Executive Summary:
This project provides new concepts and innovations to decrease time needed for rail maintenance and inspection ("possession-time"). Project results offer rail infrastructure managers step-change solutions to increase capacity for trains. This to allow a modal shift from road to rail which is one of the main target points of the European Commission to make the European area more competitive and greener.
At nighttime there is a competition between track inspection & maintenance with rail freight traffic. Both are in most cases forced by passenger traffic to the night. Reduction of time for inspection & maintenance creates more capacity for freight trains.
The project also touched possibilities for more efficiency in maintenance operations and -planning. A multi-disciplinary team consisting of infrastructure managers, rail-contractors, universities, research institutes and consultancy firms bundled their expertise into innovative solutions that can be implemented within a range of 5-10 years. A broad set of potential new approaches or techniques were developed. It spans from applying new methodologies in the rail infrastructure maintenance industry by using the Toyota Lean approach, new inspection tools, a different approach for large maintenance works like grinding and tamping to new integral approach for maintenance- and inspection planning & scheduling.
This joint-research work was made possible through funding by the European Commission Research framework (FP7).

Project Context and Objectives:
The high level aim of the project is to make the movement of freight by rail more dependable– i.e. reliable, available, maintainable and safe -through the generation of additional capacity on the existing network. Through the widespread introduction of automation that is designed to improve the Reliability, Availability, Maintainability and Safety (RAMS) of railway infrastructure equipment and systems. The projects’ aim is to reduce the required possession time (downtime) of the railway by as much as 40%.

To achieve this five objectives are set:
1: adopting best practice from other industries in maintenance optimisation (e.g. highways, aerospace).
2: developing novel track inspection approaches for freight routes with a scope on in-train measuring and self inspecting switch.
3: researching and assessing innovations that can improve the effectiveness and efficiency of large scale inspection & maintenance processes with a scope on track and switch maintenance, track inspection;
4: further developing of key technologies that will drive the development of modular infrastructure design.
5: developing a new maintenance planning and scheduling tool that is able to optimise the maintenance activities, taking account of the benefits brought about by other improvements in this project.

Project Results:
The project was focused on 5 fields of innovation: applying best practices from other industries of which the Lean approach was chosen, inspection, maintenance, modular switches & crossings and planning & scheduling. Highlights of these innovation-
fields are elaborated in the following chapters.

1. Lean Analysis of Track Maintenance

The concept of “lean manufacturing” has been around for many years, derived mostly from the Toyota Production System, concentrating on reducing waste in production processes. As part of the AUTOMAIN project, these principles were applied to key track maintenance processes including tamping, grinding and S&C maintenance. The project engaged support from KM&T who are specialists in Lean Analysis techniques, a high proportion of their consultants being ex-Toyota employees. Working with support from the University of Birmingham, they undertook an initial analysis of tamping, taking into consideration the process right from the early planning stage through to execution. The investigation involved Structured Observations where staff from KM&T attended an actual maintenance shift, noting down what activities took place, timings, resources involved etc. This was then followed by Value Stream Mapping workshops attended by experienced front-line maintenance staff, where the process was mapped out using sticky-notes to describe the various stages and people involved in a typical maintenance shift. This also provided an excellent opportunity to gather ideas from those at the sharp end of ways in which processes, practices and equipment could be improved.

Several railway administrations participated, namely Network Rail, Deutsche Bahn, SNCF, ProRail and Trafikverket, the last two being through their maintenance contractor Strukton. This meant that it was also possible to compare and contrast the different approaches taken by different European railway administrations, and the investigation threw up some interesting findings:

- 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 bidirectional traffic during maintenance.
- There are a number of technological developments that could further enhance productivity such as multifunctional high output machines capable of recording and working in either direction, and which minimize 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.

The success of the study on tamping lead to similar exercises being undertaken for grinding and S&C maintenance activities, and the information gathered from all three exercises was used to support and inform subsequent parts of the AUTOMAIN project. A full copy of the subsequent reports can be found on the AUTOMAIN website.

2. Inspection

In-Service track monitoring by using a freight locomotive or passenger commuter train. Measurement trains need much capacity on the network as they need to measure at low speed. This innovation makes a distinction between inspection and monitoring. Continuous monitoring can help to detect abrasion or degradation of the tracks by pointing out changes in the data daily provided. Daily monitoring is possible by measurement with in-service trains running at normal speed. AUTOMAIN tested two approaches: measurement with a freight locomotive and using a passenger train. The freight train measurement was demonstrated by Deutsche Bahn on the European Freight Route between Rotterdam and Dillingen. On this line a lot of heavy trains are operating and the track degradation is higher than on other lines. In the UK measurements were made on a part of Southern Railways’ commuter train network. Both tests use different measurement devices.

The Deutsche Bahn test used an advanced measurement concept installed on a class 189 freight locomotive. The monitoring
system provided track alignment and track defect information. These data is displayed using a web based interface. The analysis included a maintenance assessment, based on the failure prediction algorithms. The selected system design, which took into account the high requirements of the railway, ensured high quality measurements and long-term stability. The system was installed in November 2013, first results were collected during the project. Further testing will take place beyond the project and is expected to finish by the end of 2014.

In the UK a measurement device mounted on a commuter train bogie was used. Elaborate testing took place during the project. A benchmark with measurements of inspection machines was executed. Results allowed the project to develop and calibrate prediction algorithms. These algorithms proved out to be useful to predict timely need for maintenance. Both systems will be used beyond this project to identify and quantify the benefits of measurement systems on in-service trains and will be a reference system for future simplification and developments. A maintenance strategy that will take into account the prognosis of track degradation is necessary to achieve all benefits form in-service trains measurements systems.

Advanced Switch & Crossing Inspection

Switches and crossing (S&C) are a critical part of any railway system, and although they make up on average just 5% of the total track length, they account for up to 30% of the annual maintenance and renewal budget. If not properly maintained or inspected with sufficient rigor, S&C can also cause derailments that tend to result in significant disruption to train services, and even the loss of life. Across Europe, there have been a number of serious derailments at S&C in recent years due to missing or loose track components. But there is also a significant issue relating to the quality of repairs carried out to switch rails and crossings. A typical repair will involve preparation of the damaged surface, welding additional material to that damaged section, and then grinding it back to the required profile. However, the tools currently available do not enable a sufficiently accurate assessment of repair to be made, and this can cause serious problems. In the UK for example, there have been four derailments as a result of inadequate repair and inspection of switch rails in recent years, two at London Waterloo in 2006, one in Glasgow in 2007, and a fourth near the Princes Street Gardens in Edinburgh 2011.

There is also a more widespread problem where a poorly repaired switch means that the maintenance team have to return prematurely to site in order to undertake further repair work. While such cases do not necessarily pose a significant derailment risk, this causes additional disruption, and takes up valuable time and resources that could be employed elsewhere. As part of the AUTOMAIN project, the University of Birmingham has therefore developed a lightweight laser based trolley to accurately assess rail profiles through S&C. The trolley uses two scanning lasers commonly employed in the production industry to scan all the important contacting surfaces through S&C. The trolley has initially been developed to assess S&C against Network Rail standards, and algorithms have been successfully demonstrated for the assessment of switch blades. Algorithms to assess crossing profiles are currently under development, and the longer-term ambition is to use this technology to inspect S&C from service vehicles running at line speeds. The trolley also has the potential to gather sufficient data points to build up an accurate 3D model of the switch, potentially enabling more advanced assessment of the true risk of derailment to be made using vehicle dynamics modeling software for example.

There have been a number of other developments as part of the AUTOMAIN project to improve the maintenance and inspection of S&C, and full details of these and the laser based inspection trolley can be found in the Work Package 3 reports on the AUTOMAIN website.

Track measurement in switches

Today’s effectiveness of operation depends very often on the flexibility within operation and the availability of tracks in stations and marshaling yards. Only a handful of closed switches can influence operation dramatically. Therefore, in AUTOMAIN an Automatic Switch Inspection device was developed. A laser scanning measurement system is used to measure cross sections in 2 cm steps in the whole turnout. In AUTOMAIN we used a laser-scanning device of the SIM car by Strukton/Eurailscout with a software developed by DB. All these measurements were done with 40 km/h. The identification of the switch / frog was tested with GPS, map mapping and RFID’s. After the tests, RFID’s were chosen because of the future possibility to do the complete processing online on the car. Therefore special switch information must be available, which can
be written on the tag. The measurement car with additional post-processing software is also able to measure the track geometry. That opportunity offers a reduction of “wiggle-runs” of the regular Track Geometry Measurement cars in stations too. The demonstrator shows impressively, that approx. 130 Switches can be inspected during one night shift, compared by 5 per day by the traditional hand measurements. Another advantage is the fact, that the measurement train gets an own “screenplay” and a schedule. No traffic interruption is necessary; no staff is in dangerous tracks. After the measurement a post-processing plot the inspection results and copy them to the inspection database.

3. Maintenance

High Performance Grinding

The approach rail grinding varies throughout Europe, and there are an increasing number of technologies available to remove material from the railhead. But it was though that there are also significant improvements to be made to planning and the execution of grinding to maximize effectiveness, while minimizing the disruption caused by this maintenance activity. Therefore, as part of the AUTOMAIN project, a Lean Analysis study was commissioned to identify areas of improvement in the planning and undertaking of a typical grinding shift. This study, performed by industry experts KM&T with the support of the University of Birmingham, included two core elements: 1) Structured Observations where a grinding shift was observed and evaluated by representatives from KM&T and 2) Value Stream Mapping workshops where experienced operators and planners were brought together to “map out” the stages involved in planning and undertaking a typical maintenance shift, and suggest ways in which this could be improved.

The study involved three railway administrations, namely Network Rail, Deutsche Bahn and Trafikverket, and it highlighted some significant differences in the approach they take. For example, planning / lead times vary from 12 months to 48 months in advance, and total cycle times (i.e. the total amount of time spent on planning and undertaking maintenance) varied between 500 minutes to 3 000 minutes. But there were also general themes such as the need to make better use of ultrasonic inspection data, to optimize grinding plans according to the actual volume and type of traffic on a given route, and to ensure that those planning grinding fully appreciate key factors that influence the success of a given maintenance possession. There were various technological innovations suggested to reduce “waste as defined according to the principles of Lean. Examples include the use of service vehicles to undertake pre-maintenance inspections, and improved methods to measure, quantify and predict RCF to enable a more targeted approach to be taken. Performance incentives and Key Performance Indicators were also highlighted as an issue as these are not sufficiently well aligned to drive the efficient use of available possession time. This potentially includes:

• Encouraging the use of track friendly vehicle designs by introducing differential track access charging to reduce the problem “at source”
• Setting maintenance targets that incorporate the quality and longevity of the maintenance undertaken
• Aligning performance indicators to minimize overall possession time and maximize maintenance effectiveness and longevity
• Ensure that performance indicators do not result in overly aggressive grinding practices that can actually damage the railhead

As for the actual grinding activity, the time spent on different activities was analyzed. Within this breakdown, significant scope was identified to reduce time spent on non-value adding activities, examples of which variously included slag collection and the need to verify the final ground rail profile manually. As with the earlier study on tamping, the study provided an excellent opportunity for front-line staff to air their views and suggestions for improvement, and the information gathered from the exercise was used to inform subsequent AUTOMAIN activities. A full copy of the report and its recommendations can be found on the ATUOMAIN website.

High performance tamping

Tamping restores the required track geometry and is necessary for safety reasons. Depending on the state of the track and the operational conditions the tamping intervals are between 2 and 7 years. For highly loaded tracks high performance or high efficient tamping is necessary to reduce possession time and to provide more time for operation. The research of AUTOMAIN
points out, that for example:

• Detailed analyses and optimization of planning and maintenance processes,
• The use of high performance tamping machines like three or four sleepers tamping machines,
• The development and use of high performance single failure tamping machines or
• Improved maintenance strategies using forecast of deterioration and combined maintenance activities are adequate possibilities/adjusting lever to increase efficiency of maintenance and thus reduce possession time in short or mid-term.

Detailed analyses of the track geometry showed the impact of single failures on the need for tamping. In cases where the distances between single failures are greater than the minimum distance, which depends on boundary conditions, the use of improved single failure tamping machines reduces the possession time noticeable. Looking into the future and therefore into the mid- and long-term perspective the direct use of track recording car measurements for the tamping machine or an improved fix-point measurement system with higher measurement speed will reduce possession time noticeable. The maximum possession time reduction will be achieved if the maintenance is reduced to the minimum. This would be possible if the root causes for single failures or “local need” for maintenance will be removed or the track design is changed or optimized, e.g. slab track or under sleeper with pads. In both cases the economic impact has to be taken into account by estimation the life cycle costs. The change or improvement of track construction is necessary in any case if the possession time has to be reduced below the “natural limit of the track”. More trains on a track results in general in higher deterioration and therefore more maintenance.

4. Modular switches & crossings

Switches and Crossings are key components in the railway networks. They 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. Degradation is depending on factors such as traffic load, speed and intensity. For tracks with high loads and intensity the need of modular design and efficient methods are essential to reduce the track possession time for inspection, renewal and replacement of infrastructure in order to increase the time for more time for operation. Lean Analysis with tools like Value Stream Mapping has been very useful in the work and shows both wastes and opportunities. Following are example of improvements for reducing possession time in short or mid-term:

• Implement increased lengths of spare parts, will reduce need of adaptation out in track during installation.
• Create standard work in order to optimize planning and maintenance processes:
  o A lot of activities which is done doesn’t add value to the process
  o Some activities is done within the track possession time but can be done outside the possession time
  o A lot of activities can be done more efficient which means shorter time and with more secured result
  o Implement stock of non-standard material, will reduce the use of temporary solutions, which has negative effect on both the quality of temporary reparations and the need of going out to track several times for maintenance and inspection activities.

In mid and long term perspective the AUTOMAIN project has given two improvements, one that reduces possession time in track for inspection and one who increase the technical level of the result.

1. On-line measurement through camera from Overhead (OH) line. With this equipment inspections can be done basically from anywhere anytime and without the need of having people to go out in track. This is very good both for S&C which are placed in tunnels or far away but also from a safety aspect since no people has to be out in track.
2. Panel replacement. Today only small parts are replaced during the maintenance activities. The technical level of the S&C will decrease for every event and needs to be done with a higher frequency. By replacement of panels the technical level of the S&C can be kept high for a long time. This is done by installation of pre-assembled large panels of S&C. These panels are assembled in a workshop with very good conditions of having a good result of the maintenance activity.
5. Planning & scheduling

Outcome 1: Integration of both global planning and local scheduling of maintenance operations
AUTOMAIN developed a new planning concept to optimize maintenance activities, resources and timetable slots. The algorithms embedded in our tool enable to synchronize different levels of planning and scheduling. Indeed, both macroscopic and microscopic aspects are integrated in a same approach. To the best of our knowledge, this integration is something new, developed within WP5 of project AUTOMAIN. The need to handle different levels is quite clear. Indeed, scheduling individually each maintenance operation without a global view might lead to machine unavailability or incompatible operations being planned simultaneously. However, not taking into account particularities of operations at a more detailed level may also result to conflicts with other trains or unfeasible task times.

The macroscopic vision consists in having a global optimization of a fleet of maintenance machines, such as measurement, grinding and tamping machines, and defining for each of them its activity over a time horizon of several months or years. Obviously, sufficient travel time should be allowed between successive operations of a single machine. It is also necessary to make sure that incompatible operations are performed at the same time, and that no operations are planned during the machine’s own maintenance. Another aspect is the need to perform operations in a certain order. This kind of interoperation constraints must be integrated to make sure that the resulting optimized planning will be feasible. Finally, the optimization of possession time requires to have a global vision on all operations, in order to identify those, which can be combined during the same track possessions. On the other hand, microscopic constraints must be considered for each maintenance operation. The most significant of these considerations is, naturally, to integrate maintenance within the commercial traffic.

The link between global and local is obtained by specific algorithms which are able to split large operations over several possessions, and which find the optimal routes of machines over the network between operations. These algorithms have to deal both with the global planning aspects and with local considerations. Consequently, our tool is composed of several modules dedicated to these specific problems to provide ultimately a global planning defining when and how each maintenance operation is performed.

Outcome 2: Capability to optimize different criteria
The tool developed within WP5 of AUTOMAIN is able to deal with objectives of different natures. For instance, it can optimize either capacity of the network, by minimizing track possession times, or machine usage, by minimizing the number of km traveled between operations, or even find compromises between these criteria. Optimizing network capacity is made possible by combining several operations into a single possession. Obviously, these operations must be compatible with each other when it is decided to combine them. Even if tests should be performed on a broader range of situations, early experimentations showed that the reduction in possession time obtained by the optimization algorithms developed could reach up to 14% compared with basic planning rules. Besides, a maintenance planning of machines over a time horizon of a few months generates a lot of travels from the end of an operation towards the beginning of the next operation planned on the same machine. Depending on the sequence of operations on each machine, the total distance traveled by machines can vary in great proportions. Intuitively, the ideal situation would be to perform operations geographically close to each other during the same time period. Given the deadlines potentially imposed on operations, this is not always possible. Moreover, the computational complexity of this type of problem is known to be very high. Even with only one machine, the well-known Traveling Salesman Problem (TSP) has a high theoretical complexity. For these reasons, dedicated algorithms were developed and applied successfully. The first results show that using this type of algorithms to minimize distance traveled can save up to 69% if full priority is given to this criterion, or 42% if possession time is also optimized. Hence, depending on the needs and on the user, the tool developed within WP5 of AUTOMAIN is able to optimize criteria of different natures. One major advantage over other tools is that it can handle them simultaneously and can thus somehow bring together the different approaches of the different stakeholders of the maintenance business, in particular infrastructure managers and machine owners. Indeed, the objectives of these actors are often different, resulting in negotiations and iterations to build together acceptable planning

Potential Impact:
As anticipated from the outset, the main impact of the project has been in innovations that have the potential to create extra
capacity on the existing rail network. These have been achieved by focussing effort on lean processes (WP2), inspection technologies (WP3), high performance maintenance (WP4) and improved scheduling and planning of maintenance (WP5). As a result of the activities in these work packages and the implementations developed in the demonstration work package (WP6) it has been shown using a robust evaluation process (developed in WP1) that the project has the potential to reduce possession time (downtime) by as much as 40%. This directly aligns with the committed aim of the project at the application stage.

Developing innovations that have the potential to achieve such a level of possession reduction is a significant result and a major achievement that has attracted the attention of various partners who have stated their intention to exploit the results of the project.

During the final phase of the project a series of national dissemination events were organised. The aim of the ‘national workshops’ was to highlight in specific countries the innovations, focussing particularly on key national needs. These workshops were extremely important in both disseminating of the results of the project and encouraging organisation to form firm plans for exploitation of the project results.

Workshops were held in the following locations:
4th December 2013 – Lulea, Sweden (Lulea Technical University) – all aspects covered with a focus on high performance maintenance (50 attendees)
9th January 2014 – Paris, France (UIC) – all aspects covered (35 attendees)
22nd January 2014 – Milton Keynes, UK (Network Rail) – all aspects covered with a focus on lean methods and monitoring (70 attendees)
27th January 2014 – Braunschweig, Germany (Technical University of Braunschweig) – specifically focused on maintenance planning and scheduling (12 attendees)
29th January 2014 – Utrecht, Netherlands (ProRail) – all aspects covered with focus on lean methods and monitoring (65 attendees)

Through this series of workshops over 230 people were reached.

At the outset of the project an exploitation plan was developed. The exploitation plan was focussed on the specific innovations planned from the project, namely:
Innovation 1: A new methodology for analysing and optimising maintenance processes by applying best practice from other industries
Innovation 2: Higher performance infrastructure inspection methods
Innovation 3: Higher performance rack maintenance methods
Innovation 4: Modular infrastructure components and subsystems which lend themselves to automated removal and fitment
Innovation 5: The improvement of automatic maintenance scheduling and planning systems, which focus on scheduling maintenance around the timetable, so as to reduce disruption to scheduled traffic and to increase useful capacity.

During the final phases of the project, and in particular during the dissemination events and the final event in Utrecht on 30th January 2014, firm plans for exploitation were discussed and agreed as follows:

Innovation 1 resulted in the development of processes for the application of lean thinking to railway maintenance. Within the project these processes were specifically tested and applied to tamping and switch maintenance. As a direct result of the work within the project KM&T (an SME) have already undertaken further work to extend and formalise the processes for Network Rail. In addition KM&T have recently commenced a project for Network Rail to support the upgrade of London Bridge station. Prior to the project KM&T had not worked in the railway industry. EFRTC (in conjunction with the University of Birmingham) are planning a proposal to the Horizon 2020 Research and Innovation
Innovation 2 generated three specific routes for exploitation: (i) in-service track monitoring; (ii) advanced switch and crossing inspection; (iii) laser based track measurement in switches:

- Work on in-service track monitoring is being exploited by Deutsche Bahn (DB) in Germany and Network Rail (in conjunction with the University of Birmingham) in the UK. A further research grants has been awarded to the University of Birmingham to progress the development of the in-service train monitoring innovation into a product.
- The developments on advanced switch and crossing inspection that were carried out and validated in the project will be taken forward by Strukton.
- Network Rail (in conjunction with the University of Birmingham) is taking forward the laser based track measurement system for switches. Since the project end a workshop has been held to develop an exploitation plan for this innovation and this has been presented to the Office of the Rail Regulator. Further validation trials have been carried out.

Innovation 3 developed a series of improvements and best practice suggestions for higher performance track maintenance methods. These have generated interest with the infrastructure managers involved in the project, particular in Sweden with Trafikverket; however, due to the nature of these innovations the lead time and investment cost is significant and therefore a clear route to exploitation has yet to be developed.

Innovation 4 in the area of modular infrastructure components and subsystems innovations in the area of modular switch and crossing components have been developed by Lulea Technical University and Vossloh. There is a clear plan to take these innovations forward and patents are currently being applied for. Once the patents are granted, practical exploitation of the results will proceed.

Innovation 5 focussed on maintenance scheduling and planning a software application was developed which contained algorithms for scheduling maintenance activities. These algorithms are of particular interest, and will be incorporated into a new software application that is now being developed by a spin-out company of the Technical University of Braunschweig.

In summary, all of the innovations developed in the project have a clear pathway to innovation, and in a number of cases this exploitation process is well underway.

List of Websites:
www.automain.eu

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