AUTOMAIN

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

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D2.2: Lean Analysis of Track Maintenance Process

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Document Summary Sheet

This document contains the result of the work from the second phase of Work Package 2 (WP2) of the AUTOMAIN project. As stated in the preceding Deliverable 2.1, the main objective of this phase is to analyse current working practices in relation to tamping, and understand how these could be improved through the introduction of new technologies and methods. The work is based on the application of Lean Analysis techniques (namely Structured Observations and Value Stream Mapping) to evaluate current track maintenance practices and processes. It also includes Social Network Analysis of the communications involved in planning railway maintenance.

The document is the report covering deliverable D2.2.

Additional information	
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History			
Draft 1	29 March 2012	First draft	Initial document written by Stephen Kent for internal circulation and review by members of WP2. Report based on working documents produced by KM&T and UoB.
Draft 2	4 May 2012	Second draft	Feedback from participants incorporated, and Executive Summary and Conclusions sections written by Stephen Kent. Chapter 7 completed by Stephen Kent and Danny Mignott.
Issue 1	10 May 2012	First issue	First issue of report incorporating further feedback from participants.

Executive Summary

This document is the report covering Deliverable D2.2 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 and compare the approaches taken by a number of railway administrations participating in AUTOMAIN. The previous deliverable concluded that the focus of the work should be on tamping, and two methods were used to evaluate and compare current practice, namely:

- Structured Observations – where 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 as a means of identifying issues and suggestions for improvement

Additional work on the Social Network Analysis (reported initially in Deliverable D2.1) was also undertaken. The analysis highlighted a number of interesting differences between administrations, and a selection of key findings and recommendations is as follows:

- There is scope to reduce the duration of possessions by employing best practice such as using data from track recording cars to calculate vertical and lateral alignment corrections, having multi-skilled staff, and enabling adjacent lines to remain open to bi-directional traffic during maintenance.
- There are a number of technological developments that could further enhance productivity such as multi-functional high output machines capable of recording and working in either direction, and which minimise set up times on site.
- There is often insufficient emphasis placed on the longevity of the maintenance that is performed, with targets currently based only on track lengths maintained.
- There is scope to improve the planning of track maintenance, and this appears to have even greater potential to reduce overall possession times than improvements to the actual maintenance processes and technology.
- There is a need for a more reactive approach to planning and undertaking maintenance, with a shorter interval between planning and implementation, facilitated by improvements to both technology and process.

There were a large number of other suggestions for improvement generated by this work, many of which directly support or have implications for subsequent work packages within the AUTOMAIN project. These ideally need to be prioritised according to their likely effectiveness, cost-benefit ratio, and potential impact on other AUTOMAIN work packages.

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1.0 Introduction

The key objective of Work Package 2 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. The first part of the 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 selected for further evaluation. Therefore this deliverable looked at the application of best-practice maintenance technologies and procedures in relation to tamping possessions.

This was done by using various Lean Analysis techniques and tools that have previously proven effective in other industries (please refer to Section 2.3). It was anticipated that the primary benefit of this approach would be to provide greater insight into areas for improvement within the industry.

The consultancy company KM&T was commissioned to undertake Lean Analysis of typical tamping possessions for a number of railway administrations participating in the AUTOMAIN project including Network Rail (UK), SNCF (France), Deutsche Bahn (Germany), ProRail (Netherlands) and Trafikverket (Sweden), the last two being though their maintenance contractor Strukton Rail. This involved KM&T undertaking a Structured Observation of a tamping shift in each country, followed shortly afterwards by an office based Value Stream Mapping (VSM) workshop.

These sessions proved to be highly effective and worthwhile, and there were a number of clear and interesting differences noted between different railway administrations, as well as a good number of common issues, and a raft of suggestions for improvement. However, it should be borne in mind that only a single Structured Observation and a single VSM workshop were undertaken for each administration. It is therefore not advisable to draw conclusive comparisons on the relative merits of the practices and processes of different administrations based on this report.

The objectives of Deliverable 2.2 were further supported by development of the Social Network Analysis undertaken by the University of Birmingham, the initial stage of which was reported in Deliverable 2.1. The further work described here maps out the social interactions that take place during the planning process, with actual interactions measured by means of an on-line questionnaire.

The direct output from both the Lean Analysis and the Social Network Analysis has been detailed separately in two working documents submitted separately by KM&T and the University of Birmingham. This report summarises the output of both of these to form Deliverable 2.2.

2.0 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 proposed changes is in a number of stages, the first of which is 2026 (i.e. fourteen years from now).

2.2 The Tamping Process

The action of rail traffic causes track to degrade over time and 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 (slow walking pace), 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

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.

There is an alternative process called stoneblowing that is used in the UK, along with tamping. While similar in many ways, instead of squeezing existing ballast, a measured quantity of fresh stone is blown underneath each sleeper to effect a change in track height.

2.3 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 1 – 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 and non value-adding activities. From these, three core approaches were proposed for the AUTOMAIN project:

- to undertake 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
- to map out both the maintenance and planning processes during as series of Value Stream Mapping (VSM) workshops, including the quantification of key parameters wherever possible (the duration of the task, the manpower required, the probability of each step occurring right first time etc.)
- to produce 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.

2.4 KM&T

KM&T is a UK based consultancy firm that specialises in applying lean processes to services, manufacturing and operations in numerous industries. Working throughout Europe, North America, the Middle East and Australasia, 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 started by an ex-Toyota engineer with the intention of applying this approach and associated techniques to other companies and industries. A large proportion of KM&T consultants are also ex-Toyota employees who have first-hand experience and knowledge of lean approaches.

2.5 Social Network Analysis

A Social Network Analysis is a way of evaluating the roles and communications that take place during a process or situation. It can be used to identify information bottle necks, observe the influence of organisational structure on communication flows, and help identify the key / most influential roles within an organisation. This can ultimately be used to help construct internal networks that are more resilient to adverse change, and that can adapt and react quickly while operating in an effective and efficient manner.

This analysis technique was applied to Network Rail's Aligned Planning Process (described below) to determine how accurately this represents reality, and to determine whether there is scope for improving this process. It was also used to map out the timescales involved with communication between roles during the track maintenance planning process.

2.6 Network Rail's Aligned Planning Process (APP)

In order to simplify any complex process such planning track maintenance, there needs to be an understanding of what the process actually is. Network Rail attempted to do this by generating the "Aligned Planning Process", shown diagrammatically in Figure 2, which represents a summary of the rail standards involved in planning track possessions.

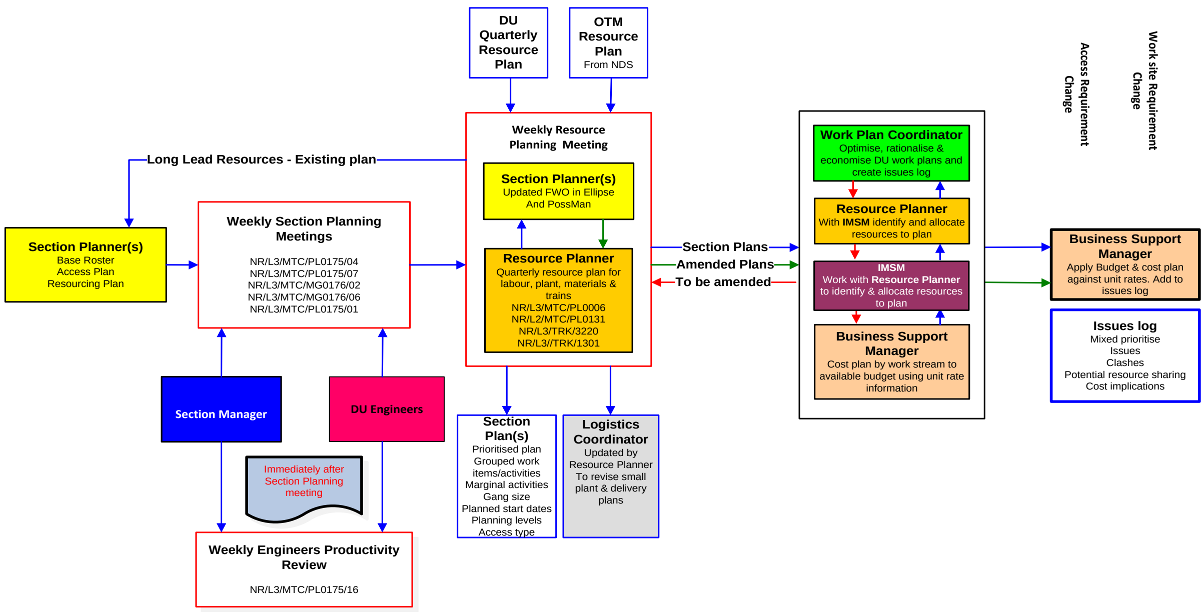

Figure 2 – Network Rail's Aligned Planning Process

3.0 Summary of Work Undertaken

The Lean Analysis was undertaken by KM&T between September 2011 and December 2011, and involved the following railway administrations (presented in date order):

- Network Rail in the UK
- Deutsche Bahn in Germany
- SNCF in France
- Trafikverket in Sweden, through their maintenance provider Strukton Rail
- ProRail in the Netherlands, through their maintenance provider Strukton Rail

Running in parallel, the University of Birmingham undertook further Social Network Analysis of Network Rail's track maintenance planning process.

3.1 Structured Observations

Structured Observations were undertaken for a single maintenance possession for each of the administrations listed above. Each event was attended by KM&T representatives who observed the full maintenance shift, from the 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 5 generic tasks:

- confirmation = confirming granting of possession
- waiting = waiting for equipment to arrive
- communication = phone calls and creation of documentation
- tamping = carrying out the tamping activity
- transportation = moving of tamping equipment to location

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. For this study, it would have been very difficult and time consuming to arrange observations of directly comparable tamping shifts for the different railway administrations. A decision was therefore taken to observe broadly similar possessions, accepting that there would be differences in the type and reason for the maintenance, type of track, machine, time of day etc.

3.2 Value Stream Mapping (VSM) Workshops

Each of the above observations sessions was followed shortly afterwards by a VSM workshop, attended by experienced machine operators and maintenance planners, hosted and directed by representatives from KM&T. Additional support was also provided by the

University of Birmingham at a number of these workshops, primarily to assist with the translation of railway terminology. 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 previously by KM&T from the Structured Observations

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 process of tamping, in terms of the overall availability of track, the planning process is of equal (if not greater) importance:

- maintenance needs to be carefully planned to avoid waste – the overall maintenance process will only be efficient if the right machine and staff are sent to the right location at the right time
- it is likely that, at some future point, the targeting of maintenance will be based on the measured rate of deterioration at each precise location – it is therefore important that the maintenance planning process can react sufficiently quickly to cope with this

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 Process Map (Network Rail tamping posession)

Each vertical line of 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 is a white note which was used to gather estimates for key parameters including:

- the cycle time for each step (how many hours it take to complete a particular step)
- the manpower required
- the chances of the step being "right first time"
- the operation frequency (how many times a particularly task is undertaken for a particular process) – this also gives an indication of the amount of re-work

Beneath the white notes are further rows of blue notes to record concerns, and yellow notes to record ideas for improvement. As can be appreciated from Figure 3, the sessions tended to elicit a large number of concerns, but they also generated a similar number of ideas for improvement (further detail is provided in Section 5.0). Ideas generated that were not specific to a particular step were recorded in a separate area denoted the "car park".

Following this analysis, a Hand Off Diagram was also produced to detail the communications that take place between different roles during the planning, tamping and post tamping stages. This was used to demonstrate the complexity of interactions between those involved. An example diagram is shown for the Strukton Rail workshop below, and further information on Network Rail's specific process can be found in Deliverable 2.1:

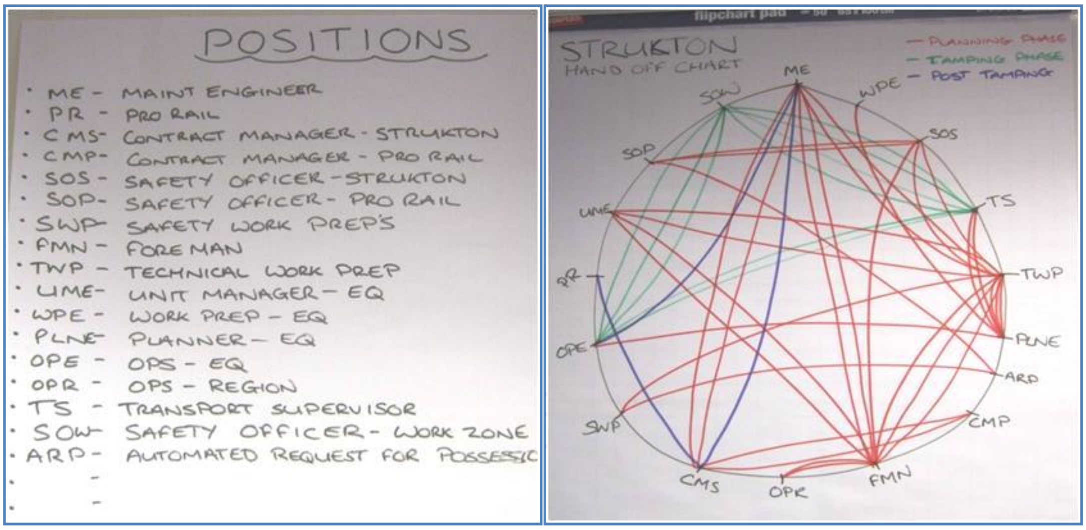

Figure 4 – Typical Hand Off Diagram (Strukton Rail)

3.3 Social Network Analysis

This work was completed in two stages, the first being an analysis of Network Rail's Aligned Planning Process (APP) to identify roles involved in the planning process, and also to gain insight into the structure of the social network that might exist between these roles (as reported in Deliverable 2.1). This was followed by the capture of the actual social network that exists by means of a questionnaire issued to members of a UK based track maintenance delivery unit. This on-line questionnaire was sent directly to the staff performing the roles identified, asking them to indicate via means of a sliding bar scale the relative amount of communication they had with other roles, as well as various other communication parameters. Analysis of this data provided an indication of the number and complexity of communications, the number of roles involved, the identification of information sinks generators and distributors, it enabled a time plot to be generated showing the timescales involved, and identified the overall distribution of communication activity.

This work was comparable to the Hand Off Diagrams produced by KM&T, as described in Section 3.2. However, the UoB studied a single railway administration in depth, while the less detailed study by KM&T enabled comparisons to be drawn between different administrations.

4.0 Findings – Structured Observations

Please note that although comparisons are made below between different administrations, this was on the basis of information gathered from a single Structured Observation for each administration. The type of maintenance being undertaken and its objectives were not necessarily the same in all cases, and the operating conditions varied significantly (e.g. the ProRail and SNCF observations were undertaken for daytime possessions, whereas the others were at night). Therefore care needs to be taken when drawing comparisons between railway administrations from what follows.

The primary observation made is that only a limited proportion of the overall possession was spent on the tamping activity, typically between 42% and 50% (noting that it was not possible to record exact timings for the SNCF possession). The remaining possession time was taken up to varying degrees by:

- confirmation = 6% to 15%
- waiting = 7% to 25%
- communication = 1% to 10%
- transportation = 17% to 21%

There were a number of further differences noted which influenced the overall rate of productivity:

- the need to undertake a recording run prior to starting tamping accounted for 9% of the Network Rail possession, but no recording run was required by SNCF as track data had been pre-loaded from a measurement train
- there was variation noted in the production rate of different operators of during the Network Rail possession, although it should be borne in mind that there is usually a degree of natural variation during night shifts, and there may have been other factors such as variations in the size of lift required at different locations
- the SNCF, Trafikverket and ProRail maintenance was targeted at specific locations within the possession, whereas the Network Rail and DB maintenance was undertaken on a continuous length of track
- the number of concurrent processes was different between administrations, with DB having dedicated personnel for track measurement, ballast shaping and the protection of track and lineside cabling, which potentially increases productivity at the cost of extra manpower

It was also observed that in the case of the SNCF possession, the adjacent line remained open to traffic, although the overall volume was low at just 2 trains in a 2 hour period. It is unclear whether this was true of the other maintenance possession observed, but it is understood that Strukton also undertake work on certain ProRail lines with adjacent tracks open to bidirectional traffic.

Although the speed at which the tamping process can be undertaken is limited by the rate at which track can be clamped, lifted, slewed and squeezed, the number of tamping banks (i.e. the number of sleepers that can be treated in one movement) can have a significant impact on productivity. The chart below shows the relative capacity of different machines in terms of metres tamped per hour:

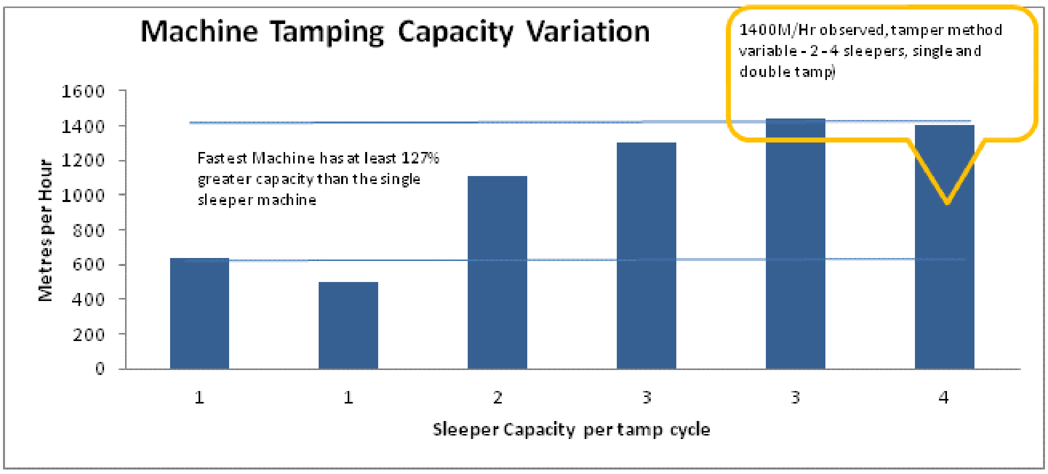

Figure 5 – Tamping Machine Capacity

From this, it is clear that the production rate for machines with three of four banks of tamping tines can be substantially higher than those with a single bank. However, it should be borne in mind that there are circumstances where it is not optimal to use multiple bank tampers such as where the spacing of sleepers is uneven.

A further observation was that the operators from Strukton Rail (working on behalf of ProRail and Trafikverket) were multi-skilled. This potentially allows all three members of the team to rotate roles during the course of the shift, potentially increasing overall flexibility.

5.0 Findings – VSM Workshops

As discussed in Section 3.2, the VSM workshops looked at both the planning stage as well as the maintenance possession that followed. This inevitably brought out various planning process issues which, although not directly part of AUTOMAIN's scope, potentially impact on the overall effectiveness and responsiveness of a maintenance programme.

Before looking at specific details, it is worth noting the very large number of steps typically involved in both planning and undertaking maintenance, as illustrated by Figure 3. A second observation is the very low ratio of value added activities to non value added activities. Many of the non value added activities relate to safety, but it is conceivable that changes could be made to the way in which these safety related steps are undertaken which could improve productivity without compromising safety.

5.1 Planning Complexity

The more complex the planning process is, the more scope there is for things to go wrong, thereby reducing the overall efficiency of the maintenance process. In addition, the greater the complexity, the less reactive a process tends to be, potentially limiting the ability to deal with emerging issues and problems in an efficient manner.

As a measure of planning complexity, the total number of steps involved in planning and undertaking a typical track maintenance possession was counted. The total varied between 44 and 72, with typically only 1 or 2 representing value added activities. Part of this variation could be due to differences in the level of detail with which steps were recorded, or due to the network size and traffic density. But even accounting for this, there does appear to be significant variation in the complexity of the planning process between administrations.

5.2 The Planning Period

It was suggested that the length of time required for existing planning processes means that maintenance planners are in some cases having to take an educated guess as to what maintenance will be required on a particular section of line well at some point in the future. This frequently means that the maintenance undertaken does not necessarily match the maintenance actually required. This is potentially wasteful of resources, and it can result in unnecessary work being undertaken.

The maintenance planning period was therefore investigated, and the time taken from the start of the maintenance planning process through to the actual possession was typically between 10 and 36 months. While this is a large variation between administrations, the key point is that almost all preventive (non-emergency) maintenance activities are planned at least 1 year in advance.

5.3 Cycle Time

Although not directly within the scope of the AUTOMAIN project, the total cycle time (i.e. the total amount of time spent on planning and undertaking maintenance) was estimated for a typical tamping shift from the information collected at the VSM workshops. This varied between approximately 800 and 1200 minutes (please note that values were not available for DB). While there is some variation, this suggests that it takes a total of around 17 hours to plan and undertake a typical tamping maintenance possession. This total was split further according to activity type:

- data collection including track condition information (1% to 8%)
- planning (46% to 52%)
- preparation including pre-tamping shift checks and site meetings (8% to 12%)
- tamping (27% to 39%)
- documentation including signing off and hand back and shift reports (3% to 5%)

While there was variation between administrations, it is that the planning stage that commonly takes the largest overall proportion of the overall cycle time, with tamping only accounting for between 27% and 39%.

5.4 Right First Time

An assessment was made of the likelihood of an initial plan of action being implemented "as originally envisaged", i.e. without further revision. Although the method used to assess this was relatively crude, this was estimated to be between about 1% and 7%. Although these numbers may be surprisingly low, this is not necessarily due to any inadequacy of those involved in the planning and implementation of maintenance. It more reflects the complexity of current maintenance planning processes and the large number of external factors that affect it. The length of time that the planning process currently takes is almost certainly also a factor. Were a more reactive approach taken to track maintenance, the percentage of right first time possessions would almost certainly improve.

5.5 Concerns & Opportunities

A large number of concerns were raised at each workshop (typically around 60) along with a slightly lower number of ideas and suggestions for improvement (typically around 50). In order to better assess these, they were categorised as shown in Figure 6 below (the red line shows the cumulative values):

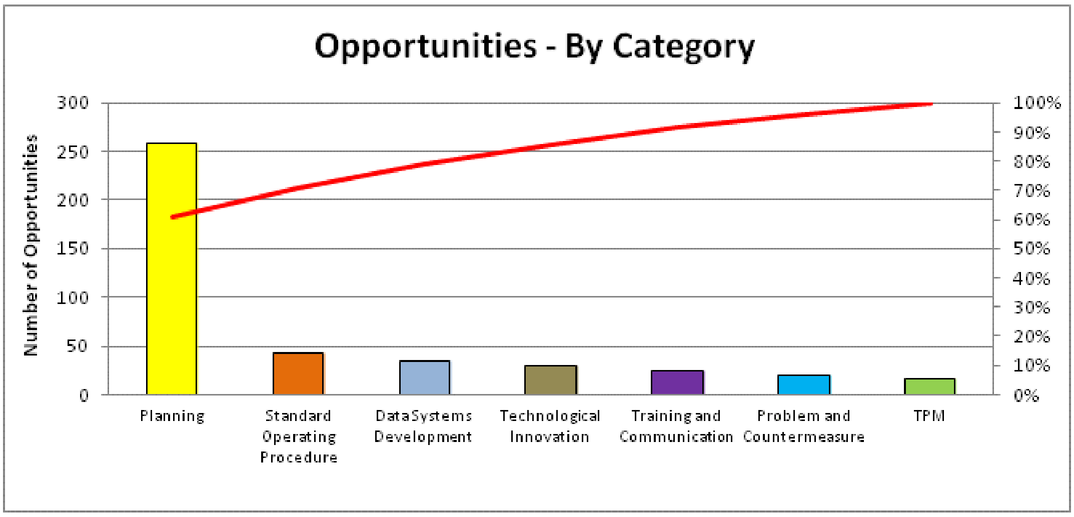

Figure 6 – Suggestions for Improvement

Although there were a good number of suggestions made in all areas, the graph demonstrates that there is greatest scope for improvement in the area of planning. A summary of the key concerns and opportunities is presented below.

5.5.1 Targeting of Track Maintenance

A common theme was the opportunity to improve the selection and targeting of areas of track for maintenance. In many cases, this is not done being done as effectively as it could be, partly due to incentives being based solely on the length of track maintained, and more widely due to the time required to organise and arrange tamping for a particular route or section of line (typically between 1 and 3 years).

It was felt that this situation could be improved by changing the incentives used by administrations, focussing more on the effectiveness of the maintenance that is undertaken. It could also be improved through the introduction of a more responsive approach to dealing with emerging track maintenance requirements. It was further suggested that frequent track recording using in-service vehicles would provide the rate of deterioration information necessary to support a more responsive maintenance planning process. But others suggested that trend analysis based on the measurements currently made by dedicated track recording trains is sufficient to predict when maintenance will be required.

5.5.2 Allocation & Availability of Suitable Resources

Although planners have a great deal of skill and experience, it was highlighted that there are no specific software tools available to help them deal with the very complex task of aligning requirements and resources (i.e. typically done using an Excel spread sheet). A similar concern was also raised in relation to the decisions on what remedial measure(s) should be applied to address specific problems at a particular location. For example, it is unclear how far track should be allowed to deteriorate before intervention is appropriate, and what rate of deterioration should trigger a particular maintenance activity.

Aligning resources and requirements was often made more difficult by a lack of machinery and manpower, and the almost inevitable mismatch between machine and track availability. It was suggested that national visibility of resources rather than the current local level would help mitigate this effect.

It was also commented that maintenance budgets and tamping targets without due consideration for the amount of work that actually needs to be undertaken, on some occasions being insufficient, and on other occasions being excessive.

The situation is complicated further by the need to use a specific type of tamper to maintain switches. It was suggested that machines able to work both plain line and S&C areas would be of benefit, and although so-called “universal tampers” do exist, their output is tends to be significantly lower than that for dedicated plain line machines.

5.5.3 The Reliability of Planned Possessions

Planned maintenance is frequently cancelled, delayed or curtailed due to problems or last minute changes due to problems with stabling or the incorrect booking of paths for tampers to and from work sites. Weather conditions were also cited as a further reason, with ballast being frozen solid in winter, and concerns over track buckling causing concern during summer months. More accurate weather predictions would be beneficial, and there may be other means of more accurately determining the risk of track buckling in the summer which could potentially be employed to reduce overall possession cancellation rates.

5.5.4 The Quantity of Track Maintained

There were a large number of issues cited that influence the quantity of track maintained during a given possession duration. This included:

- the distance between the machine stabling point and the worksite
- the limited speed of the tamper when travelling to and from the work site
- the low availability of track crossovers, which frequently result in long distances being travelled to get machines to the work site
- the time spent waiting for the machine to warm up
- whether the machine arrives at the work site facing in the correct direction to start work immediately
- the maximum speed the driver deems it safe to traverse a worksite, with some going at speeds significantly lower than the maximum allowable according to safety regulations (typically 40 kph within a possession)

- whether a recording run is required, and the time required to input track geometry data into the machine's control system
- whether or not the machine can record in one direction and then immediately start tamping in the other (some designs can only measure and work in a single direction)
- the other work activities going on at the same work site

Certain of the issues raised could be solved through technological developments such as using tampers capable of recording and tamping in either direction. There are other innovations suggested including machines that could warm up while travelling to work sites, and machines that require no manual intervention to set up. The Non-Intrusive Crossover developed in the UK was also mentioned as one way of tackling the lack of available crossovers.

Others suggestions require a mix of technological and operational developments such as the use of track recording cars to provide pre-maintenance track data, thereby removing the need for an extra recording run prior to maintenance. Alternatively, track recording equipment could be installed on service vehicles, or on the tamper itself, traversing the worksite at some point prior to the maintenance possession. The development of so called "Geotag" systems which automatically transfer data to the tamper in preparation for maintenance was also mentioned.

5.5.5 The Quality & Durability of Track Maintenance

There were several comments made about the lack of standardisation regarding key tamping parameters such as the optimum speed of tamping, the pressure to be applied to the tamping tines, and the depth at which they are inserted. It was suggested that there is a need for better guidance on the optimum approach.

It was further suggested that maintaining track to a very high quality could reduce the overall deterioration rates. By contrast, more than one workshop suggested that a significant proportion of tamping actually makes track quality worse (as much as 25%). The reasons for this were not made clear, but if true, this indicates that there are problems with the current approach.

It was also commented that stoneblowing can provide a more durable track geometry than tamping, though it may only be suitable for certain lines.

5.5.6 Other Suggestions

Track maintenance machines have been developed that can drive on and off the tracks, typically by pivoting on a central hydraulic ram at level crossings. The use of such machines could improve flexibility, potentially enabling quicker access to work sites and reducing the time taken to clear the work site in preparation for re-opening it to traffic. This could also be beneficial in terms of targeting smaller areas at short notice.

As described previously, considerable time is spent establishing and subsequently releasing possession of the line. It ought to be possible to run the tamper as a "slow moving train", whereby it provides its own protection by activating track circuits or other train detection equipment in the same way that a regular train would. This would offer considerable scope to increase productivity, reduce both planning and possession time, cut down manpower requirements and allow a more responsive approach to be taken to track maintenance. It is understood that this approach is currently being considered by Network Rail, and trials have also been undertaken by Strukton. These trials involved maintaining short sections of track in between regular train services, but production rates were low, and extra personnel were required at road crossings.

5.6 The Hand Off Diagram

A complexity of the planning process was also reflected in the Hand Off Diagrams. There was a degree of variation in the number of roles involved in planning the maintenance process, between 17 and 24, with a much larger variation in the number of Hand Offs (i.e. communications between roles), between 42 and 114. This suggests that some administrations are more efficient than others, but in all cases, there are a large number of roles involved and a large overall volume of communication.

6.0 Findings – Social Network Analysis

A social network diagram showing the analysis of Network Rail's Aligned Planning Process (APP) was reported previously as part of Deliverable 2.1 (contained in Appendix 1). For this deliverable, a questionnaire was issued to investigate the actual social network that operates in reality, and the responses received were sufficient to map the process for a typical maintenance planning team, as shown in Figure 7.

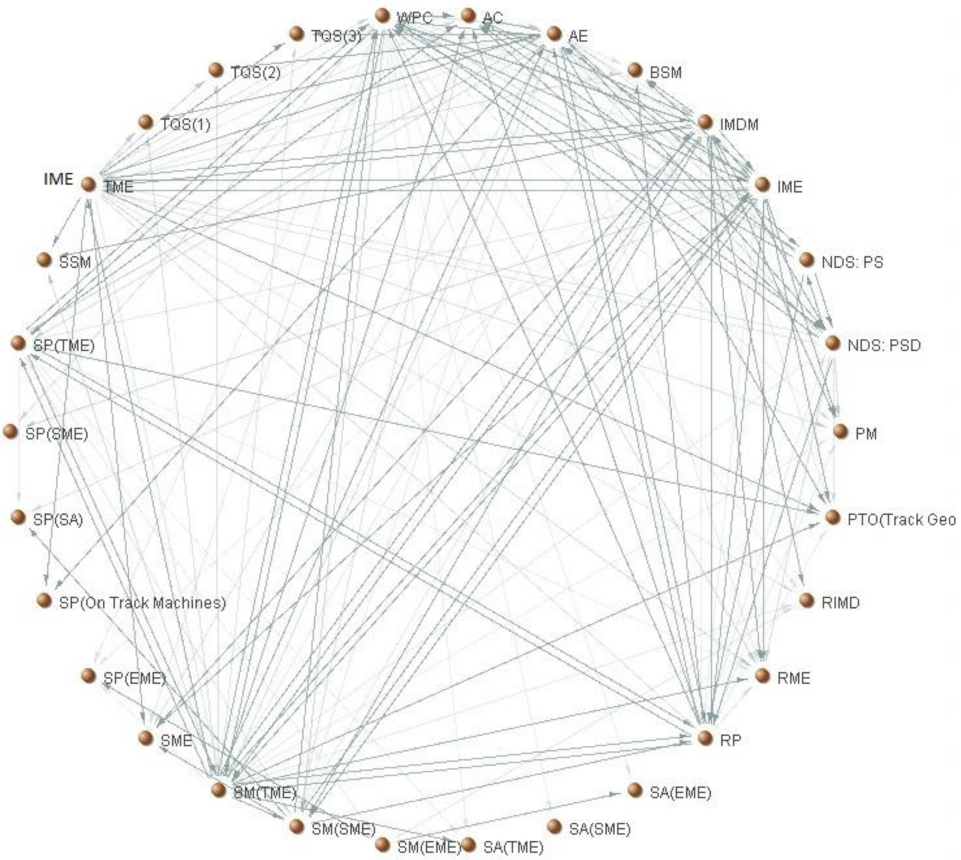

Figure 7 – Actual Social Network According to Questionnaire

Each node around the circle represents a role within the process, and each line representing a communication between those roles. Comparing the above with the diagram produced for Deliverable 2.1, the actual planning process appears to be slightly simpler than that according to the APP – there were slightly fewer roles involved than identified in the APP for example. But in general, it was felt that the APP represents an excellent effort at summarising all the rail standards involved in planning track possessions in the UK.

Further analysis was undertaken of what proportion of the overall communications take place when in the planning cycle. Shown below are two figures, the first according to the APP and the second according to the results of the questionnaire:

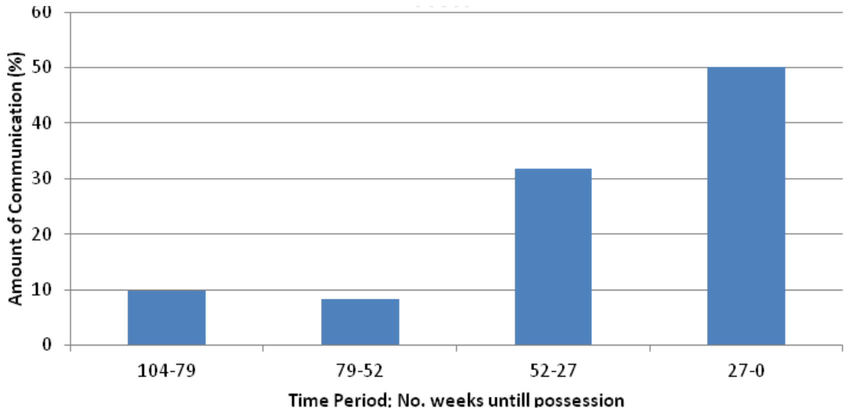

Figure 8 – Timeline of Communication According to APP

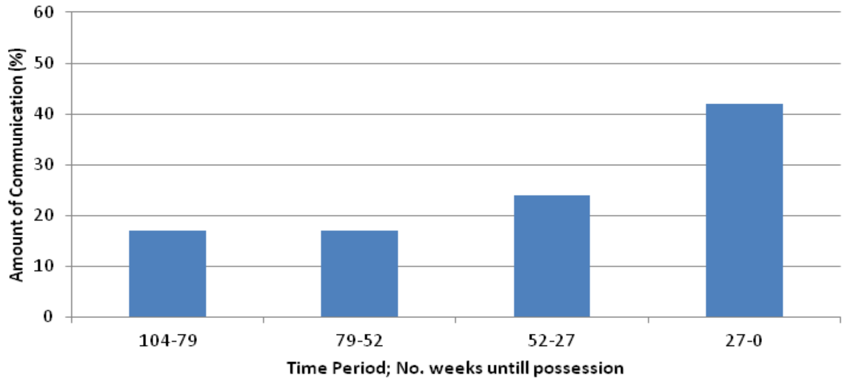

Figure 9 – Timeline of Communication According to Questionairre

There is a strong similarity between the distributions, suggesting that the people in the network adhere to the timetable laid out by the APP, and the detailed analysis showed that the majority of communication for a possession occurs in the last 27 weeks of the process. This suggests that there may be scope to reduce the overall planning timescales.

7.0 Opportunities for Lean Approaches

A review was undertaken of the findings of the Structured Observations, VSM Workshops and the Social Network Analysis from a lean process perspective. This analysis was split into aspects relating to planning, operating procedures, and supporting data systems.

7.1 Planning

One of the key observations was that the planning of track maintenance involves a complex and lengthy process, involving multiple departments with long lead times. This hinders the flow of information, which in turn delays the decision making process and creates waste within the value chain. Breaking this analysis down further:

- Planning procedures:
    - the planning processes lacks standardisation, with not only variation between administrations (which is to be expected), but also variation between regions
    - there is considerable interference to the planning processes from a multitude of unplanned events such as changes in policy, budgets, availability of machinery or other high priority maintenance work for example
    - there are multiple re-work loops due to low levels of information and long time frames
    - there is relatively low utilisation of possession time, and often a low level of confidence which prompts high levels of contingency time to be planned in
- Manpower & skills:
    - the effectiveness of the plans can be hindered by the degree of variation in delivery rates between different machine operators
    - there were instances where the scheduling of manpower resulted in high value machinery standing idle during possessions, and other instances where appropriately skilled staff were not available at the required time
    - there is low visibility of skill level requirements or status within maintenance crews, and low visibility of optimum training requirements
- Infrastructure:
    - there was a low level of standardisation in terms of infrastructure design (e.g. variable sleeper types and spacing) which further complicates the planning process
    - there is considerable potential to improve the overall Life Cycle Cost through improvements in the planning stage

    - the reduction in the availability of convenient stabling points greatly reduces operational flexibility
- Machine selection:
    - there was limited flexibility and highly variable capability between machine types
    - the suitability of tamping machine designated for a given location / possession was frequently less than optimal
- Target setting:
    - targets are frequently set according only to the length of track to be tamped, which tends to result in inefficient and ineffective maintenance planning
    - there is insufficient understanding of the optimum point at which to plan intervention

From these observations, a number of proposals were developed in five key areas.

7.1.1 Standardised Planning Procedures

There is an opportunity to better standardise procedures and processes across regions and railway administrations. This would assist with the adoption of best practice, and increase the proportion of events happening right first time. It would also help optimise the use of possession time, drive correct behaviour, and reduce the need for contingency time. This also applies to the selection of machine (and machine settings) to ensure that the optimum set up is employed for a given track section or route. The intention should be to design processes and procedures such that they are easy to do correctly and difficult to do incorrectly, in effect error proofing the process.

7.1.2 Improved Manpower & Machine Allocation

There is benefit to be gained from improving manpower scheduling procedures to ensure that appropriately skilled staff are available when required. This potentially includes both the development or introduction of improved manpower scheduling systems, and increased staff versatility. The approach of training up a workforce such that they are multi-skilled has already been shown to be successful in other industries. Here, it could help reduce the number of cancelled or curtailed track possessions, as well as increasing the overall efficiency of the work undertaken during the possession.

Similarly, there is also benefit to be gained through ensuring the best allocation of machinery for a given set of maintenance requirements. Software is available for this, but is not widely used.

7.1.3 Infrastructure Development & Design

A number of issues were identified where the design of the infrastructure hinders efficient maintenance. When designing new or renewed infrastructure, there is a need to plan track layout and design for efficient subsequent maintenance, for example mandating the use of hollow sleepers where cable runs cross the track. There is also a need for greater standardisation, ensuring that track always has consistent sleeper spacing, track fixings etc. The consideration and incorporation of stabling to facilitate maintenance is another consideration, ideally reversing the current trend to remove crossovers and sidings. Although there are cost implications, consideration of optimal track design and construction from a total life cycle point of view might well justify such approaches, but there is currently insufficient understanding of what the optimum design actually is.

7.1.4 Tamper Development

While improvements to machine allocation (as described in Section 7.1.2) would be beneficial, the development of multi-purpose tampers capable of working plain line at high production rates as well as maintaining switches could also increase productivity. Likewise, the ability to record and work in either direction would reduce the amount of non-productive time during a typical maintenance shift. Emphasis is currently placed on the first cost of track maintenance machinery, but the value of potential savings over the life of the machine may well justify greater initial expenditure.

7.1.5 Improved Target Setting

There are instances where, for example, the duration of a planned possession does not match with the amount of work to be undertaken (this could be insufficient or excessive). There is an increased need for a data led approach to define realistic maintenance targets. This also ties in with the need for better machine allocation and the need for multi-skilled operators. There is also a pressing need to revise targets to consider both the quality and longevity of the maintenance that is undertaken.

It is also interesting to note the different approaches by different administrations, certain of whom will tamp through an entire section of line if there are several small areas requiring attention, while others will transit between sites. It remains unclear what the best approach is, although it is quite conceivable that different approaches will be appropriate under different circumstances.

7.2 Operating Procedures

In terms of the procedures and practices applied during a typical maintenance shift, there were significant differences observed, particularly between different administrations. This was particularly evident in the area of safety procedures, and also for the start up checks and pre-shift briefings. It was observed that safety measures typically happened in series, and it may be possible to deploy safety measures as a parallel activity, or to undertake them in a different way. One example would be undertaking machine safety checks and safety briefings prior to arriving on site, and further study of best practice would be worthwhile.

It is also worth considering that if the duration of possessions were to become shorter, there should be increased potential for “make ready time” prior to possessions.

7.3 Supporting Data Systems

Data recording and analysis typically forms a critical component for delivering quality results in accordance with customer demand. In relation to track maintenance, insufficient or inaccurate data relating to the track condition was frequently cited as the cause of poor decisions being taken on where and when to tamp. The need for accurate, comprehensive and regular infrastructure condition data was clearly identified to enable track deterioration rates to be monitored. This potentially also negates the need for pre-maintenance recording runs during the possession, thereby saving valuable time.

Although this issue relates more to technology than directly to the adoption of a lean approach, none-the-less, the accuracy and timeliness of track data impacts directly on possession time and the effectiveness of the maintenance undertaken.

7.4 Organisational & People Issues

A high number of concerns raised during the workshops related to poor communication, fluctuating skill levels and knowledge of staff. From observation, clear roles & responsibilities and standards are not always understood, yet this is crucial at every level of an organisation.

In order to tackle this, the greater adoption of Standard Operating Procedures, where the right level of information is provided to the right people, could help. A further suggestion is increased visibility of staff skills, perhaps in the form of a versatility matrix, identifying who is competent to work in which area and at what level.

8.0 Conclusions

Lean Analysis techniques are applicable and helpful within the railway context, and they provide an effective method of bringing issues and potential solutions to light. They also provide a structured channel of communication between staff and the management of large and complex organisations such as railway administrations. Here, the analysis has been used to look at one aspect of infrastructure maintenance, and it is suggested that there would be benefit to applying this approach more widely.

8.1 Key Findings

The key findings from this study were as follows:

- There is scope to improve the effectiveness with which time is used during maintenance possessions. One area of potential savings relates to the time spent travelling to and traversing the work site (an issue likely to get worse given the tendency to remove switches an sidings), and other aspects related to the abilities of the equipment used. There is also the possibility of reducing the overall number of non-value-added procedures that currently need to be undertaken. While many of these relate to safety and are therefore rightly considered necessary, certain of these could be undertaken in a different way or at a different time to increase overall productivity.
- Improvements to the planning process have even greater potential to impact on the effectiveness and efficiency of the maintenance undertaken. There is scope to reduce the number of maintenance shifts cancelled or curtailed due to logistical problems, and also to better optimise the allocation of manpower and machinery. But there are also different maintenance strategies that could be adopted such as a more reactive, targeted approach, based on increased use of track geometry and condition data.
- There were differences observed between administrations in the complexity of the procedures involved with planning and undertaking track maintenance. Further study is required to determine the reasons for this, but there would appear to be a degree of scope to apply best practice.
- Certain administrations set production targets for maintenance planners based only on the length of track to be maintained within a given time period. This can be inefficient as it occasionally results in excessive or unnecessary maintenance being undertaken.

According to the findings, the content of following work packages within AUTOMAIN will help tackle a number of the issues highlighted. In particular, the ability to accurately measure and map out track degradation through in-service vehicle track measurement is particularly exciting, as is the proposed development of tools to help plan maintenance more effectively. A summary of the overlap with and implications for the other work packages is provided in Appendix A.

8.2 Recommendations

The recommendations from this study are as follows:

- Those railway administrations that do not already do so should consider whether it is possible to increase the use of track recording cars to determine vertical and lateral corrections required, instead of undertaking a recording run prior to maintenance.
- Training maintenance crews to be multi-skilled will increase flexibility and reduce the number of shifts cancelled or curtailed due to the shortage of appropriate staff. International exchange of experiences especially for rare high performance tamping machines will also increase knowledge of machine operators.
- A more condition based approach should be taken to track maintenance to improve its targeting and effectiveness and reduce the reliance upon educated guesswork as to what will need doing where and when at a point in time well into the future.
- 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.
- Certain administrations tamp only those areas deemed problematic, while others automatically tamp an entire length of line. An investigation is needed into which is the most effective approach, potentially also considering what is appropriate in what circumstances.
- Frequent recording by in service track measurement systems may be beneficial in detecting and rectifying emerging faults quickly and efficiently. Alternatively, better use of existing track recording data to trend deterioration rates may be just as effective. Further study is required as to the best approach.
- A system showing the national availability of maintenance resources (both manpower and machinery) would help mitigate the difficulty frequently encountered with aligning resources and maintenance requirements.
- The availability of more accurate and localised weather predictions could help reduce the number of shifts cancelled due to the risk of extreme hot / cold weather.
- Tamper manufacturers need to be encouraged to produce machinery with increased flexibility (e.g. can be used for both high output plain lines and switches), that requires reduced time and human intervention to set up, that can warm up during transit, record an work in either direction, and potentially drive on and off the tracks

at suitable locations – in order to support this, a whole life cost / benefit model or case study for an advanced tamper design should be undertaken.

- The potential use of Geotags which automatically transfer track data to the tamper in preparation for maintenance should be investigated further.
- The validity of the assertion that a significant proportion of tamping actually makes the track geometry worse needs validating, and if found to be true, the reasons for this need to be investigated and mitigated.
- There are diverging views on the effectiveness of tamping versus stoneblowing, and it is suggested that a further investigation is needed to establish whether (and under what conditions) stoneblowing is likely to be beneficial.
- It may be possible to run a tamper as a "slow moving train" in order to simply possession arrangements, effectively eliminating the non-productive time spent taking and handing back the possession. Further investigation into whether this is a realistic possibility are required.
- There have also been trials running a tamper as a "slow moving train" in between scheduled service trains in order to carry out maintenance. The experience of Strukton suggests that the production rate is low and that the success of the strategy depends on there being sufficient passing loops available. But consideration should be given to whether this approach warrants further investigation.
- There needs to be increased adoption of Standard Operating Procedures to drive correct behaviour and help error proof the process.
- The introduction of or improvements to systems (probably software based) to assist with the planning of manpower could provide significant benefit – this is already done in other areas such as crew rostering for Train Operating Companies and this software could potentially be adapted for track maintenance
- The introduction or development of a staff versatility matrix would be beneficial.
- The wider use of software systems to assist with the allocation of machinery and manpower to the maintenance requirements is worth pursuing.
- The design of infrastructure should be such that it facilitates efficient subsequent track maintenance (e.g. the mandatory use of hollow sleepers for cable runs). Guidance on this needs to be developed and it implementation supported.
- The requirements for stabling for maintenance machinery need to be considered by and incorporated into route utilisation strategies if it is not already done so.
- Machine safety checks and briefings should be undertaken prior to arriving at site if at all possible

The Lean Analysis undertaken for tamping has proven to be an effective means of bringing key issues to the surface, as well as generating a good number of suggestions for improvement. It is likely to be worthwhile repeating this approach for other aspects of track maintenance such as grinding and the inspection and maintenance of switches.

Appendix A: Summary of Implications for Other Work Packages

Many of the issues, concerns and suggestions raised during this work package have implications for other work packages within the AUTOMAIN project. A summary of the overlap in implications is provided in the tables shown below:

Standard Planning Procedures	Impact WP3 high speed inspection	Impact WP4 performance killers	Impact WP5 automated planning	Impact WP6 Demonstration
• The planning processes lack standardisation.	✓		✓	✓
• Interference to planning processes from a multitude of unplanned events			✓	
• Low utilisation of total possession length		✓	✓	✓
• Low confidence prompts high levels of contingency time planned into each possession		✓	✓	✓
Manpower Systems Development	WP3 high speed inspection	WP4 performance killers	WP5 automated planning	WP6 Demonstration
• Variable pace and delivery between operators		✓		
• Manpower scheduling procedures allow £1M + machine to stand idle during line possessions due to miss-matched rostering.		✓		
• Appropriately skilled people not always available at the correct time		✓	✓	

Infrastructure Development	WP3 high speed inspection	WP4 performance killers	WP5 automated planning	WP6 Demonstration
• Low standardisation of infrastructure design (e.g. variable sleeper types)		✓	✓	
• Potential for improved 'Total Life Cycle Cost' analysis during infrastructure planning phases.	✓		✓	
• Tamper 'Stabling Points' being removed or falling into disrepair reduces flexibility for tamping operations		✓		
• Potential for 'Systematic Maintenance Planning' during infrastructure design phases	✓	✓	✓	

Machine Selection	WP3 high speed inspection	WP4 performance killers	WP5 automated planning	WP6 Demonstration
• Low flexibility and highly variable capability between machine types		✓	✓	
• Low suitability machines regularly sent to tamping zones		✓	✓	
Target Setting	WP3 high speed inspection	WP4 performance killers	WP5 automated planning	WP6 Demonstration
• Low logic in some cases for tamping length targets with a possession		✓	✓	✓
• Low logic to target specific tamping zones	✓	✓	✓	✓
• Low understanding of optimum track condition to prompt tamping	✓		✓	✓

Standard Operating Procedures (SOP's)	Impact WP3 high speed inspection	Impact WP4 performance killers	Impact WP5 automated planning	Impact WP6 Demonstration
• SOP creation for best practice standardisation across regions		✓	✓	✓
Data Systems Development	WP3 high speed inspection	WP4 performance killers	WP5 automated planning	WP6 Demonstration
• Increase frequency of measurement runs	✓		✓	✓
• Reduce/consolidate data handling systems to one common system across the organisation – reduces variety and simplifies the process			✓	
• Automate analysing of data - optimises resource availability by freeing up staff and reduces the planning process			✓	
• Implementation of Geotag system - to eliminate the need for track visits	✓	✓		✓
Technological Innovations	WP3 high speed inspection	WP4 performance killers	WP5 automated planning	WP6 Demonstration
• Strong collaboration with Tamper Manufacturers to develop the high impact / high priority systems		✓		
Total Productive Maintenance (TPM)	WP3 high speed inspection	WP4 performance killers	WP5 automated planning	WP6 Demonstration
• Implementation of a robust equipment maintenance system improving availability and reliability		✓	✓	