts and crossovers to be maintained more efficiently.

The UK is currently the only country to currently use stoneblowing on any significant scale, although trials have been undertaken by SNCF / RFF in France, and the Ministry of Railways in China and Queensland Rail in Australia have both purchased a machine<sup>11</sup>.

### 3. Development History

Stoneblowing was originally developed by British Rail Research in the 1970s, primarily in response to the problem of ballast memory. The engineers involved looked for alternative techniques and developed stoneblowing as an automated form of Measured Shovel Packing. An experimental stoneblower was developed in 1981 and early results were encouraging, followed by a prototype stoneblower developed by Plasser & Theurer that was less successful<sup>12</sup>.

A contact was subsequently given to Pandrol Jackson (now Harsco Rail) to build 11 plain-line stoneblowers, and these have been in operation on the UK rail network since 1999. Subsequent orders have brought this up to a total fleet size of 18, and these machines have been used to maintain in excess of 25,000 km of track to date. However, 5 of these plain line machines are currently in storage for a number of reasons<sup>13</sup>:

- The greatest return on investment for stoneblowing is to treat or stabilise near life expired track and the machines were used intensively for this for the early years following their introduction. Much of this track has now been stabilised or replaced, but there persists a widespread misconception that this is “all they are good for” which prevents them being used on higher quality track in some areas.
- The operational cost of stoneblowing is generally higher than for a tamper of comparable output:
  - the first cost of the machine is higher than that for a comparable tamper
  - stoneblowers cost more to maintain, partly due their increased complexity, and also because the technology is not as refined as tampers, which have been continually developed and refined since the 1950s
- The tamping fleet has also been reduced to save costs in recent times, with the total number in operation falling from a peak of approximately 100 machines to around 60 and the reduction in the stoneblowing fleet is roughly in proportion to this.

The initial fleet of plain-line stoneblowers are now nearing the end of their intended design life of 15 years, and Network Rail is looking to procure the next generation of machines in the near future.

<sup>10</sup> Interview with Andy Key, 12<sup>th</sup> October 2012

<sup>11</sup> Report review by Andy Key, January 2013

<sup>12</sup> “British Rail, 1974-1997: From Integration To Privatisation” – Terry Gourvish & Mike Anson, Oxford Press, 2004

<sup>13</sup> Interview with Andy Key, 12<sup>th</sup> October 2012

Following the success of the plain line machines, a second contract was placed for machines capable of maintaining S&C, the multi-purpose stoneblowers. Three multi-purpose machines are currently in operation in the UK and in great demand, with Network Rail keen to expand the fleet accordingly.

#### **4. Review of Published Material**

A brief review was undertaken of articles and papers published on stoneblowing. This review concentrated primarily on those articles that could be easily obtained from the internet, supplemented by two further sources:

- the reference text “Track Compendium” by Bernhard Lichtberger<sup>14</sup>
- a lecture on stoneblowing presented by Peter McMichael at the University of Birmingham in January 2012<sup>15</sup>
- a reference text “Comprehensive Rail and Track Related Research” by Dr. Allan Zarembski<sup>16</sup>

A summary of each of these documents is provided below.

##### **4.1 Track Compendium**

The Track Compendium is a well recognised and well respected publication, endorsed by the UK’s Permanent Way Institution. The main reference to stoneblowing is contained in Section 15.6, entitled “Correction of Track Geometry” and this describes a number of limitations and shortcomings of the technology.

The primary concern relates to the stone particles acting as “ball bearings” underneath the sleepers, thereby significantly reducing lateral track stability. Without stabilisation, it is suggested that track treated by stoneblowing can only be traversed at reduced speed due to the danger of track bucking as a result of this reduction in lateral track stability. There are several further concerns described including:

- the inability of stoneblowing to produce track with a Standard Deviation of better than +/- 3 mm
- that track maintained by stoneblowing is significantly less durable than that maintained by tamping
- the significantly lower working speed of stoneblowers
- that stoneblowing can only be used on plain line, and is only appropriate for secondary routes that exhibit a high degree of ballast contamination

These concerns contrast strongly with the UK experience of stoneblowing as discussed in Section 0.

##### **4.2 Presentation by Peter McMichael**

Peter was responsible for the introduction of the original fleet of plain-line stoneblowers introduced in the UK, and was heavily involved with both the introduction and refinement of the fleet, as well as the more recent procurement of the multi-purpose stoneblowers. He was invited to give a talk at the University of Birmingham in 2012, and the following bullet points summarise his key points:

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<sup>14</sup> “Track Compendium”, 2<sup>nd</sup> Edition, Bernhard Lichtberger, Eurail Press, 2011

<sup>15</sup> “Principles of Stoneblowing and Recent Technical Developments”, presented by Peter McMichael at the University of Birmingham, January 2012

<sup>16</sup> “Stone Blowing: An Alternative Approach to Track Surfacing”, Dr Allan Zarembski, available from the Railway Tie Association, no date

- stoneblowing is a particularly cost effective way to maintain track that is close to life expired (i.e. that has become “un-tampable”)
- however, it is also suitable for use on all categories of UK mainline track and can significantly extend maintenance intervals
- it causes considerably less damage to the ballast than tamping, as measured by the quantity of fines produced during a typical maintenance cycle
- the latest generation multi-purpose stoneblowers can be used to maintain S&C, and feature parallel operation which increases the speed and quality of maintenance over crossovers, turnouts etc.

He also suggested that TSRs have traditionally been imposed immediately following stoneblowing, with lines typically re-opened for 75 mph (120 km/h) running, but that this was under review. (TSRs are no longer required for the maintenance of plain line<sup>17</sup>).

#### ***4.3 Stoneblowing: An Alternative Approach to Track Surfacing***

This article described three sets of tests comparing the durability of track maintained using tamping and stoneblowing conducted in the USA. The first set of tests was undertaken at the Transportation Test Centre (TTCI) with heavy haul axle loads, and the tamped track then returned to its original pre-maintenance geometry after 50 MGT, whereas the stoneblown track maintained an improved geometry. In the second set of tests, both were tested on an American freight railroad, and the tamped track was returned to its original geometry after 50 MGT, with the stoneblown track lasting for 90 MGT before requiring attention.

The third set of tests was undertaken by the American Association of Railroads, where two sections of track were treated with tamping and stoneblowing and the standard deviation monitored over 20 MGT of traffic. The results are interpreted to suggest that stoneblowing is unable to support larger lifts (over 1 inch). However, the article does acknowledge that the two maintenance methods were compared on track of notably different quality.

The interpretation of the results shown in Figure 3 of the paper is also questionable, and this chart actually appears to demonstrate the following characteristics:

- for stoneblowing, the standard deviation for the maintained track is actually slightly worse than pre-maintenance immediately following treatment, but the track quality then improves and appears to stabilise at 20 MGT
- tamping achieves a significant initial improvement in track geometry, with the standard deviation starting to deteriorate by 20 MGT

An attempt was made to obtain further information on the tests conducted in the USA, ideally including the original papers upon which this summary paper was based. But the age of the research meant that finding the original papers proved difficult, and was not pursued further.

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<sup>17</sup> Report review by Andy Key, January 2013

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## 5. Industry Consultation & Interviews

In support of this work, three key railway professionals with first-hand experience of stoneblowing were interviewed:

- Andy Key – Senior Fleet Engineer for the UK’s fleet of stoneblowers, and responsible for the introduction of the new S&C stoneblowers on Network Rail.
- David Oldroyd – A railway engineer with over 20 years experience in on-track plant and a fellow of the UK’s Permanent Way Institution since the mid 1980s.
- Paul Baker – An experienced railway engineer specialising in wheel / rail interaction with first-hand experience of using stoneblowers on the East Coast Mainline (ECML).

There was a high degree of consensus between those named above, and the information provided is summarised as follows:

### 5.1 Suitability for Different Track Types

The experience of those operating stoneblowers in the UK is that stoneblowing is effective for all categories of track, with the following two exceptions:

- it should not be used immediately following track renewals as it requires a consolidated base of ballast beneath sleepers to be effective, typically requiring at least 10 MGT of traffic
- the current generation of stoneblowers are not suitable where very high standards of track quality are required such as dedicated high speed lines for speeds in excess of 200 kph (e.g. High Speed 1)

It was also noted that there are certain locations where tamping cannot be used, but stoneblowing can:

- certain locations with limited vertical clearance due to the smaller minimum lift that can be implemented with stoneblowing (see Section 5.6)
- on bridges where the depth of ballast is too shallow for tamping, but stoneblowing can still be used

One important consideration / limitation is that stoneblowing relies on the sleepers being lifted cleanly to provide sufficient clearance for stone to be injected beneath. Therefore all fixings between rail and sleeper need to be in good condition for maintenance to be effective.

### 5.2 Size & Quality of Injected Stone

The stone injected under the sleepers is granite (i.e. the same material as regular ballast), but the particle size is significantly smaller at a nominal 22 mm in diameter. This occasionally raises concern about the possibility of the smaller particles migrating through the ballast layer and potentially having a detrimental effect on drainage. This has not been found to be problem in practice, and it was also noted that for ballast cleaning, particles of 22m diameter are typically re-used.

It is widely agreed that the quality of the stone injected is important to the success of stoneblowing, but there was disagreement on whether this is necessary to ensure a high level of track stability and durability, or whether it is important to ensure trouble-free operation of the stoneblower.

### 5.3 Lateral Track Stability & Speed Restrictions

Lateral stability of track is reduced by stoneblowing, but it is considered no worse than tamping for a given size of applied lift. It is, however, important to note that a 45 mm overlift is required for stoneblowing in order to inject stone beneath the sleepers (i.e. for a 5mm residual lift, the applied lift is 50mm). This is significantly more

than a typical effective lift for tamping which is currently considered to be 25 mm in the UK, although research in Switzerland<sup>18</sup> comparing the effects of varying tamping depth (20mm and 60mm) and track lift (15mm and 25mm) found that the most significant improvement resulted from the deeper tamping rather than track lift.

In the case of both tamping and stoneblowing, it is necessary to have a healthy ballast shoulder to ensure adequate lateral track stability is maintained. Tampers consume a small proportion of the existing ballast to effect a change in track height, and ballast shoulders may require “topping up” and re-profiling. By contrast, stoneblowers carry approximately 18 000 kg of fresh stone to inject under the sleepers, which is typically more than enough for all but the longest shifts on the roughest track.

#### **5.4 Speed Restrictions Following Maintenance**

It is a characteristic of stoneblowing that the immediate improvement in track geometry is limited, with track typically taking around 0.4 MGT of traffic to settle to the desired geometry. Although TSRs are no longer required following stoneblowing on plain line, as with any high lift maintenance, care needs to be exercised in respect of the rail’s Stress Free Temperature (SFT) and during hot weather where there may be a risk of track buckling.

It is conceivable that Dynamic Track Stabilisation (DTS) could be used following stoneblowing, as is common practice in mainland Europe following tamping. However, little use is currently made of DTS in the UK, but a trial to establish the effectiveness of this approach would be worthwhile.

#### **5.5 Working Speed**

Although not as fast as continuous-action tampers, the working speed of stoneblowers is considered to be comparable to that of a modern mid-range tamper operating in the UK. The plain-line stoneblower treats two sleepers at a time, and its movement and operation is computer controlled which helps ensure a consistent production rate and quality. On many lines in the UK, it is not possible to use multiple tamping bank continuous-action tampers due to insufficiently consistent sleeper spacing.

In Europe, there is greater use of high output continuous-action tampers, and significantly higher production rates are achieved; typically 1200 m/hour for a Plasser & Theurer 09-32 machine (2 sleepers treated at a time), 1600 m/hour for an 09-3x (3 sleepers) and 2000 m/hour for 09-4x (4 sleeper) machines. As mentioned above, achieving these production rates is dependent on the quality track quality and sleeper spacing.

#### **5.6 Minimum Lift**

Studies undertaken in the UK showed that there was no sustained lift for an initial lift of less than 15 mm. The minimum effective lift is considered to be 25 mm to achieve a sufficiently durable track geometry. The minimum effective lift for stoneblowing is much smaller, with residual lifts 1 mm being achievable by controlling of the amount of stone injected (0.55 kg per mm of residual lift). However, it is important to note that an initial 45 mm overlift is applied in order to inject the stone under the sleepers, which results in a residual lift immediately following maintenance of between 20 mm to 25 mm. This then settles to the desired lift with the action of passing traffic. It is conceivable that the use of DTS could reduce this effect.

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<sup>18</sup> “Improving ballast tamping process” by Chiara Paderno, Oxand Sàrl, Lausanne, Switzerland at WCRR 2011

This ability to apply small lifts has been particularly useful on the West Coast Mainline (WCML) at locations where overhead restrictions mean that it is not possible to use a tamper due to “high spots” in the track.

### **5.7 Re-blowing Previously Treated Sites**

It is possible to re-treat a site previously maintained using stoneblowing, and occasionally desirable to do so, treating a site several times in quick succession in order to achieve the desired track quality, stability and / or durability. It is also possible to tamp a site previously treated by stoneblowing, although this undermines the benefit(s) gained from stoneblowing.

### **5.8 Durability of Maintained Track Geometry**

The widespread view of track engineers in the UK is that stoneblowing is significantly more durable than tamping, by a factor of between 2 and 3 for typical UK track. It can also provide an effective way of treating problematic areas such as wet spots where tamping tends to be ineffective. There is also interest in applying it at the transition to bridges, which has traditionally been a troublesome area for the track engineer.

### **5.9 Planned Future Developments**

There are a number of developments planned in the UK for stoneblowers and associated technologies:

- Stoneblowers currently undertake a recording run in one direction followed by a maintenance run in the reverse direction. It is hoped that the next generation of machine will also be able to read data from Network Rail’s EM-SAT track recording vehicles directly obviating the need for the pre-maintenance recording run.
- The level of skill required of stoneblower operators is currently significantly higher than that for tamper operators, and it is planned that the next generation of machine will be easier to use / operate.

As mentioned previously, Network Rail is looking to procure the next generation of machines and it is hoped that these will incorporate the features listed above.

## **6. Meeting the Objectives of AUTOMAIN**

The core objective of AUTOMAIN is to reduce the impact of predominantly night time possession on freight paths / capacity in Europe. It is anticipated that stoneblowing could contribute to achieving this goal in the following ways:

- The UK experience is that track maintained by stoneblowing is more durable than track maintained by tamping. This increased durability would need to be balanced against the higher production rates achieved by continuous-action tampers in Europe, and this balance will probably be different depending on the categories of line and traffic. It is likely however, that stoneblowing has the ability to reduce overall maintenance times for a proportion of Europe’s freight routes.
- Stoneblowing provides a particularly effective and durable means of treating problematic locations such as wet spots, and it is also an established means of deferring ballast cleaning and renewals at sites with poor ballast condition. Using stoneblowing in a targeted fashion to treat these locations would enable the track to remain open to traffic, where more serious and time consuming intervention would otherwise be required.

- Stoneblowing causes less damage to ballast than tamping, potentially increasing ballast life and the interval between highly disruptive ballast cleaning or track renewals. A more targeted and localised approach to track quality improvement would also lead to reduced ballast attrition.

The benefits of stoneblowing are well established for UK track conditions, and it is likely that benefits would come from using this technology on a wider scale within Europe. There may be technical issues to be resolved, for example, the maximum lift that DB currently allow for tamping is 40 mm<sup>19</sup> and stoneblowing generally requires lifts larger than this. But there is clearly the potential to use stoneblowing as a complimentary process to help achieve AUTOMAIN's objectives.

## 7. Conclusions

### 7.1 Key Findings

With the exception of the Track Compendium<sup>8</sup>, there is general consensus on the following key points in relation to stoneblowing:

- stoneblowing can be used on all categories of track with the exception of newly laid lines and very high speed lines
- it tends to result in a more durable track geometry, estimated at between 2 and 3 times longer than tamping for typical track in the UK
- working speeds and production rates are comparable to a modern mid-range tampers operating in the UK, but are significantly lower than high output continuous-action tampers as used in mainland Europe
- ballast life is extended due to the reduced damage caused by stoneblowing compared to tamping (although it should be noted that there are differing views on the extent to which tamping causes ballast damage)
- stoneblowing is a particularly effective means of treating wet spots, and can be used to defer ballast cleaning at sites with poor ballast condition
- the improvement in track geometry following stoneblowing is not immediate, and traffic is required for the track to settle to the desired geometry, although this no longer limits the speed at which plain line track can be re-opened to traffic
- the latest generation of multi-purpose machines can be used on S&C, and are proving popular with track engineers

The introduction of stoneblowers has improved the way track is maintained in the UK, and the overwhelming view of those involved with its development and operation is positive.

### 7.2 Implications for AUTOMAIN

The key objective of the AUTOMAIN project is to reduce the impact of track closures (i.e. maintenance possessions) necessary to maintain running lines in order to increase overall capacity for freight services. There are a number of attractive features of stoneblowing that could help meet this objective:

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<sup>19</sup> email from Burchard Ripke – 10<sup>th</sup> December 2012

- 
- the increased durability of track maintenance would result in an overall reduction in track possession time, although this needs to be balanced against the higher production rates achieved by continuous-action tampers in mainland Europe
  - the reduction in damage to ballast has the potential to extend the interval between highly disruptive ballast cleaning and track renewals
  - it offers an effective means of treating problematic areas such as wet spots, and can be used to defer disruptive ballast cleaning at problematic or near life expired sites

It is also noted that the machines have been designed to be quick to set up, and as the operator does not need to leave the machine, it is safe for adjacent lines to remain open to traffic. The control system is also relatively advanced, ensuring consistent production rates and quality of maintained track geometry.

### **7.3 Recommendations**

There appears to be potential to use stoneblowing to help meet the objectives of the AUTOMAIN project, most likely as a complimentary process to tamping rather than as a direct replacement. It is recommended that a further study be undertaken to quantify the potential savings in terms of overall possession time, and to evaluate where stoneblowing could be used to greatest effect for different European track and maintenance scenarios.

One of the characteristic of stoneblowing is the time taken for track to settle to the desired quality following maintenance. Although it is no longer considered necessary to limit the speed at which lines are re-opened to traffic, the use of Dynamic Track Stabilisation immediately following stoneblowing has the potential to reduce this effect. It is recommended that further investigation be undertaken of the potential benefit(s) of this approach.

## Appendix E: S&C Maintenance – Lean Analysis of Current Processes

### Executive Summary

This document contributes to Deliverable D4.4 of AUTOMAIN, an EU-funded project aimed at reducing the possession time required for railway maintenance in order to increase overall network capacity for rail freight. The work primarily involved using Lean Analysis techniques to observe and evaluate current maintenance practices in relation to the maintenance of S&C. The study was commissioned separately to the main AUTOMAIN project by Trafikverket, and therefore focuses on the practices and procedures undertaken in Sweden. Further study would be required to compare the approaches with other railway administrations participating in AUTOMAIN.

This work follows on from two previous deliverables looking at tamping and grinding, and as with the previous work, two main methods were used to evaluate and compare current practices, namely:

- Process Observation – where an actual maintenance shift was observed in detail
- Value Stream Mapping (VSM) workshop – a paper based exercise that maps out processes and procedures, used as a means of identifying issues and suggestions for improvement

This report details the Structured Observation and VSM workshop, provides analysis and commentary of key aspects such as the proportion of value added activities, and acts as a means of collecting and collating concerns and suggestions from front line staff. The main findings were as follows:

- there are refinements and improvements that can be made to the planning process that will help minimise overall possession time, but the impression is that these are unlikely to achieve the step change required by AUTOMAIN
- related to the above, in terms of crossing build-up welding repairs, it is difficult to predict reliably using current inspection methods what work will be needed to repair a damaged crossing, or whether the crossing is sufficiently bad to require replacement – this is particularly an issue for manganese crossings
- where repairs are performed, the success of the repair is dependent on the skill and judgement of the operator, and this could be made more consistent
- in terms of the observed crossing replacement, there appears to be significant scope to reduce the overall time through more efficient work practices and the provision of duplicate equipment
- the processes and procedures employed ideally need to be reinforced to prevent unnecessary problems from being encountered during crossing replacement, and a similar applies to build-up welding repairs

In terms of suggested improvements, consideration should be given to the following:

- there are a number of new / alternative technologies that should be investigated standardise and reduce the time taken to repair / replace crossings, ideally enabling maintenance to be reliably achieved within a single 3 or 4 hour shift
- given the problems with in-situ build-up welding repairs, there is an argument for replacing crossings as standard practice, with welding repairs carried out under controlled conditions in a workshop

In terms of meeting the objectives of the AUTOMAIN project, further structured observations of build-up welding repairs and comparable practices in other countries would almost certainly prove useful.

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## 1. Introduction

The key objective of the AUTOMAIN project is to look at ways of reducing what are predominantly night-time maintenance track closures that impact negatively on rail freight capacity. Two preceding work packages identified tamping and grinding to be the maintenance activities with the greatest impact on longer duration possessions, and selected for further evaluation using Lean Analysis techniques. Following the success of this work, a further study was commissioned by Trafikverket to evaluate the maintenance of S&C, looking for best-practice maintenance technologies and procedures, as well as highlighting areas and opportunities for improvement for the future.

The consultancy company KM&T was commissioned to undertake analysis of an actual maintenance possession using a structured Process Observation, along with an office based Value Stream Mapping (VSM) workshop. As with the previous tamping and grinding studies, the analysis proved worthwhile with a good number of issues and opportunities for improvement raised.

The investigation and direct output from the Lean Analysis was produced by KM&T, with the University of Birmingham providing support to produce this report, funded as part of its contribution to the AUTOMAIN project.

## 2. Background Information

### 2.1 The AUTOMAIN Project

The core objective of the AUTOMAIN project is to improve the efficiency of track maintenance to increase the availability of the network for freight traffic<sup>20</sup>. The proposed time horizon for widespread implementation of the proposed changes is in a number of stages, the first of which is 2026 (i.e. fourteen years from now).

### 2.2 S&C Maintenance

The action of rail traffic causes track to degrade over time, and this includes Switches & Crossings (S&C) which are a key component of the overall time and cost required to maintain and run a railway network. One of the key areas of wear is at the crossing where the wheel transfers load from one section of rail to the next. This is a high impact zone that is typically cast from special high strength steels for longevity. Such crossings typically suffer from wear, metal flow (lipping) and Rolling Contact Fatigue (RCF) and are inspected at regular intervals. If the crossing is found to be in poor condition, there are two approaches used to rectify the situation:

- surface build-up welding (i.e. repair)
- crossing replacement

The decision as to whether to repair or replace a crossing follows a series of inspections including visual inspections and ultrasonic inspection. Surface build-up welding is used if it is deemed at the inspection stage that the degradation is not severe enough to warrant a complete replacement. The surface of the crossing is prepared (ground back) and then additional metal is welded to the crossing which involves building up damaged wing rail and crossing nose using manual metal arc welding. The additional weld material is then ground back to the required profile.

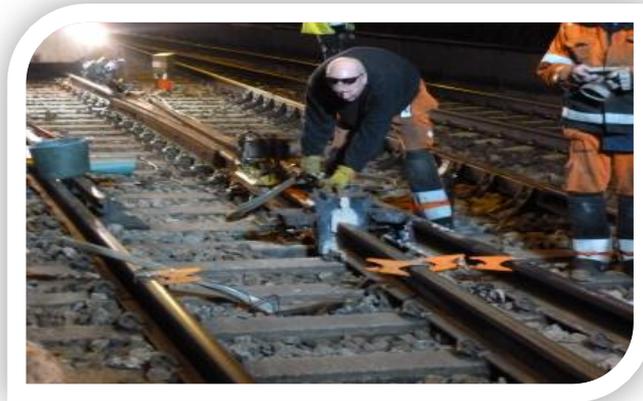
Occasionally, when the metal is ground back prior to a repair, the condition of the underlying material is found to be poor. This problem made worse by the challenge of inspecting manganese crossings with ultrasonic techniques, which tend to perform poorly due to the large cast grain size of manganese steel causing too many

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<sup>20</sup> A full description of the project and its objectives can be found in the introduction to Work Package 1, Deliverable 1.1

“echoes”. A temporary repair therefore has to be made prior to arranging replacement of the crossing at a later date.

In the case of a crossing replacement, it is necessary to cut the adjacent rails at four points, remove and replace the crossing, and then weld in the new crossing using alumino-thermic welding. The welds then need to be re-profiled by cutting and grinding.



*Figure 1 – Preparation of an Alumino-thermic Weld*

In the case of both repair and replacement, the grinding is done manually using powered manual grinders such as the Robel type grinder shown below. The process and the quality of the finish are dependent on the skill and expertise of the person undertaking the grinding.



*Figure 2 – Manual Grinding*

Surface build-up welding generally requires longer possession times than crossing replacement; the typical time for a build-up welding repair is 6 to 8 hours, whereas a crossing replacement might typically take 4 to 6 hours.

### **2.3 White Time / Space Working**

In Sweden, it is common to use so called “white time” or “white space” to undertake maintenance tasks. This is the time between normal train traffic, and the amount of time available depends on how busy the line is, typically from 20 minutes during the day up to as much as 6 hours during the night depending on traffic volumes and whether the line carries freight services.

### **2.4 Lean Techniques and Analysis**

Lean is a proven business improvement methodology that originated from the automotive industry in Japan in the early 1940s. It is essentially a number of simple and robust tools and techniques based around a way of thinking way for ‘continuous improvement’ in order to meet or exceed ever increasing customer expectations. It empowers all levels of a business or organisation to work in an efficient manner, whilst focussing on five key areas of a business: People, Safety, Quality, Cost and Delivery. Within this, a key focus of the lean methodology includes the on-going identification and elimination of “waste” within an activity, process or organisation which is defined as “anything that the customer is not prepared to pay for”. This can come in several different guises:

	WASTE TYPE	RAIL INFRASTRUCTURE - EXAMPLES
T	Transportation	Excessive movement of raw materials
R	Resources	Lack of employee involvement
I	Inventory	Excessive stock piles of raw materials
M	Motion	Walking from machine to machine
W	Waiting	Waiting for raw materials or permissions
O	Over Processing	Over engineering (making better than it needs to be)
O	Over Production	Excessive finished goods (making too many)
D	Defects	Reworking a product or plan due to error

Figure 3 – The Different Forms of Waste

There are a large number of analysis tools available from the “lean toolbox” that assist with the identification of waste. From these, two core approaches were selected:

- Process Observations of the maintenance process (also known as Structured Observations) from an independent third party perspective, noting key parameters such as the timing of key activities and opportunities to reduce waste
- mapping out both the maintenance and planning processes during a series of Value Stream Mapping (VSM) workshops, including the quantification of key parameters wherever possible such as the duration of the task, the manpower required etc.

This approach has previously proven successful in a diverse range of companies and organisations, highlighting scope for significant improvement in processes and procedures. It also provides a means and opportunity to re-connect an organisation’s management with what is happening at ground level, and it provides staff with a means of communicating ideas for improvement back up the through the organisation.

### 2.5 KM&T

KM&T is a UK based consultancy firm that specialises in applying lean processes to services, manufacturing and operations in numerous industries. KM&T have helped to improve working processes for some of the world’s largest organisations and identify efficiency savings worth millions of pounds a year. Toyota is regarded as the world’s foremost developer and users of lean principles and methodologies, and KM&T was set up to apply this approach and techniques to other companies and industries. A large proportion of KM&T consultants are ex-Toyota employees with first-hand experience of lean approaches.

## 3. Summary of Work Undertaken

The Lean Analysis for maintenance in S&C was undertaken by KM&T in late 2012, and involved representatives from Trafikverket, their maintenance contractor Infranord, and Vossloh who manufacture S&C, as well as

associated maintenance equipment and services. Of the various maintenance tasks undertaken on S&C, the maintenance of crossings by repair / replacement was selected for this detailed study.

### **3.1 Process Observation**

A Process Observation was undertaken for a single maintenance possession, attended by KM&T who observed the maintenance shift through to handing back of the line. Key observations were recorded, and the shift was subsequently broken down into 3 generic categories:

- value added activities
- necessary non value added activities
- non value added activities

This information is presented in Section 4, along with a summary of the observations made during the visit. Due to the observed maintenance shift starting earlier than had been expected, the record of individual event timings was incomplete, limiting the usefulness of this data.

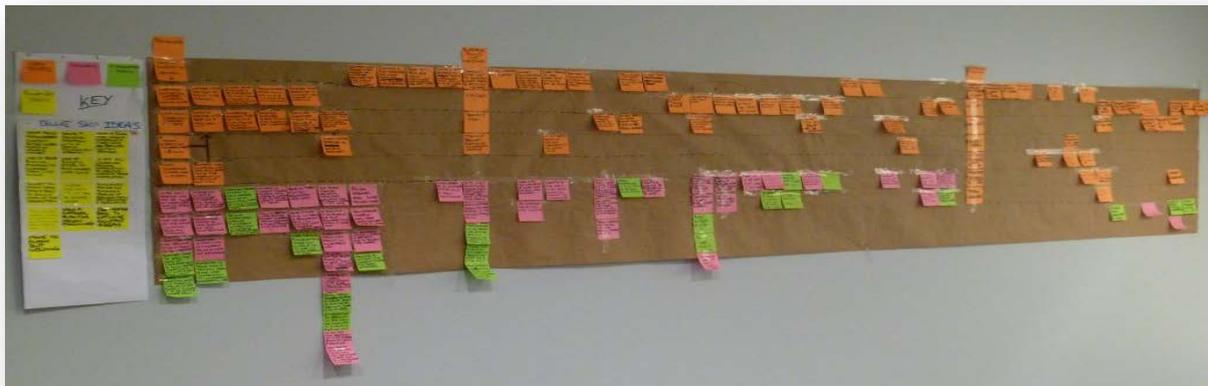
### **3.2 Value Stream Mapping (VSM) Workshop**

A VSM workshop was also undertaken, attended by representatives from various organisations including experienced machine operators, infrastructure managers, track experts and maintenance planners, hosted and directed by representatives from KM&T. The workshop followed a standard pattern:

- the various steps involved were mapped out through discussion amongst attendees
- concerns and ideas for improvement were elicited from those present, supported by observations made by KM&T from the Process Observations

As stated previously, the objective of AUTOMAIN is to increase the efficiency of track maintenance in order to increase track availability. While this could potentially be viewed purely as relating to the actual maintenance process, in terms of the overall availability of track, the planning process is also widely considered to be important. For example, the maintenance needs to be carefully planned to avoid waste, ensuring that the right machine and staff are sent to the right location at the right time, supplied with appropriate background information / data and objectives.

It was therefore considered important to map out not only a typically maintenance possession, but also the planning process leading up to that possession. The mapping process itself was undertaken by placing “Post-It Notes” on a large roll of backing paper on the wall of the room as shown in the photograph below:



*Figure 4 – Value Stream Mapping*

Each vertical line of Post-It Notes represents a different stage in the process, with a description of specific steps recorded on the orange Post-It Notes. Further Post-It Notes are then used to record concerns (pink) and ideas for improvement (green), with ideas generated that were not specific to a particular step recorded in a separate “Blue Sky Ideas” area.

Please note that due to time constraints, it was not possible to undertake the detailed analysis of cycle times, resource levels, percentage of “right first time” etc. as done for the grinding and tamping VSM workshops.

#### **4. Findings – Process Observation**

The S&C maintenance shift took place on the 6<sup>th</sup> November 2012 on Track Section 414 of the Western Mainline, near Gnesta, south west of Stockholm. The line carries a mix of commuter and freight services, and the task was the complete replacement of a crossing within 2 x 3 hour shifts, planned to be undertaken during “white time” during the early hours of the morning.

The shift was originally planned to take 3 hours, but traffic conditions were such that 4 hours were actually available on the first of the two possessions. The work involved an excavator and a welding train (i.e. a wagon equipped with manual welding equipment), and there was a crew of six as follows:

- 2 welders
- 1 safety manager
- 1 excavator driver
- 1 welding train driver
- 1 train warner / watcher (i.e. lookout)

A detailed breakdown of the work steps observed is contained in Appendix A, and is summarised in the pie chart shown in Figure 5:

### Process Observation Breakdown

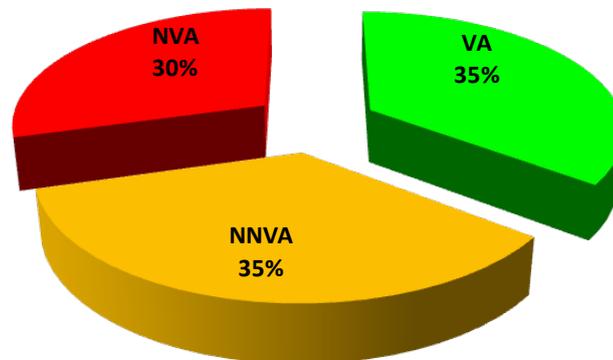


Figure 5 – Value Added Breakdown of S&C Maintenance Shift

According to the above chart:

- 30% of all tasks were deemed as Non Value Add, i.e. activities that do not contribute to the product or the process and should ideally be eliminated as they are considered as waste according to the lean principles.
- 35% of the tasks were Necessary Non Value Add, meaning tasks which are likely to prove difficult to remove in the short term, but which it may be possible to eliminate or reduce in the medium term.
- 35% of the tasks were considered to be Value Added, i.e. steps in the maintenance process that improves the product for the customer.

There were also a number of specific observations made during the course of the shift:

- As mentioned previously, the maintenance activities were able to start 1 hour earlier than the scheduled 1:00am track entrance time due to no train traffic on the working line.
- For the majority of the shift only 33% of the crew were actively working at any one time, resulting in a large amount of waiting time.
- There appeared to be an opportunity for certain longer duration tasks to be conducted in parallel with others to significantly reduce overall working times.
- There was a large degree of motion undertaken by welders as they walked to collect different pieces of equipment, tooling and material. This could have been supported by or undertaken by other crew members.
- The adjacent track was open and operating with high speed traffic, but there appeared to be no physical precautions taken (e.g. barriers) to separate the work area from this traffic.
- During winter months, the crew stated that ice from passing trains has the potential to break off, putting the crew at risk of serious injury.
- The alumino-thermic welding process is time consuming, requiring on average 22 minutes per weld (4 welds were required), i.e. a total of almost 1.5 hours in welding time alone.

- Single pieces of key equipment and tooling prevented a number of tasks from being undertaken simultaneously.
- Some of the equipment was old and no longer operating well (hammers were used to “encourage” them to work).
- The excavator had to make 3 x 1 km (approx.) trips to transport the old crossing to the sidings, where a trailer could be used to transport the crossings in a single trip.

As noted previously, the crossing replacement was conducted over 2 shifts during white time, and approximately 90% of the work required was completed during the first shift. In this instance, a small increase in the efficiency of the work undertaken would have enabled it to be completed in a single shift.

## 5. Findings – VSM Workshop

As with the previous tamping and grinding VSMS, it was felt important to include the planning stage to elicit planning or process related issues that could impact on the overall effectiveness of the maintenance undertaken. The Value Stream Mapping (VSM) workshop was therefore used to map out three distinct areas as follows:

- maintenance planning
- surface build-up welding (i.e. crossing repair)
- crossing replacement

The workshop prompted attendees to raise concerns relating to each of the work steps, each of which was then documented by KM&T. This was followed by the generation of ideas or opportunities for improvement to help address the concerns highlighted. This information was subsequently used to generate the prioritised list of concerns and opportunities shown in Appendix B and Appendix C.

### 5.1 Maintenance Planning Timescales

The maintenance planning period was studied from initial track inspection to the day of the re-opening of the track. The simpler a processes is, the more reactive it tends to be. By contrast, the more complex a process is, the slower tend to be reaction times to emerging issues, often failing to seek resolution in a timely manner. The overall planning process for the maintenance of crossings is summarised as follows:

- crossing inspection conducted
- type of maintenance decision made
- maintenance suggestions forward to the Track Master
- maintenance activity added to high level plan (i.e. the master plan)
- high level plan presented to Contract Manager
- dates and times negotiated with train operator
- requests for maintenance are approved or rejected

Track inspections are undertaken according to the schedule outlined in Figure 6 below. It is these inspections which determine whether the crossing is to be repaired or replaced, noting the limitation of ultrasonic inspection techniques on manganese type crossings as discussed previously.

Inspection Type	Conducted by	When
Overhaul inspection	Trained Welder	3 years prior to maintenance
Manual ultrasonic inspection or close visual inspection		3 months prior (but carried out once a year)
Visual inspection	Contract Manager	3 months prior to maintenance
Visual inspection	Contract Manager	2 weeks prior to maintenance

Figure 6 – Inspection Schedule

The planning process for both build-up welding repairs and crossing replacement follow the same steps until 2 weeks before the activity is to take place. This is when a work area inspection is carried out, and the Contract Manager, Safety Manager and welder assigned to complete the repair decide on the scope of work required.

The planning time frame to obtain track access is dependent on the length of time required in order to repair or replace the crossing. The table shown below indicates the time frames typically needed to request track access:

Requested Possession Time	Request Time Frame	Time of Day Activity Takes place	Detail
3 Hours	14 Weeks	Day and Night	Easier and cheaper to secure
4 Hours	14 Weeks	Day and Night	Time of day dependant on white time availability
6 Hours	14 Weeks	Night	Will require a re-route, carrying additional costs
8 Hours	14 Weeks	Night	Will require a re-route, carrying additional costs
12 Hours	14 Weeks	Night	Very expensive and less likely to be agreed due to budget constraints
48 Hours	16 Months	Weekends	Extremely expensive & disruptive requiring replacement services by road

Figure 7 – Possession Request Timeframes

It can be seen that for white time possessions (which can be from 20 minutes up to about 6 hours depending on traffic), the maintenance plan needs to be submitted 14 weeks in advance. At this stage it is usually possible to extend white time possessions by 1 to 2 hours without incurring mayor additional costs, typically between 1000 and 10 000 € per hour depending on how it affects traffic. Possessions that are significantly longer than the available white time will incur additional costs for re-routing traffic for example.

Where a weekend possession is required, this needs to be presented in February of the year before (i.e. typically 16 months prior) so that it can be incorporated in the working timetable. Such possessions tend to involve major disruption and cost, requiring replacement bus and truck services.

In the run up to the possession, the Contract Manager then carries out the following tasks to ensure that all materials and equipment are confirmed prior to the maintenance activity:

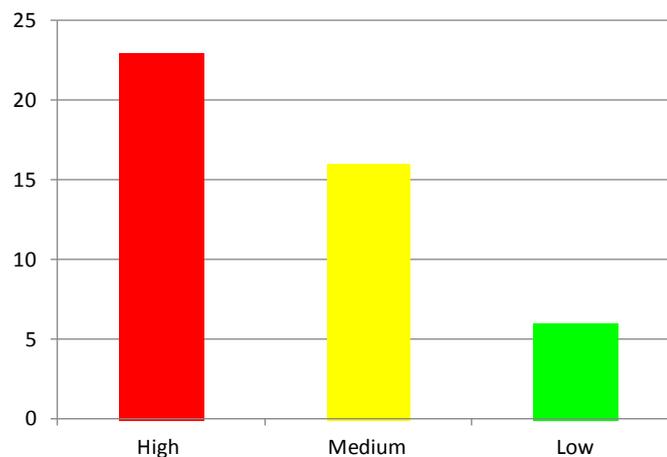
Order of Sequence	Activity	Time Frame
1	All necessary material ordered	4 weeks prior to maintenance
2	Crew and light machinery Confirmed	4 weeks prior to maintenance
3	Train path booked for light machinery	2 weeks prior to maintenance
4	Confirmation of crossing replacement made to train dispatcher	1 week prior to maintenance

*Figure 8 – Activities of Contract Manager*

In the above table, “light machinery” includes the excavator and welding train as described previously. It was also noted that provisional maintenance windows (i.e. possessions) are routinely booked into the long term maintenance plan without knowing exactly what work will be required.

### **5.2 Project Work Stream Analysis**

A total of 45 concerns were raised during the workshop. These were scored according to frequency and impact to produce a prioritised list as shown in Appendix B. The breakdown of high, medium and low priority concerns is shown below:



*Figure 9 – Breakdown of Concerns by Priority*

There were 23 concerns rated as having a high impact on possession efficient which were then categorised according to one of seven Project Work Streams, as shown in Figure 10

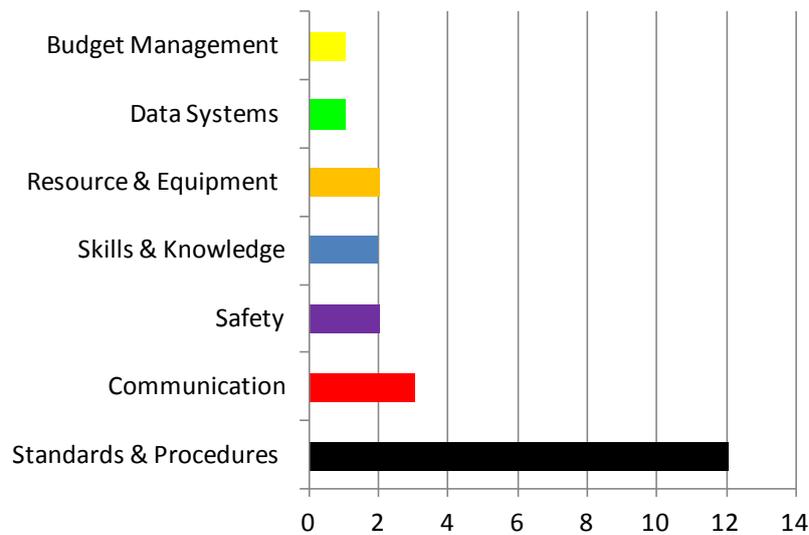


Figure 10 – Categorisation of High Impact Concerns

Categorised and filtered in this way, by far the greatest number of concerns related to standards and procedures, followed by a reasonably even spread across the other six categories.

### 5.3 Specific Concerns

#### Planning

Due to the similarities of the planning processes, the concerns raised in relation to planning tended to be common for both build-up welding repair and crossing replacement. A full list of concerns is contained in Appendix B, and below is a list of the highest priority concerns:

- Time in track is often requested but not used by contract managers, resulting in higher costs, high amounts of rework to re-schedule the activity during the planning stage, and potential for the crossing to degrade further which can result in longer and more expensive maintenance.
- Poor target setting (i.e. understanding what work is required and how long it will take) can occasionally result in less time being required in track than was originally planned. For longer possessions, this can mean that trains have been re-routed unnecessarily, resulting in unnecessary cost and disruption.
- Last minute requests for time in track carries the risk of not securing suitable equipment and/or machinery, due to being outside of the standard 4 week request window.
- If maintenance activities are rejected and/or rescheduled outside of the standard request time frame, the budget for the activity is often lost.
- The train operator regularly rejects maintenance requests if the time frame requested exceeds the white space for the track.
- Non-standard crossings i.e. curved crossings require longer lead times for manufacture, and this is not always taken into account when ordering of material, with the risk of not having the crossing in time and subsequent cancellation of the planned maintenance activity.

- If the efficiency of the maintenance work is improved to enable it to be completed within 3 hours, the window for planning longer term maintenance activities could be reduced to 5 – 9 weeks, making the planning process more reactive and cheaper.

### **Build-Up Welding Repair**

There were a number of specific concerns raised in relation to crossing repairs, the key ones being as follows:

- When the contractor conducts a site inspection 2 weeks prior to maintenance it is often realised that the time allocated to complete the repair work is insufficient. This is mainly a result of poor target settings (i.e. understanding of what work is required and how long it will take) during the initial planning stages.
- Access to the work site via the gated access roads cannot always be achieved due to the contractor not being authorised to have a gate key which can result in significant delays to starting work.
- The type of repair method (permanent or temporary) cannot be determined until the fault area has been ground back. If a temporary repair is used, the contractor will have to return to the worksite at a later date to rework the fault area and make it permanent.
- For temporary repairs, no standard procedure exists which results in large variations in the quality and life cycle of the repair.
- Following a repair, a standard requirement to return to the work area after 0.1 Million Gross Tonnes (MGT) to rework the profile is often not done due to cost constraints.

### **Crossing Replacement**

**A lower** number of concerns were raised in relation to crossing replacements, the main ones being as follows:

- The rails need to be measured and marked prior to cutting in order to confirm the length is equal to that of new replacement crossing. This is not always done, and has occasionally resulted in the replacement crossing being the wrong length.
- During dryer periods, and dependant on the surrounding environment, grass fires are common due to sparks from the manual grinding machine.
- The rail temperature is normally checked before cutting, but in very cold temperatures, it has the potential to crack during the cutting process, which means that lengthy repairs have to be conducted to the rail before the new replacement crossing can be put into position.

### **5.4 Specific Opportunities**

A number of ideas or opportunities were raised during the workshops relating to improvements that could achieve significant cost and time savings. Again, those at the planning stage tended to be common for both build-up welding repair and crossing replacement. A full chart is provided in Appendix C, and the most promising are as follows:

#### **Planning**

- If it were possible to develop the means by which all maintenance activities could be completed in 3 hours, this would enable planning to be completed in 5 to 9 weeks with a subsequent reduction in overall costs.
- During 2011/2012 there were 100 maintenance activities of all types that were planned during the 16 month planning window, but 864 maintenance activities were carried out (i.e. 764 unplanned activities) – this suggests that there is significant scope to improve the inspection and early detection systems.

### **Build-Up Welding Repair**

- Using a water spray to cool welded areas before grinding would significantly reduce the cooling time of the rail, which in turn would reduce the amount of time in track. Care would, however, need to be taken to avoid cooling the rail too rapidly as this could affect the structure of the steel.
- The use of a manual milling machine instead of a manual grinder would streamline the re-profiling of the crossing, as the desired rail profile is built-in to the milling head. This would ultimately save time in track, and would potentially result in a higher quality of profile / finish.
- Large amounts of time in track could be saved in track if a plasma cutter is used instead of a manual grinder to initially remove material from the fault zone.

### **Crossing Replacement**

- The addition of a second crew member cutting the rail in parallel would halve the time taken to cut the crossing.
- The preparation of the next mould while the alumina-thermic welding is in progress will stream line the welding process and potentially give a 30% improvement in time.
- Investment in duplicate tools and equipment will allow many tasks to be conducted in parallel with each other saving significant time.
- Following the alumino-thermic welding, a large amount of excess material has to be cut from the rail, and this is currently done once all 4 welds are complete. By having additional crew member to start material removal shortly after each weld has been completed, the overall time required would be reduced.

### **5.5 “Blue Sky” Ideas**

A number of further ideas were suggested during the workshop in relation to both crossing repair and replacement, and these are summarised in the table shown below:

Blue Sky Idea	Activity Type	Benefit	Effort
Laser profile measurement system to give better understanding of issues and causes of poor crossing quality	Build Up Welding & Crossing Replacement	High	High
Use a swing nose crossing instead of a fixed nose crossing will reduce contact fatigue	Crossing Replacement	High	Medium
X-Ray all crossing before installation to identify defects within the rail, before installation	Crossing Replacement	High	Medium
Pre machine rail to optimise contact areas	Crossing Replacement	High	Low
Use stone blowing strategy to increase track life cycle and reduce costs	Crossing Replacement	High	Medium
Collect all track data (good & bad) to build a clearer picture of track degradation	Build Up Welding & Crossing Replacement	Medium	Low
Use of bainitic steel will increase track life cycle	Build Up Welding & Crossing Replacement	High	High
The use of laser welding will significantly reduce the welding times	Build up welding	High	Medium

Figure 11 – Summary of Blue Sky Ideas

Certain of the above suggestions are currently being evaluated as part of the AUTOMAIN project; a trolley based laser profile measurement system is being developed, and a report detailing the experience and potential for stoneblowing has also been produced.

## 6. Performance Killer Analysis

Further analysis was subsequently undertaken based on the list of concerns raised at the VSM workshop. The aim of this exercise was to identify the most effective solutions to those issues of highest concern. This was done as follows:

- Each concerns raised during the VSM workshop was scored in terms of priority.
- A list of potential solutions and / or mitigations was developed, drawing on both the work of the VSM workshops and any other ideas suggestions raised during the exercise, and then prioritised.
- The priority scores from the concern and potential solution(s) were then combined to identify the most attractive options.

A full copy of this evaluation is contained in Appendix D, and the most attractive options identified with scores of 9, 8 or 7 are summarised below. Please note that this was by necessity a relatively simple qualitative analysis.

### 7.1 Score of 9 (maximum)

#### Planning:

- Standardise work to fit a maximum 4 hour period in order to make possessions more acceptable to train operators and therefore easier to arrange.
- In order to minimise the impact of long lead times:

- adopt a longer planning horizon for maintenance of curved S&C
- discourage the future use of curved S&C by applying a large cost penalty when planning new or renewed track layouts
- standardise wherever possible on a few types and geometries of S&C for new track layouts or renewals to reduce delivery times
- stock a range of non-standard S&C components to ensure delays are minimised
- In order to help ensure that the correct materials are always ordered, ensure that information on the BIS is always updated following maintenance, and increase the understanding of the materials by Project Managers.

### **Build-Up Welding Repair & Crossing Replacement:**

- Allow contractors to sign out access keys so that they have easier and quicker access to track access roads, preventing delays accessing the work site.
- Make train dispatcher numbers available on the internet so that maintenance crews can get in touch with the right person quickly and efficiently.
- Standardise the approach to work and equipment to help:
  - reduce equipment faults
  - reduce the number of temporary repairs undertaken and ensure that they are undertaken to a good standard
  - ensure that marking out is always done correctly, and prevent the situation where there is the wrong amount of rail in the track
- Instead of repairing damaged crossings on-site, replace them and undertake repairs under controlled conditions back in the workshop. This would help:
  - prevent delays due to unexpected problems found during on-site repairs
  - reduce the impact of harsh weather conditions
  - reduce the exposure of workers to dust and fumes
- Ensure that all necessary documents have been completed before work can be “closed” in the BESSY / BIS system to:
  - ensure a consistent quality of reporting
  - enable welding reports to be easily located
  - ensure that the requirement to return to site after 0.1 MGT is carried out
  - help make sure that all documentation is available prior to arriving on-site

### **7.2 Score of 8**

#### **Planning:**

- Develop a better understanding of the reasons for track and crossing degradation, gathering better data on rates of deterioration to:



- 
- identify root causes of problems so they can be addressed permanently
  - improve prediction of where, when and what maintenance will be required
  - Improve inspections by:
    - providing inspectors with better information on the traffic over a specific crossing since last inspection
    - developing a single, central system to manage all maintenance activities and the data relating to them
    - rotating inspectors across different routes to increase their overall experience and expertise
  - Ensure preventative actions are reliably undertaken whenever identified to help reduce the cost of unplanned or emergency work.
  - Work order numbers should be confirmed by SMS instead of faxes which are slow and inconvenient.

### **Build-Up Welding Repair & Crossing Replacement:**

- Contained within “Score of 9” suggestions.

### **7.3 Score of 7**

#### **Planning:**

- Install weatherproof monitoring / inspection systems in track to reduce the impact of poor weather conditions on the quality of inspections.
- The development of the maintenance plan needs to be aligned with the maintenance budget – currently the plan is created a year in advance of the budget meaning that the plan has to be re-worked if the full budget is not allocated.
- Improve the design of the maintenance contract to ensure requests for track access are done in a timely manner.
- Develop more detailed maintenance plans at an earlier stage to avoid the situation where track access is requested but is then not used.

### **Build-Up Welding Repair & Crossing Replacement:**

- Modify the system of keys so that the same key is used for track access and lighting.
- Introduce protection between maintenance staff and passing trains to reduce the risk of injury.
- Measure rail temperature and in cold conditions, mark the length and make a pre-cut between the markings so that if the rail breaks it is still possible to have the correct length gap required when the final cut is made.

## 7. Conclusions

As with the previous lean analysis studies, the exercise proved useful in bringing issues and possible solutions with S&C maintenance to light. It also provided front line staff with a means and opportunity to put forward suggestions as to how practices, processes and equipment could be improved.

### 7.1 Key Findings

The Project Work Stream Analysis clearly showed that the most important concerns raised during the workshop related to standards and procedures used for S&C maintenance. The key findings from the Process Observation, VSM workshop and additional Performance Killer analysis are summarised below.

#### Planning

- The process of inspecting and arranging possessions appears to be well defined and does not appear overly complex, but possessions need to be requested quite a long time in advance (a minimum of 14 weeks).
- The shorter the possession required, the easier it is to arrange and the less costly it is, particularly if it can be accommodated in “white space”.
- A number of concerns related to the requesting of time in track (i.e. possessions):
  - time booked by Contract Managers occasionally goes unused
  - there can be difficulty in arranging short notice repairs or those which are to take place outside white space / time
  - budgets can be lost due to the rejection or re-scheduling of maintenance
- Poor target setting (i.e. understanding what work is required) was also cited as causing unnecessary delays and costs where the work takes less time than expected.
- Non-standard crossings are difficult to deal with due to the long lead time for replacement components, and this is not always adequately taken account of during the planning process.
- The great majority of S&C maintenance activities are planned at relatively short notice following a visual inspection of S&C (i.e. at 14 weeks), with only about 1 in 7 being contained in the long term maintenance plan.

#### Build-Up Welding Repair

- There were two issues raised relating to target setting:
  - at the inspection 2 weeks prior to maintenance, it is sometimes realised that the amount of time allocated for a repair is insufficient
  - in addition, it can be difficult to determine what repair is required until the metal is ground back, which then results in a temporary repair being made
- There are no standard procedures for temporary repairs, resulting in large variations in quality and longevity of such repairs.

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## Crossing Replacement

- When the results of the Process Observation were analysed according to lean principles, the tasks were split fairly evenly between value added, necessary value added and non-value added. This suggests that there is scope to reduce “waste” as defined by lean principles.
- Staff time on-site was not being used efficiently, with only 33% of the crew actively working at any one time for the majority of the shift. There were various activities that could probably have been undertaken in parallel, though this was hampered to some extent by the availability and condition of key equipment.
- The marking up of rails prior to cutting is not always performed or done sufficiently accurately and the crossing does not always fit sufficiently well, resulting in extended repair times.
- In drier periods, sparks from grinding can initiate grass fires which then require to be extinguished, taking up valuable manpower.
- Rails can crack during cutting in very cold conditions, causing substantial delay while repairs are made.
- Although not directly a productivity / efficiency issue, concern was raised that ice can break off trains on adjacent lines that are open to traffic and potentially injure members of the maintenance crew.

## 7.2 Recommendations

The study produced a large range of recommendations, many of which were common or related to both crossing build-up repair and replacement. Therefore the following summary has been split accordingly.

### Planning

- Inspections could be made more effective by providing those involved with more information about the site (traffic since last inspection etc.) and possibly better inspection equipment, particularly for use on manganese crossings. Rotating inspectors across different routes would increase their experience and expertise.
- It is recommended that further investigation be undertaken to establish whether there are or could be better inspection techniques and/or deterioration rate prediction methods available. This could increase overall planning efficiency as faults could be detected earlier, and the deterioration of S&C more accurately predicted. This would help increase the proportion of work included in the long term maintenance plan, increasing overall planning efficiency and effectiveness. It would also potentially enable more detailed maintenance plans to be made at an earlier stage, reducing the occurrence of unused possessions.
- A better understanding of deterioration based on gathered data may help identify root causes for crossing deterioration (e.g. undesirable wheel / rail interaction). This could be supported by remote inspection equipment.
- Allied to the above, having a single database containing all of the information relevant to a particular crossing in one place would help plan activities and identify failure patterns and root causes. It might also help ensure that planned preventative maintenance is always carried out.
- A study should be undertaken to establish what would be required in order for all S&C maintenance activities to be reliably completed in a 3 or 4 hour shift. If this could be achieved, it could greatly assist

planning and reduce costs. If 3 hours were achievable, planning could be completed in 5 to 9 weeks instead of the current 14 week horizon.

- The following options should be considered in order to minimise the impact of long lead times on maintenance efficiency:
  - adopt a longer planning horizon for maintenance of curved S&C
  - discourage the future use of curved S&C by applying a large cost penalty when planning new or renewed track layouts
  - standardise wherever possible on a few types and geometries of S&C for new track layouts or renewals to reduce delivery times
  - stock a range of non-standard S&C components to ensure delays are minimised
- Greater emphasis needs to be placed on the entering of key information into the BIS to help with planning, and to make sure that better information is readily available to those involved with planning and undertaking maintenance activities.
- The timing of the maintenance plan and the allocation of the maintenance budget need to be better aligned to avoid having to re-work the plan if the requested budget is not made available.

### **Build-Up Welding Repair & Crossing Replacement**

- A trial should be undertaken to establish whether the overall time taken to effect a repair could be reliably reduced to three or four hours by:
  - using a plasma cutter to remove and prepare the damaged crossing
  - using water mist sprays to cool welded areas more rapidly (four welds currently take around 1.5 hours to complete)
  - using a manual milling machine instead of a grinder to restore the rail profile through the crossing (this would also help reduce the risk of lineside fires)
- Related to the above, the Process Observation suggested there is scope for certain activities to take place in parallel to reduce overall working time (the observations relate to crossing replacement, but similar comments are likely to apply to repair):
  - having a second crew member cutting the rails in parallel
  - preparation of the next mould while welding is in progress on a previous one
  - having an second crew member starting to remove excess material from welds as soon as they are completed
- The equipment used by maintenance teams needs to be in good condition, and there needs to be sufficient equipment to enable parallel working for certain tasks as described above.
- Standard processes need developing for maintenance tasks including:
  - measuring rail temperature and applying a pre-cut below a certain temperature
  - ensuring that the measurement and cutting of rails is sufficiently accurate to ensure that the replacement crossing always fits

- developing standard procedures for temporary repairs to reduce the variation in quality and durability
  - ensuring that the post 0.1 MGT reworking of a repaired rail's profile is always carried out
- Consideration should be given to whether it is feasible to always replace crossings rather than doing repairs on-site. If this were possible, it offers the following potential advantages:
  - it would prevent delays on-site due to unexpected problems encountered during a repair, and avoid the need to undertake temporary repairs
  - it would reduce the impact of harsh weather conditions which can affect the ability and quality of repairs to crossings
  - it would reduce the exposure of workers to dust and fumes
  - replacing a crossing typically takes less time to than to repair one
  - the quality of the repair is likely to be to a higher standard if done a in workshop, and both profile and crack inspection could be done more easily
- There were also a number of relatively simple, practical suggestions that could increase work efficiency as follows:
  - contractors should be allowed to sign out access keys, and ideally the same key should be used to control lighting
  - train dispatcher numbers should be made more easily accessible, through a protected website for example
  - work order numbers should be sent by SMS instead of being faxed

### **7.3 Other Recommendations**

There were a number of “blue sky” ideas that may be worth further consideration as part of the AUTOMAIN project or otherwise:

- Develop a laser based profile measurement system to assist with crossing repair and replacement, as well as to increase understanding of wear and deterioration (*this is already being done as part of the AUTOMAIN project*).
- Investigate the feasibility of replacing traditional crossings with the swing nose type to reduce contact forces and metal fatigue.
- Introduce X-Ray equipment to identify crossing defects prior to crossing installation, or possibly also to assist with track inspections.
- Develop a better understanding of the relationship between track geometry and S&C deterioration rates.
- Investigate the use of stoneblowing to increase the longevity of S&C by providing a more durable supporting ballast structure (*a report on stoneblowing has been produced as part of the AUTOMAIN project*).
- Determine whether bainitic steel could be advantageous to increasing track life.
- Investigate the potential for laser welding in crossing replacement and repair.

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It is further recommended that further Process Observations and VSM workshops be undertaken so that comparison can be made between the maintenance practices of different administrations.