AUTOMAIN

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

Project Reference: 265722
Research Area: SST.2010.5.2-1

Task 3.2: Modular, Self-Inspecting Infrastructure

Deliverable Reference No: D3.2

FINAL – Issue 2

Dissemination Level		
PU	**Public**	

Document Summary Sheet

This document contains a summary of the work undertaken for Task 3.2 of the AUTOMAIN project. This task relates to the development of self-inspecting infrastructure and the development of appropriate technologies to support this innovation.

Additional Information	
Subproject / Work Package:	WP 4.3
Authors:	Clive Roberts – University of Birmingham Stephen Kent – University of Birmingham Marius Rusu – University of Birmingham Dan Larsson – Damill Stéphane Huguet – Vossloh Cogifer, SIEMA Applications Joost den Decker – Strukton Matthias Asplund – Luleå University of Technology Matti Rantatalo – Luleå University of Technology Uday Kumar – Luleå University of Technology Arne Nissen – Trafikverket
Participants:	University of Birmingham Deutsche Bahn Trafikverket Strukton Damill AB Vossloh Cogifer Luleå University of Technology
Document date:	31st January 2014
Status:	Final

Draft 1	24th May 2013	Basic structure of the report created by University of Birmingham for subsequent internal circulation to appropriate members of AUTOMAIN Work Package 3.
Draft 2	20th June 2013	Draft contribution added by University of Birmingham.
Draft 3	21st August 2013	Further contributions added by Damill and University of Birmingham.
Issue 1	9th September 2013	Further material added by University of Birmingham based on contributions from SIEMA & Strukton, plus material previously presented by participants.
Final	11th October 2013	Minor modifications and up-issued to as Final version.
Final Issue 2	31st January 2014	Additional chapter added describing case study undertaken by Luleå University of Technology on the use of overhead cameras.

Executive Summary

This document is the report covering the work undertaken as part of Task 3.2 of the AUTOMAIN project, an EU-funded project aimed at reducing the possession time required for railway maintenance in order to increase overall network capacity for rail freight. The work involved developing the technology and software to enable infrastructure to be inspected automatically and / or remotely, i.e. without the need for staff to go on or near the running line.

While there has been significant progress in the development of track inspection vehicles to assist with the inspection of plain line, the inspection of S&C is predominantly still done by visual inspection, supplemented by measurement using hand-held gauges and other manual inspection tools. However, it can be difficult to access key S&C to undertaken regular inspections, and both the inspection and remediation required can reduce the availability of lines.

This task seeks to address this issue by promoting the development of technologies that will enable S&C to be inspected automatically. This report describes the evaluation of inspection requirements, and then the development and evaluation of five specific inspection technologies:

- infrastructure mounted video cameras
- high speed inspection of switches using lasers
- the SIM (Switch Inspection Measurement) wagon
- in-service track geometry recoding
- instrumented washers and alternative approaches to securing track components

In addition, three higher level enabling technologies were also considered:

- the development of a suitable Man Machine Interface
- modular components to facilitate rapid track maintenance, ideally incorporating facilities to support automatic inspection
- the potential for self-powered wireless sensors to be used to monitor or measure various aspects of the infrastructure

The report includes a concept design for a self-inspecting switch and supporting systems that would be effective in supporting the goals of the AUTOMAIN project.

Table of Contents

Glossary

alignment	lateral track geometry
contact angle	the angle of contact between the flange of a wheel and the rail
DB	Deutsche Bahn
four foot	the area between running rails
lipping	metal flow due to the action of passing traffic that forms a lip on the head of the rail
LTU	Lulea University of Technology
MMI	Man Machine Interface
Network Rail	the UK mainline infrastructure owner
NMT	New Measurement Train – Network Rail's track recording train
RFID	Radio Frquency Identification
S&C	Switches & Crossings
top	vertical track geometry
TRL	Technology Readiness Level
TSR	Temporary Speed Restriction
UoB	University of Birmingham

1.0 Introduction

The key objective of the AUTOMAIN project is to look at ways of reducing what are predominantly night-time maintenance track closures that impact negatively on rail freight capacity. One of the key ways of doing so would be to reduce the degree of manual inspection of the infrastructure conducted manually by staff during track maintenance possessions. A second approach would be to move away from conservative fixed time interval inspections to on-condition based maintenance. Both of these approaches would be facilitated by self-inspecting infrastructure.

A further approach is to increase the modularity of track components so that faulty components can be quickly and easily replaced with minimal setting up and adjustment.

This report covers the work done for Deliverable 3.2 of the AUTOMAIN project looking at the possibility of developing self-inspecting Switches & Crossings (S&C), including consideration of how modular components could be incorporated into S&C hardware. One of the challenges of such an approach is to ensure that any automated system provides the same (or a higher) level of safety assurance as current manual practices.

In order to achieve this, an initial study was undertaken of the current inspection requirements for S&C for participating railway administrations. Technologies that could reasonably be used to replace manual inspection were then identified, and from these, the most promising were selected for further evaluation as described in this report.

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 suggested changes is in a number of stages, the first of which is by 2026 (i.e. thirteen years from now or earlier if possible).

2.2 The Degradation of S&C

Track degrades with the passage of traffic due both to mechanical loading and frictional contact between when and rail, and at some point, maintenance or other intervention will be required. Inspection is a key part of the maintenance process, and its purpose is to gather information on the condition of the assets. The main two reasons for undertaking inspection are to:

- assure that the assets are in a good condition and therefore can be kept in operation
- to provide the repair team information about the status of the asset

Inspection has both important safety and economic implications, and the way in which inspection is performed is usually set out by the infrastructure owner and/or by the maintenance contractors.

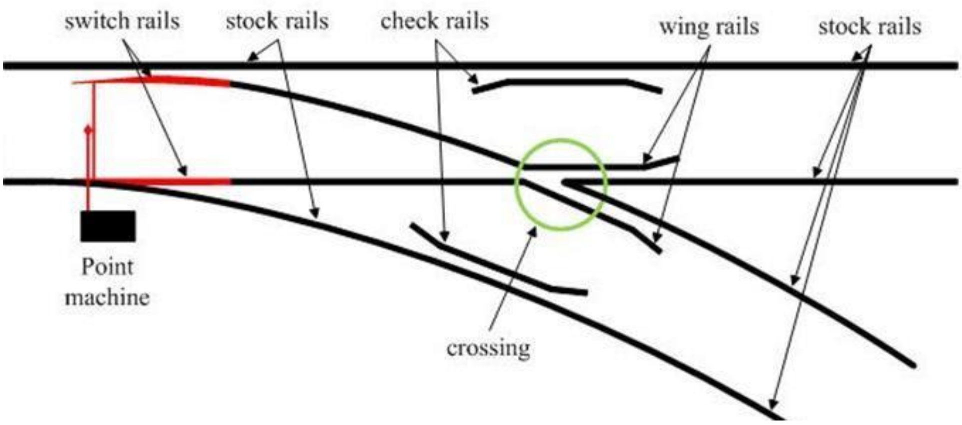


Figure 1 – Main components of S&C

In terms of S&C, there are two critical areas that require regular inspection as they can suffer significant deterioration that poses a significant derailment risk if left unchecked (please refer to Figure 1):

- the tip and initial part of the switch rails where the diverging rail is first introduced to the wheel

- the crossing where the inner wheel either continues on the through route, or transfers to the diverging route

Both of these areas require their condition, and in particular their profile, to be carefully controlled. Should the contact angle between the two become too shallow for example, a flange climb derailment could occur. There are also other key factors such as ensuring that the gap between stock rail and closed switch blade is within specified limits – an excessive gap could result in the wheel striking the head of the switch blade, thereby damaging it and in the worst case causing a derailment. A further area of risk is the stretcher bars (not labelled) which ensure that the two switch rails remain a correct distance apart. Should the bar become damaged or detached, derailments can occur such as the Potters Bar and Greyrigg incidents in the UK (see Figure 2).

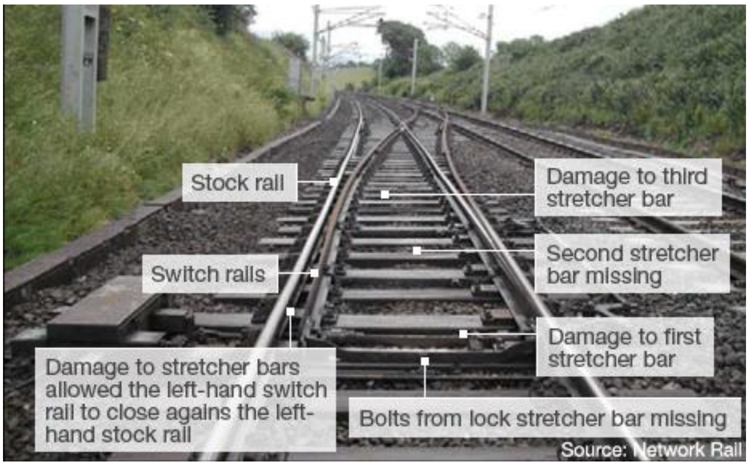


Figure 2 – Greyrigg derailment causes (Network Rail)

In order to prevent such occurrences, railway administrations employ a system of regular inspection to ensure that S&C remains safe for train operation. The exact nature and frequency of inspection varies between railway administrations, as well as according to factors including the traffic type, tonnage and line speed.

Such is the critical nature of S&C, there are usually specific standards for inspection of the switch and crossing elements. Switches are typically inspected on a periodic basis according to the category of line in which they are installed, as well as their degradation history.

2.3 Current Inspection Approaches

Currently, inspections are generally done by a combination of a visual inspection of general condition, and measurements made using manual gauges. Some administrations have started to introduce automatic or remote inspection technology, but no railway has yet reached the point at which manual inspections are no longer required. One of the key challenges to reaching this ultimate goal is that any system for self-inspection needs to be able to perform the same range of checks to at least the level of accuracy currently achieved by manual methods.

2.4 Self-Inspection

The aim of this work is to develop self-inspecting infrastructure, concentrating initially on the critical area of S&C. This could be interpreted as a system that requires no human intervention. However, the core aim of the AUTOMAIN project is to reduce the impact of maintenance and inspection on the availability of train paths. In order to satisfy this, it is suggested that the core aim of this work should be to avoid the need for staff to go on or near running lines in order to check whether S&C conforms to required standards.

Taken from this point-of-view, the remit widens to include remote inspection techniques that might still involve human intervention or judgement. For example, this could include a qualified person conducting a general visual inspection of the condition of S&C from video captured from lineside equipment, inspection vehicles, or from in-service inspection systems.

2.5 Inspection vs. Condition Monitoring

Automatic self-inspection has a number of commonalities with condition monitoring in that both typically measure some aspect of the railway and its performance. However, condition monitoring systems are usually employed to measure the performance of a component or system and detect any deterioration. This may indicate a problem is developing, which can then be addressed before it impacts on services, thereby providing a useful tool to support effective management of the railway. By contrast, an inspection system is typically employed to assess whether a component or system is within or outside acceptable limits and specifications at a particular moment in time. While this can also be useful to help manage the railway, there is greater emphasis on ensuring that the railway conforms to required standards and remains safe to operate. The differences can be illustrated by two different systems developed to assess crossings:

- A condition monitoring system has been developed by Vossloh that measures the vibration levels at crossings as trains pass by. This system continuously detects the vibration levels and characteristics over time, and looks for changes that might indicate a problem is developing with the crossing. The system is looking for the symptoms that indicate a problem is developing, but it does not determine the cause of any problem, and there is no standard against which the vibration levels can be assessed.
- The laser profiling trolley described later on in this report is used to assess whether the shape of the crossing conforms to acceptable standards for wear, contact angle and so forth. It is only used on a periodic basis and therefore does not pick up the daily deterioration of the crossing. But it is used to determine that the shape of the crossing is within acceptable tolerances, and should provide a sufficiently high degree of repeatability and accuracy to allow manual inspections to be replaced.

It is apparent from the above example that there is distinction in terms of whether the system assesses the general condition of a component / system (condition monitoring), or conformance with standards (inspection). This can make a significant difference in terms of the frequency and accuracy / precision with which measurements need to be made:

- with of condition monitoring, measurements are generally recorded on a continuous or frequent basis looking for changes in levels over time, with accuracy and precision of measurements being of secondary importance
- inspection is usually performed at a fixed periodicity and typically requires precise measurement or assessment against a calibrated gauge, with limits that provide sufficient confidence the item will remain acceptable until the next inspection

This distinction can influence the technology employed in terms of what measurement technology is appropriate and other factors such as the power requirements: a condition monitoring system typically requires a power supply for continuous operation, whereas a comparable inspection system might only “wake up” once a month to assess the condition of an asset. This might make it easier to run inspection systems from locally generated power for example (solar, wind, energy harvesting from vibration etc.).

This distinction can also influence the level of automation that can be applied to a particular measurement / assessment. Typically, the continuous measurement done by a condition monitoring system is likely to require some form of automatic analysis, usually by computer. In the case of periodic inspection, while computer analysis might well still be involved, there is greater scope for human involvement, for example to assess the condition of a switch blade using a video camera.

So while condition monitoring is useful in managing the railway effectively and detecting problems before they impact on services, it cannot usually replace inspection tasks as it either does not measure what is required, and typically cannot guarantee the same level of accuracy as a self-inspection system.

2.6 Target Assets

There is a balance to be struck between the cost of employing new technology and the benefit it will bring. In terms of self-inspecting S&C, it is only likely to be worthwhile:

- where there is a high density of S&C such as in the vicinity of mainline stations
- where access to S&C is physically difficult such as crossovers between adjacent tunnels, or at very remote locations
- for S&C that is at heavily used locations such as on the approach to busy stations or where busy routes diverge, particularly where there are no alternative routes available – these are sometimes referred to as “Golden Assets”

At other locations, S&C is either less critical due to lower traffic densities, or due to the availability of alternative routes in the event of problems or maintenance and inspection requirements. It is likely that the sort of inspection technology described in this report is, initially at least, likely to be restricted to Golden Assets or locations where physical access is difficult.

But with the desire to increase the amount of predominantly night time freight traffic, access to undertake maintenance and inspection activities will to become more difficult to arrange, and with increasing traffic volumes, the number of Golden Assets is also likely to increase. It is therefore anticipated that over time the need for automatic inspection technologies will also increase.

2.7 Point Machines

The inspection of point machines and their associated track components is an essential part of maintain a safe and operational railway. In terms of inspection, the requirements vary between machine designs, but as an example, the most commonly used machine in the UK is the HW 2000 which requires frequent inspection, including a facing point lock check around every two weeks (Figure 3).

Figure 3 – HW point machine

The automatic inspection of point machines was considered during the investigation, but was not pursued for the following reasons:

- point machines are difficult to inspect without removing the cover
- there are a wide variety of differing designs, each of which requires a large number of diverse inspections to be undertaken
- different machine types can have quite different inspection intervals

This makes it difficult to develop a common approach and technology to automate such inspections. So an alternative approach has been taken by the industry to design more robust point machines that require less frequent inspection and maintenance. The UK developed the High Performance Switch System (HPSS) which was originally intended to have 20 years inspection interval. Although this has not been achieved in service, the HPSS inspection interval is still an improvement on that for standard point machines, and designs such as the Bombardier EBI and Vossloh In-Sleeper point machines only require inspection on an annual basis, and also facilitate easier track maintenance. This does, however, need to be offset against the need to close the line for any repairs, whereas this may not be necessary for trackside point machines – see Figure 4.

Figure 4 – HPSS, Bombardier EBI & Vossloh In-Sleeper point machines

While automatic point machine inspection has not been pursued as part of this investigation, the use of technology with long intervals between inspections is obviously desirable as part of any drive to reduce the impact of maintenance and inspection requirements on train paths.

3.0 Current Inspection Requirements

With the combination of significant lateral loads and complex rail geometry, a significant proportion of derailments happen at S&C. Railway administrations therefore have various inspection regimes in place to ensure that this risk is kept within acceptable limits.

3.1 Summary of Key Risks

A summary of the key risks and associate common inspection requirements is given below:

- There is usually a significant lateral load through S&C, particularly when a train is taking the diverging route. If the contact angle between wheel and rail is too shallow, the flange of the wheel can ride up the switch blade or crossing, resulting in a derailment. It is therefore important to check that the shape of the switch blade and crossing to predict the contact angle between wheel and rail and check it will remains within safe limits.
- Any sharp edges on the rail head, switch blade or crossing can “dig in” to the surface of passing wheels and provide purchase for that wheel to climb. So the general condition of critical areas such as the tip of the switch and the vee of crossings needs to be maintained in good condition and visual inspections look for imperfections or damage for this reason.
- The check rails guide the back of the outside wheel to prevent the inside wheel going striking the nose of the crossing. It is therefore important that the relative position of the check rail is within acceptable limits.
- Poor track geometry such as track twist faults can result in reduced vertical wheel loads, which when combined with the lateral load can result in flange climb. It is therefore important to ensure that the geometry through the crossing is within acceptable limits, particularly in terms of track twist.
- The switch blades with their narrow cross section need to be structurally sound as any failure of the blade is likely to result in a derailment.
- The gap between switch blade and stock rail in the “switch closed” position is critical, particularly for facing point moves. If the gap is too large, the wheel can strike the tip of the switch blade and split the switch causing a derailment (although the gap ought to be detected by the point machine). Such gaps can be caused by damages switch rail fittings, obstructions or excessive lipping for example.
- The stretcher bars maintain the correct spacing between switch blades and if these are loose or in poor condition, a passing train can split the points, resulting in derailment. So it is important to check both the condition and tightness of the stretcher bars and the nuts that hold them in place.

In the UK, separate teams are responsible for inspecting the infrastructure including rail profile, geometry and condition, and for the hardware associated with the signalling equipment, which is taken to include the point machine and associated hardware used to drive the switch blades (stretcher bars, back drives etc.). Both inspection tasks can however affect the availability of train paths.

3.2 Analysis of Inspection Standards

The starting point for this study was to establish the inspection requirements for S&C across different railway administrations. This work was undertaken by the University of Birmingham, and the initial evaluation was therefore based on Network Rail inspection standards. This provided a "base case" against which similarities and differences were noted for other administrations. A questionnaire was forwarded to a number of administrations, and of these, responses were received from DB in Germany and ProRail of the Netherlands.

The full survey responses are provided in Appendix A, and an extract is shown in Figure 5.

Category	Country	Inspection task	Network Rail inspection standards	ProRail inspection standards	DB inspection standards
Stock rail inspections	UK, NL, DE	**Stock rail checks** - sideworn stock rail towards heel or at switch tips (UK); check for rolling contact fatigue condition (NL); rigidly fixed, broken, rupture, head-checks, corrugation, wheel burns, shelling, black or brown spots, indentations AND if closure rail, then also: defects in rail foot, short/long waves, baseplates pushed down into sleepers (DE)	NR/L2/TRK/001/E01, A.10 (6)	UIC Working Group Switches & Crossings, page 31	RilF 821 - Oberbau inspizieren, page 108, 114 and 118 for closure rail
	UK	**False Flange Damage**	NR/L2/TRK/001/D01, Chapter 10		
	UK	**Stock rail lipping** - check for the presence of lipping on the stock rail throughout the movable part of the switch rail (UK)	NR/L2/TRK/0053, Chapter 13.4.3		
	NL	**Heel baseplates**		UIC Working Group Switches & Crossings, page 23	

Figure 5 – Extract from inspection requirements spreadsheet

The full table shows the range of inspections undertaken, associated standards, the current inspection methods, and typical inspection frequencies.

This work identified that there are a great deal of common inspection requirements, which is perhaps unsurprising as almost all S&C is built using the same general principles. It is estimated that there is an approximately 80% overlap between the countries involved in the study, and the most important checks tended to be common between administrations.

In order to make further analysis simpler, the inspections were categorised as shown in Appendix A into one of five categories, each of which is discussed below:

3.3 Categorisation of Inspection Requirements

In order for a self-inspection system to be successful, it would need to provide a similar range of checks of at least the same accuracy and frequency to those currently undertaken, and there are five broad areas that need to be inspected:

- Visual Inspection – visual checks performed with sufficient clarity and range of angles that the general condition of all key components can be assessed
- Rail Profiling – accurate measurement of rail profile for key areas of the switch and stock rails, and of the profile through the crossing

- Track Geometry – assessment of vertical and lateral track geometry, including the key assessments of cant / cross level and gauge throughout the S&C
- Component Security – assessment of the security of fastenings, securing them in such a way as it is either obvious when they are no longer tight, or are fastened in such a way that loosening is impossible
- Crack / Rail Flaw Detection – the ability to detect or see surface cracks as a minimum, and ideally also detect sub-surface cracks and their key characteristics (depth, angle etc.)

There is also a need for a standard interfacing language and interface so that all the information gathered can be accessed through a single Man Machine Interface (MMI).

4.0 Current Inspection Approaches & Available Technologies

Having established the primary requirements for a system of self-inspection, a review was undertaken of current inspection practices and technologies.

4.1 Visual Inspection

A large proportion of current inspections are conducted by manual visual inspection by trained staff, looking for obvious defects such as missing or loose components, or heavy damaged or wear in key areas. All administrations studied require visual inspections to be undertaken, although in the Netherlands, a train-mounted system is employed with multiple video cameras to provide sufficient viewing angles for the inspection to be done remotely. A typical list of visual inspection tasks would include assessing the condition of are, but not limited to:

- switch/stock rails, looking for wear, damage, lipping, RCF and false flange damage
- crossing, wing rails, check rails and flangeways
- stretcher bars, lock stretcher bars and their fastenings
- track fastenings, soleplates, baseplates, blocks, welds, ballast and vegetation

Most of these inspections can be done directly by eye, although there are certain areas such as the underside of stretcher bars where mirrors on sticks are sometimes used.

4.2 Rail Profile Measurement

Profile measurements are typically undertaken using manual contacting mechanical gauges to check if the rail profile remains within acceptable limits. Such gauges measure key parameters such as contact angles or acceptable contact zones as shown in Figure 6.

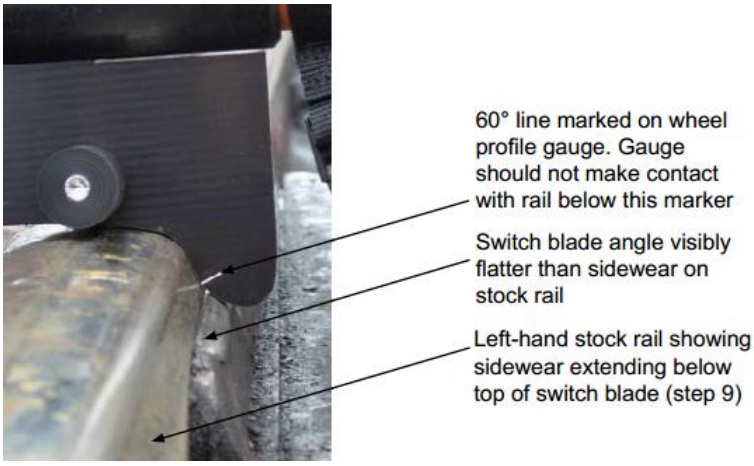


Figure 6 – Example of manual profile inspection gauge (UK)

Although there is a risk of operator error, the measurements are typically accurate to within a millimetre, and measurements are made at relatively frequent intervals, typically of 500 mm or less in critical areas. In terms of measurement gauges, the following are typically used:

- manual profile gauges are used to assess side wear and top wear of rails and crossing, switch rail damage and switch rail profile
- difference in rail heights, hogging of switch rails, switch toe position, toe opening in switch – typically measured using cant sticks (i.e. track gauges) and feeler gauges

There exist a number of more advanced methods for measuring rail profile based on contacting rollers attached to instrumented arms (e.g. MiniProf), or manually held lasers for measuring rail head profiles. But although more detailed and arguably more accurate, these can be time-consuming to use and are usually only employed where there has been a derailment or there is a specific know issue with a section of track or S&C.

More recent track recording vehicles can also automatically measure and record rail head profiles, but this tends to be limited to plain line.

4.3 Track Geometry Assessment

There are three approaches typically used to assess track geometry in the vicinity of S&C. The first is the use of a manual track gauge to measure the relative height and gauge of rails through the crossing, looking for track twist and incorrect rail spacing. This would typically include measuring the relative distance between and heights of the rails including switch rails, wing rails, check rails and crossings – see Figure 7.

Figure 7 – Typical manual track gauge / cant stick

This is typically supplemented by data from track geometry recording vehicles, although the nature of the geometry through S&C means that it can be challenging for track recording cars to provide an accurate assessment of geometry through S&C. The third option is the recent development of track geometry trolleys, capable of measuring through S&C.

4.4 Component Security

The tightness of key components cannot necessarily be checked by purely visual inspection – nuts for example work may lose their clamping force over time and this needs to be detected long before the nut comes off. It is possible to get some idea or "feel" for component security by applying a manual load to a component to assess its tightness or robustness, but a more accurate but time-consuming approach is to use a calibrated torque wrench to check every securing nut.

4.5 Crack / Rail Flaw Detection

Cracks in the rails are concern for most systems railways, and the high dynamic loads at S&C mean that defects are quite commonplace. An experienced track patrol will be able to spot surface cracks or other obvious flaws in the rail, but they are not always easy to detect, and it is difficult to assess their depth and severity. There are many inspection techniques such as the Balfour Beatty system shown in Figure 8 which can be used to detect cracks, and the most widely used detection technique is ultrasonic inspection, sometimes supplemented by Eddy Current sensors.

Figure 8 – Balfour Beaty Ultrasonic Rail Testing Vehilce

However, crossings manufactured form austenitic manganese steel (AMS) pose a particular problem as most inspection techniques do not perform well on this type of material. Research is on-going to develop new techniques, capable of reliably detecting all cracks at line speed. But for the time being, trolley based systems, measurement "walking sticks" and dye penetration are typically used to scan for cracks on key areas of S&C.

4.6 Existing Automatic S&C Inspection Systems

Harsco ASIV

Harsco Rail have developed a road-rail vehicle that can measure S&C profiles to generate a 3D model of switch blade and crossing called Automatic Switch Inspection Vehicle (ASIV), shown in Figure 9.

Figure 9 – Harsco road-rail switch inspection vehilce

Although these road-rail vehicles have been successfully demonstrated in the UK and elsewhere, they still require engineering track possessions in order to operate. With further development, such systems have the potential to be mounted to in-service vehicles, but this option is understood not to be being pursued by the manufacturer at this time.

Eurailscout SIM

A number of bespoke inspection vehicles have been designed by Eurailscout for S&C. Earlier designs focussed purely on video camera technology used to allow operator to visually inspect S&C, but this not insufficient to replace current manual inspection requirements. So the latest generation of Switch Inspection and Measurement (SIM) vehicles now includes:

- a series of video cameras to enable the general condition of switches to be assessed remotely
- a series of laser scanning units which produce rail profiles scans at 20 mm intervals at speeds of up to 40 kph
- an inertial measurement unit to account for the relative movement of the vehicle in relation to the track it is operating over

The design is based on a wagon that can form part of a regular train consist (see Figure 10). The SIM is capable of inspecting a large number of switches in a small geographic area quickly and efficiently, and is currently used to inspect 200+ switches in Amsterdam in a single 6 hour shift. The performance and capabilities of the SIM system were therefore investigated further as part of this project (please refer to Section 5.3 for details).

Figure 10 – Eurailscout SIM wagon

4.7 Data Collection, Interrogation & Interpretation

Currently, much of the information gathered through the inspection of S&C is reported manually with paper based inspection records maintained. This then requires time consuming manual data entry and collation with any other available sources of information or measurement.

Ideally, all of the information relating to a piece of infrastructure would be readily available from a single, easily accessible electronic source. This single source would provide a comprehensive view of the condition of the S&C, enabling maintenance decisions to be made in an accurate and timely manner.

4.8 Gaps in Technology

While there is a comprehensive range of technologies available for the automatic inspection of plain-line, the options for S&C are more limited. The most advanced system is probably the SIM system from Eurailscout described above which was first introduced in 2009. This is currently used successfully in the Netherlands, and is also on trial with DB. It appears to address many of the requirements of AUTOMAIN, particularly in relation to the Visual Inspection and Rail Profile categories, and further evaluation of its suitability and functionality has been undertaken as described in the following chapter.

However, the SIM wagon still requires to be loco hauled and therefore programmed into train movements. It also has a maximum operating speed of 40 kph. There is therefore potentially the need to also consider alternative technologies including infrastructure based inspection systems, and the development of more compact systems for visual inspection and rail profile measurement that could be installed on in-service vehicles.

Several developments were pursued as part of the AUTOMAIN project as described in the following chapter including infrastructure based video cameras, in-service track geometry recording for S&C, and a trolley-based rail profiling system suitable for future incorporation onto service vehicles.

Finally, there is also perceived to be a need for a standard interface, ideally web-based, so that information from disparate systems can in future be gathered, interpreted and displayed in on a single MMI. The development of such a standard also formed part of the work undertaken for D3.2.

5.0 Development of Inspection Technology

A number of technologies were developed and / or evaluated as part of the AUTOMAIN project to investigate their potential for application for self-inspecting infrastructure.

5.1 Overhead Camera Inspection

Damill AB developed a prototype CCTV installation for use at S&C. This consists of a standard CCD web-camera built in to a plastic housing that is mounted to the overhead catenary. The prototype system includes a network surveillance camera, Wi-Fi transponder and battery pack has been constructed and suspended from the catenary wire over a set of S&C at Boden in Sweden, as shown in Figure 11.

Figure 11 – Prototype CCTV suspended from a catenary wire and initial images

The figure also shows a picture taken with the system during trials at Boden during autumn 2012. The images from the trial show that the suspended camera gives a sufficiently good view of the S&C underneath that could be used for:

- finding obstacles in the switch
- inspecting the switch positioning at a given time
- looking for more severe damage to the rails

It should also be possible to measure the gauge and height of the rails. Although this is not currently possible with the prototype system, consideration has also been given to how this could be achieved (discussed below). Also, the field of view is limited, and in order to inspect a greater length of the S&C, the ability to tilt the camera using a servo would be needed. When directing the camera view further along the track, either a larger camera sensor with more pixels or optical zoom would be needed to be able to see sufficiently detailed images.

The trial was performed on a sunny day, which can be seen from the dark shadows in Figure 11. Shaded areas result in areas of low contrast in the image, which can make it harder to detect objects. This suggests that a light for the camera might be needed to make the system less weather dependent, and similarly for installation in tunnels.

Measuring Track Gauge and Rail Height

In terms of measuring track gauge, one option would be to use reference plates or a marked scale placed next to the rails in line with the rail surface, visible in the camera images. This would provide a direct translation of length per pixel in the image against which key features could then be measured. One drawback of using reference plates is the installation and maintenance of the plates, ensuring that they are installed correctly in line with the rail surface, and that they remain free from dirt, gravel and snow. But with the overall aim to reduce the need for manual maintenance, the use of reference plates might not be acceptable.

In terms of measuring rail height, another approach would be to use a line laser together with the camera to create a triangulation system. By placing a line laser at a known distance from the camera and pointing it with a known angle relative to the camera's line of sight, it would be possible to translate the position of the laser light in the image directly to a distance from the camera lens to the surface which the laser is reflected from, as shown in Figure 12.

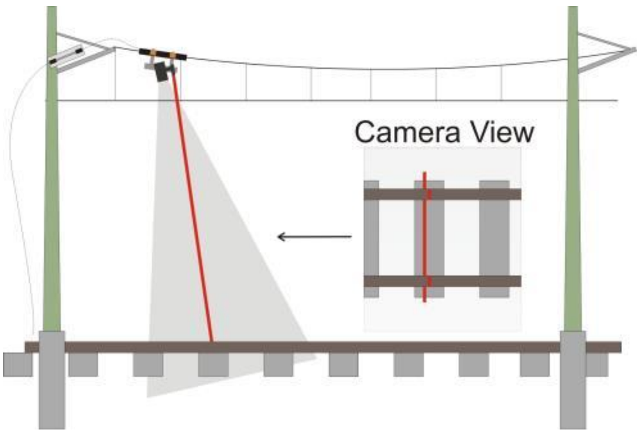


Figure 12 – Schematic illustration concept with triangulation system

The resolution of this approach is dependent on factors such as laser quality, sensor size, number of pixels, pixel size and optics quality. Some care would therefore need to be taken to select an appropriate combination of accuracy the sensor, lens and laser. But by using a combination of camera and line laser and scanning along the track, it would be possible to produce a 3D-profile of the scanned area.

Questions that arise for the concept of using a line laser together with the camera are the resolution on the distance and length measurements that can be achieved, and the length of S&C that can be inspected using only one of these systems suspended from a fixed position on the catenary wire. When tilting the system along the direction of the track, the incident angle of the laser light on the track will increase with the tilt angle which will result in less of the laser light being reflected back into the camera, particularly as the rails have a metallic relatively smooth surface.

5.2 Laser Profile Inspection Trolley

The University of Birmingham was tasked with developing a rail profile measurement system intended for use on S&C. This was to be trolley based system that could be used to improve the quality, longevity and safety of weld repairs to switch blades and crossings, thereby reducing overall track possession time. But another aim was to evaluate and develop low-cost rail profile measurement technology that could be potentially mounted to in-service vehicles. From the analysis of current inspection techniques, a list of requirements was developed as follows:

- a clear view of all contacting parts of the switch, stock and crossing
- profile measurement accuracy of +/- 0.2 mm
- it initially needs to work at walking pace, but there should be no technical barriers to operation at typical line speed (taken to be around 160 kph)
- measure distance travelled to an accuracy of +/- 1 mm
- easily installed and removed from the rail by one person
- be suitably rugged for railway applications
- provide output in a standard format for subsequent use with the proposed MMI
- maintain a suitable point of reference for all measurements to support the development of 3D models from a series of line scans

Various designs were considered, and the concept worked up using Google Sketch Up, a screen shot of which is shown in Figure 13.

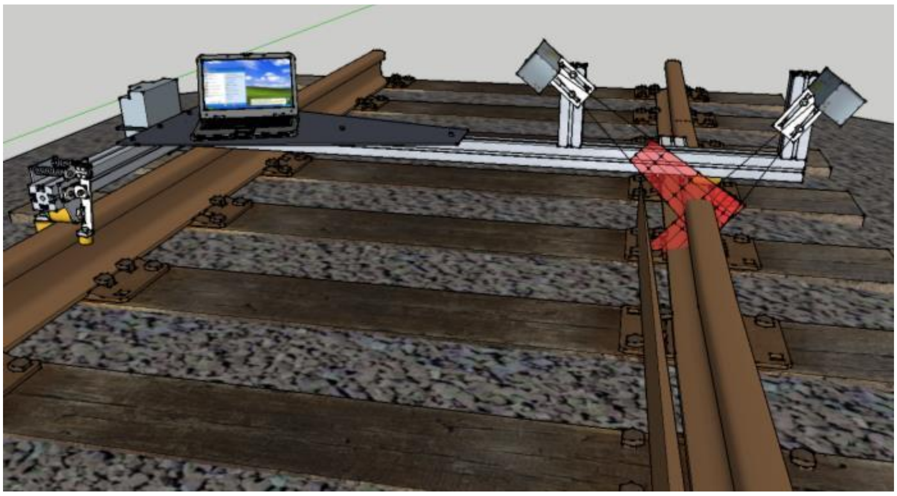


Figure 13 – Google Sketch-Up model of S&C inspection trolley

There are a number of features of the design that can be appreciated from the above images:

- the framework is made of aluminium extrusions which provides a relatively light, but strong and stiff frame
- the slots in the aluminium section enable components to be easily fitted and removed, or adjusted as the design is refined
- the design contacts the rails at three points, which prevents any “wobble”, and is sprung loaded against the field side of the outside rail
- the lasers are mounted on two vertical posts and attached such that they can be easily adjusted vertically and in rotation
- the majority of the trolley’s mass (including the battery pack) is located over the reference rail to help maintain the stability of the trolley, particularly over crossings

A great deal of care had to be taken to ensure that the required field of view could be maintained throughout the switch or crossing. The 3D model proved invaluable for determining the optimum position and angle of the laser installation. The prototype inspection trolley is shown in Figure 14.

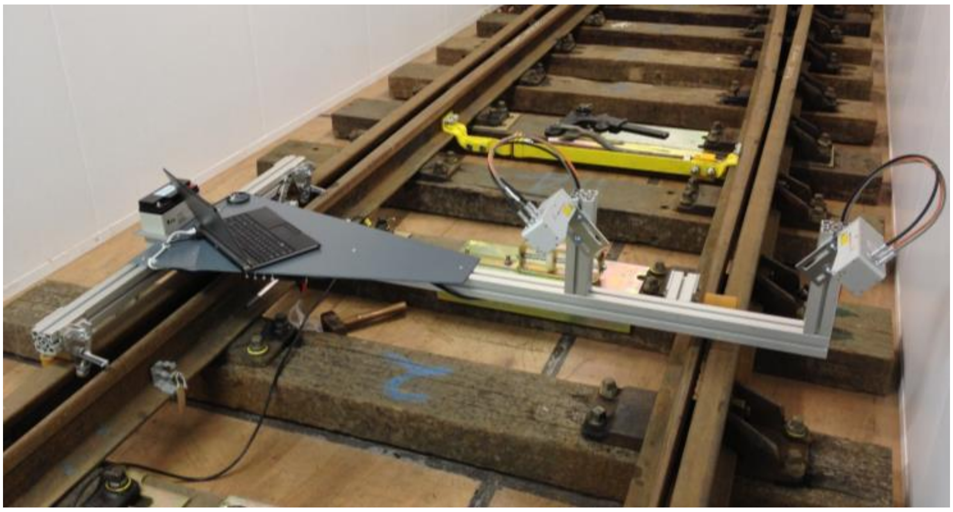


Figure 14 – Prototype S&C inspection trolley

The lasers selected for the prototype inspection trolley are from the process industry where they are more commonly used to line-scan components for quality checking purposes. They are sufficiently and have a very high scan rate, from 100 Hz (as installed) up to 30 000 Hz (available at higher cost). This suggests that it should be possible to achieve scans at 5 mm intervals at speeds of up to 300 kph.

The analysis software was developed using industry standard LabVIEW programming language, as widely used in industry for rapid prototyping and as recommended by the suppliers of the line-scan lasers. This runs on standard Windows operating systems with Ethernet communication between scanning units and analysis computer. The initial test results are promising – an example scan from the trolley is shown in Figure 15.

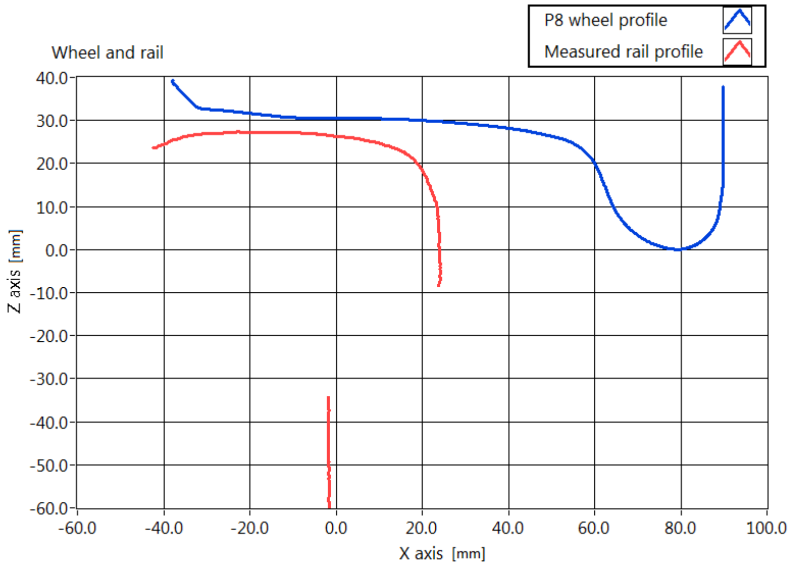


Figure 15 – Example laser line scan

The blue line in Figure 15 is the profile of a standard UK P8 wheel, and the line in red is the profile of the rail as scanned by the laser. It can be seen that the red line captures the head of the rail in good detail, but that the underside of the inside edge is missing due to the angle at which the lasers are set (this is not a problem as it is not an area of interest from a wheel / rail contact point of view).

The analysis software is still under development, but it is already capable of determining the contact angle between the rail and any standard or recorded wheel profile. It is expected that by the time the AUTMAIN demonstrations take place, the trolley will be able to perform inspections to UK standards.

The longer term ambition is to develop this technology for application for in-service inspection by fitting it to passenger vehicles or freight locomotives. The current system has the potential to undertake measurement runs over S&C at speeds of up to 5 kph. However, more expensive versions of the laser units have a significantly higher scanning rate which would be sufficient for scanning at up to 50 kph. The top level units would scan at a rate suitable for operation up to 200 kph, but other issues such as the high level of vibration and high wind loading are likely to preclude operation at such speeds.

However, for in-service train applications there is a further challenge which is particular to the UK, namely grease. While on the continent, lubricant is typically applied to the wheels and S&C is relatively free of contamination, in the UK grease is applied to the head of the rail. The lasers therefore pick up the profile of both rail and grease, potentially resulting in false alarms due highly irregular “rail head profiles”.

5.3 SIM System Trial & Evaluation

The Eurailscout SIM wagon is currently in regular operation with Strukton in the Netherlands, and it is regularly used to inspect a large number of switches in Amsterdam. DB have identified a number of stations across their network that also have a high density of switches (> 100) that would be suitable for inspection using this technology, as shown in Figure 16.

Figure 16 – Stations on DB with > 100 switches

DB are therefore working with Strukton to evaluate the performance of the SIM wagon, and an RFID tag reader has been added to the SIM wagon for easy location identification.

An initial comparison of the output of the SIM with traditional inspection methods using hand tools has been undertaken involving a total of 7 switches and 66 measuring points. A summary of the output is shown in Figure 17.

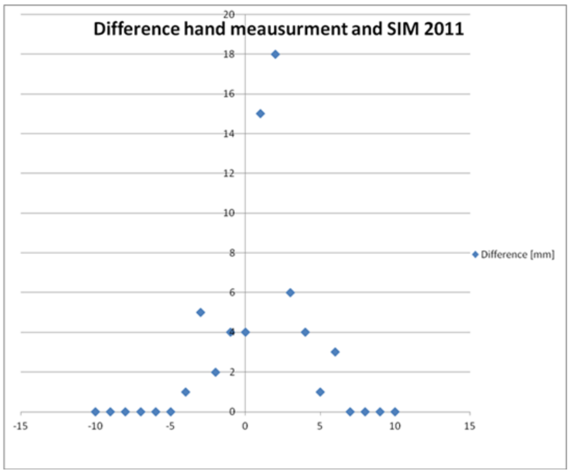


Figure 17 – Comarison of SIM & hand measurements – distribution graph

The number of measurements is shown on the vertical axis and the difference between manual and SIM measurements is horizontal axis. From this, it can be seen that 39 out of the 66 measurements were within 2 mm, with four measurements being 5 mm or more different.

The system is now on trial at two mainline DB stations, and the initial tests took place on the nights of the 3rd September 2013 at Nürnberg station, and 4th September at Rosenheim station (near Munich). The switches at these locations have been fitted with RFID tags for identification, and the trial will compare the results of traditional inspection with those from the SIM wagon. The aim of the test is to define the accuracy of the system in preparation of using it for maintenance support decisions, and to evaluate the IRISsys, the software tool used to manage inspection data, perform condition analyses and help define maintenance strategies.

In the longer term, it is intended to use the SIM measurements results for failure prediction, and the intention is to remove the need for manual in-service inspections. The SIM will also use it to inspect switches as the train travels across the network (i.e. to inspect switches between mainline stations).

5.4 In-Service Track Geometry Inspection

Track recording cars have been in regular service since the 1960s, but with advances in technology, the size and power requirements of the technology have been shrunk to the extent where it has recently become possible to fit track recording equipment to in-service vehicles. The ability of two such installations to measure and assess track geometry through S&C has been undertaken as part of the AUTOMAIN project:

- DB have been testing and evaluating a system that includes sensors mounted to the axlebox of a freight locomotive
- the University of Birmingham has developed a simpler recording device based on accelerometers, gyros and GPS that have been fitted to a multiple unit

Each of these trials is described below. It is important to note that these trails are initially focussed on measurement of plain line track.

DB Trials

The trial in Germany involves fitting monitoring equipment to a BR 189 freight locomotive operating on the Rotterdam to Dillingen route. Various sensors including gyroscopes and accelerometers have been installed, including accelerometers mounted to the axle bearings – see Figure 18.

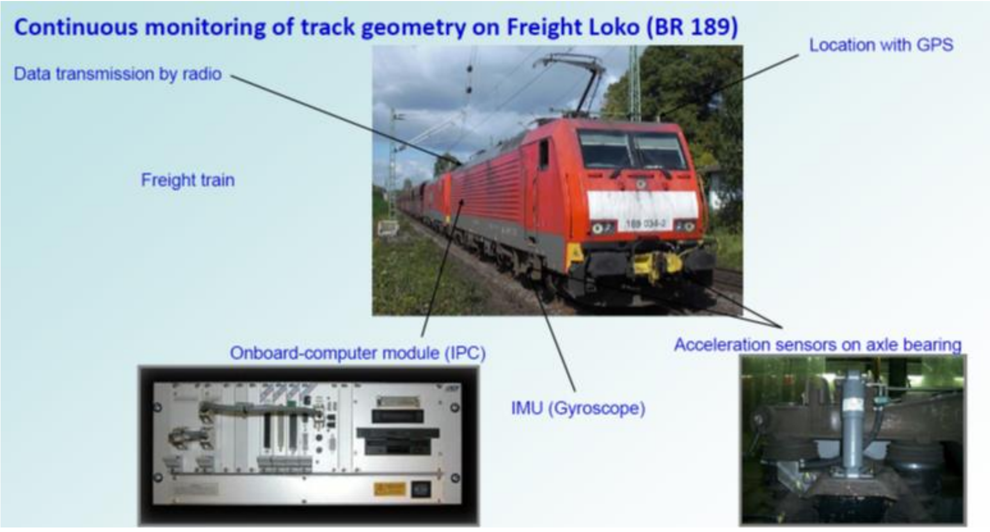


Figure 18 – In-service installation on DB freight locomotive

The locomotive regularly traverses the same route which makes it an ideal choice for monitoring the variation in measurements over time. The initial analysis has focussed on the measurement of plain-line, looking initially at vertical track geometry and the initial results look promising, as shown in Figure 19.

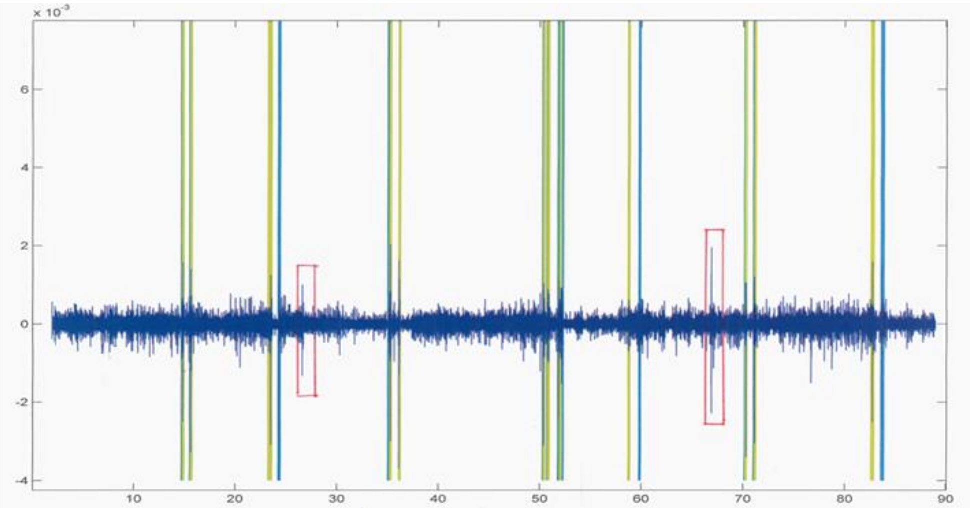


Figure 19 – Data from DB in-service trials

This shows the filtered displacement data (dark blue) against track position in km. Any of the peaks are associated with S&C as indicated by the yellow vertical lines showing the location of a facing switch and the turquoise lines showing the location of switches in the trailing direction. Further evaluation is needed to determine whether key measurements for S&C such as track twist can be made sufficiently reliably and accurately to potentially replace manual inspections. Algorithms are also under development to predict deterioration rates and optimum maintenance intervention intervals from the data to assist with the planning of timely intervention / maintenance – see Figure 20.

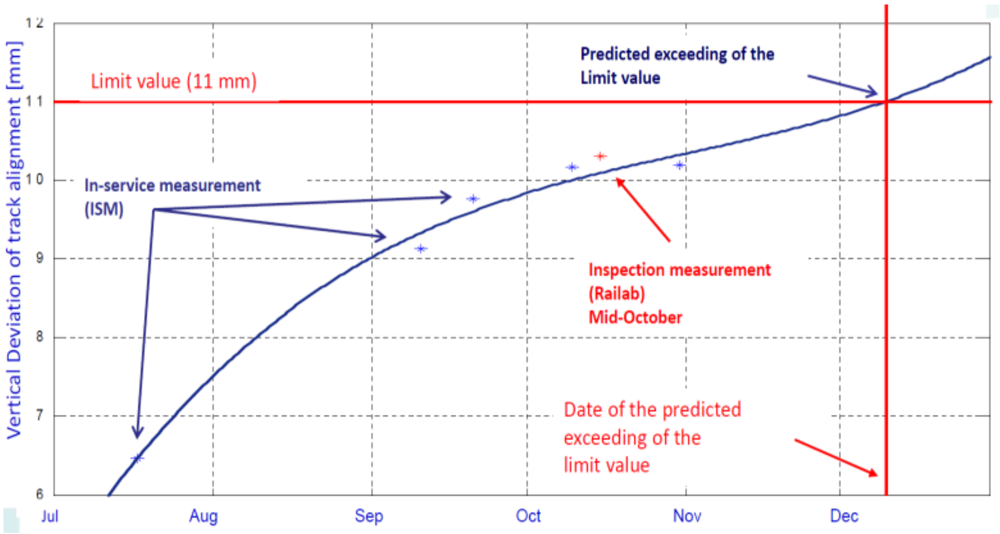


Figure 20 – DB / DLR Defect growth prediction model

Currently, these algorithms are being developed for plain-line, with data from S&C location cancelled out prior processing as the peak values over S&C distort overall track quality figures when assessing geometry against track standards.

UK Trials

The University of Birmingham has been involved in a number of trials involving the use of vehicle mounted sensors to measure or infer the condition of railway infrastructure. The most recent trial, part funded by AUTOMAIN, involved fitting inertial measurement units to a Class 377 multiple unit operating between London, Brighton and Southampton. Each inertial measurement unit includes a 3 axis accelerometer, 3 axis gyro unit, GPS and tachometer, and data has been gathered since December 2012. The installation is shown in Figure 21.

Figure 21 – UoB in-service track recording installation

The signals from the instrumentation need to be filtered and combined in order to generate required track geometry parameters. Although this is some way short of a full track recording car, the processed measurements made by this relatively simple equipment have been compared with Network Rail's bespoke New Measurement Tran (NMT). In terms of track twist, the measurements made by the two systems are remarkably similar (Figure 22).

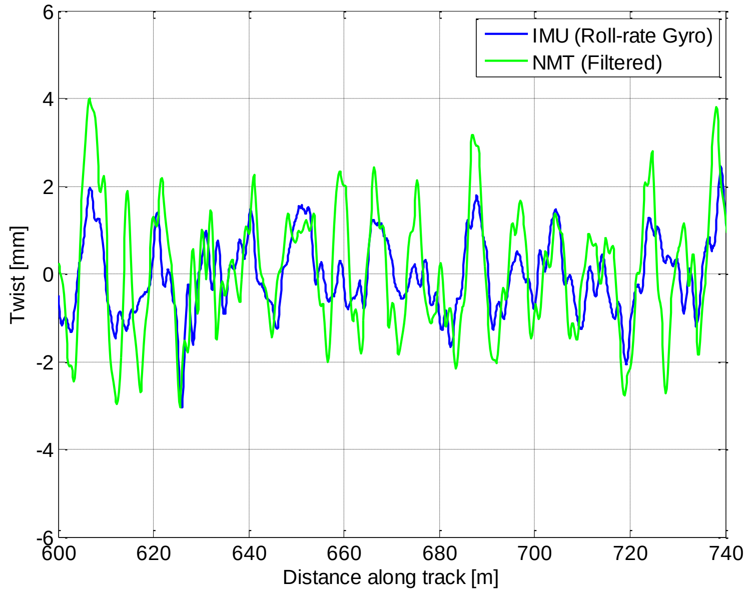


Figure 22 – Comparison of UoB and NMT track twist data

In terms of assessing S&C, the instrumentation includes GPS satellite positioning and it is relatively easy to focus in on a specific location such as frequently traversed S&C. Data was therefore examined across a section of S&C at a nearby location, in particular looking at the cross-level and track twist recorded by the on train system – see Figure 23.

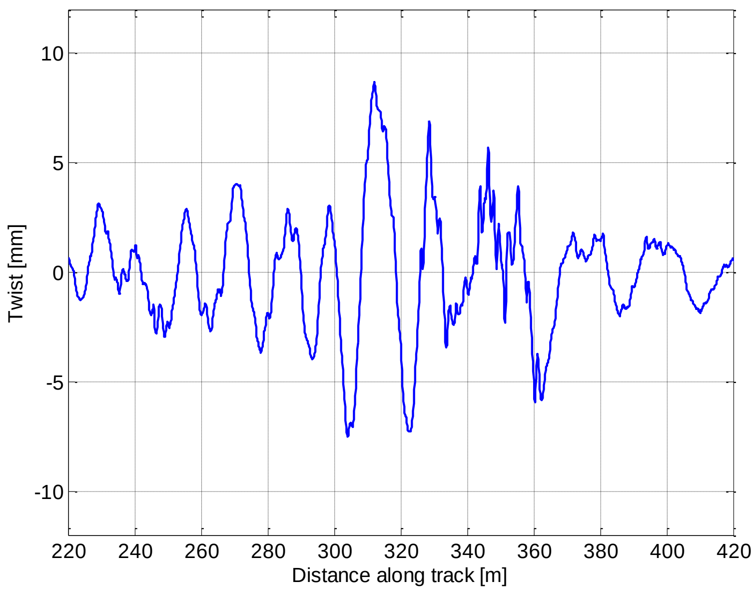


Figure 23 – Track twist over 5 m wheelbase through S&C

Comparable data from the NMT is currently being obtained so that a comparison can be made with those from the UoB in-service system. Additionally, inspection data from recent manual inspections in the relevant operating area is also being sought for further confirmation of the system's accuracy.

Although the current system is focussed on condition monitoring rather than inspection, the addition of other sensors such as cameras and laser rail profiling would enable it to form part of a more comprehensive self-inspection system for S&C.

5.5 Component Security

As discussed previously, the bolts that hold the stretcher bars that keep the rails apart are a critical item to for the safe operation of switches. Failure of these bolts or the loosening of attached nuts can cause fatal accidents as demonstrated by the Potters Bar derailment in the UK. The high level of vibration can cause securing nuts to work loose over time, and it is difficult to visually assess the tightness of standard nut and bolt arrangements. There are at least three potential solutions:

- use nuts and bolts that have some clear form of clear visual indication that they are becoming loose
- use nuts and bolts which have some form of locking mechanism so that they cannot come loose
- employ some form of instrumentation to detect when the nuts is becoming loose or the tension in the bolt is falling

Visual Indication

There are various commercially available products such as the SmartBolt shown in Figure 24 which have a tightness indicator that could potentially be detected using in-service cameras.

Figure 24 – Smartbolts with visual tightness indicator

Locking Nuts

An alternative approach is to use specialist nuts and bolts that cannot come undone. There are many different designs of locking nuts, but one of the most promising is the Tracksure Locking Device which uses a combination of clockwise and anti-clockwise threads to permanently secure the nuts, as shown in Figure 25.

Figure 25 – Tracksure locking device

These devices have been used in many countries including widespread use on London Underground, with ProRail in the Netherland and is on trial with DB. On Network Rail, an alternative device called the Hardlock is being increasingly used (Figure 26). This has a two part nut with a single, standard thread. The inner nut has a sleeve onto which the outer nut locks, effectively forming a wedge on one side of the thread to lock them in place.

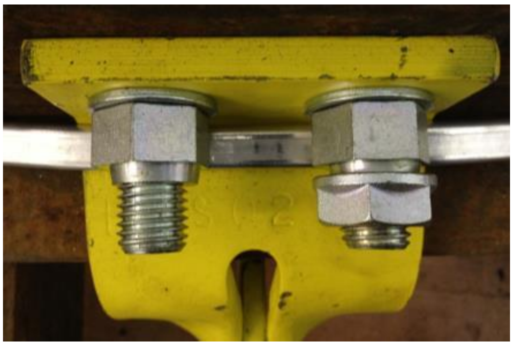


Figure 26 – Hardlock with eccentric (taper shown left)

Instrumented Washers

Although locking nuts have the potential to significantly reduce inspection requirements, they cannot be guaranteed never to work lose. In order to do away with manual inspections completely, one potential solution would be to use instrumentation to monitor the tension / torsion of bolted fastenings. There are no commercially available options in relation to instrumented washers, so the University of Birmingham investigated whether this could be a viable solution. A toroidal strain gauge was sourced and used in place of a standard washer on a laboratory switch at the university (see Figure 27).

This sensor is currently attached to a relatively simple circuit designed to check bolt tightness on a continuous basis. The circuit includes an illuminated LED to indicate correct operation that starts to flash in the event that the tension in the bolt falls beneath the threshold value (i.e. starts to work loose). This flashing LED should be easily spotted during a manual track inspection, and should be easily picked up using CCTV or inspection train cameras. However, the railway environment means that there is a risk that any LED would likely be covered with dirt after a relatively short period in operation.

Figure 27 – Instrumented washer (left)

A better option would therefore be to include a low powered radio transmission. Using modern technology this need not be expensive, and for short range transmission this will actually use less power that a continuous LED.

In terms of power, the ideal option would be for these self-inspecting washers to be self-powered. Systems already exist to harvest energy from vibration, solar or wind sources, with vibration being the most promising option for this application, and this is discussed further in Section 6.3.

6.0 Development of Enabling Technologies

In order for self-inspecting infrastructure to become a useful reality, there are a number of supporting technologies that are required.

6.1 Man Machine Interface

The technologies described above have the potential to enable self-inspection of infrastructure and S&C in particular. However, this does mean that a large volume of data and information will be collected from a wide variety of sources, which then needs to be collated in order to ascertain the status of a given asset / set of S&C.

Work Package 3.2 therefore included the development of a Man Machine Interface (MMI) suitable for this purpose that would enable trained maintenance staff to visualise and analyse the condition of particular assets and supporting decisions as to whether, where and what maintenance is required.

The key element of developing the MMI is to the architecture and specification and development of a language suitable for the exchange of data. The proposed architecture is shown in Figure 28.

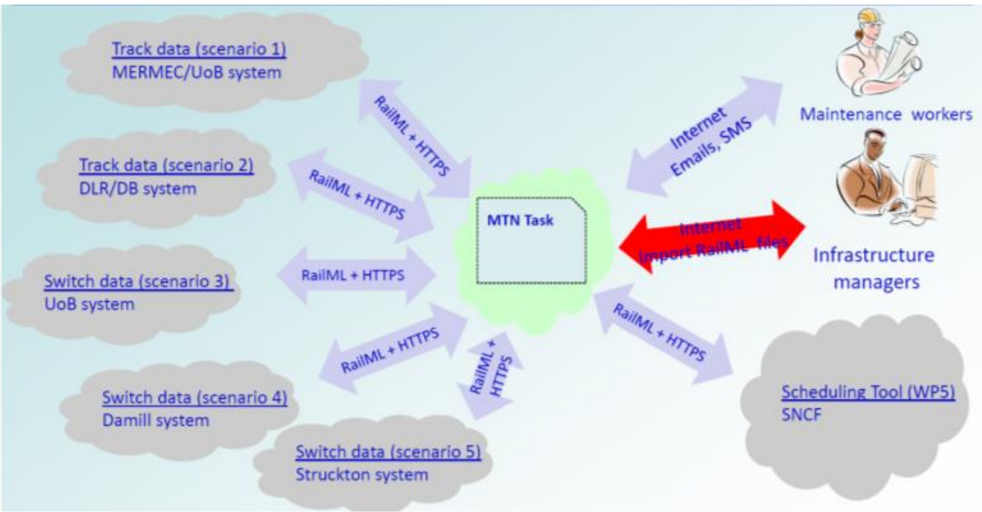


Figure 28 – Proposed MMI architecture

In this architecture, the systems (clients) have an access to the Internet to connect to the MMI server, hosted on the Internet. The transmission of information between server and clients is achieved through the standard HTTP protocols, and the system can also send and receive files (maintenance tasks newly created or updated) through this protocol.

A data schema in XML format was created using the rules of the railML standard (railml.org) and coded in a XSD file. This schema is called automainML and the main goal of this standard is to be used by all the manufacturers of monitoring and planning systems in order to offer a complete automated process of the maintenance work in railways.

The system displays a list of the maintenance tasks to perform by the user, with the list dependant on the user account (the association between user and maintenance task is performed in the railML maintenance task file). The system gives a table with the planned tasks for the assets the user is responsible for, or enables them to see who is in charge of particular assets.

Each asset can be located on the geographical map, making it easier for the user to see the assets with a special colour and shape to indicate the status of each asset. The system also shows on a common map the current maintenance tasks along the track – see Figure 29.

Figure 29 – Example MMI map

Each user belongs to a specific region. This region is defined by a polygon of GPS coordinates and a rectangle map view that contains this region. When the user logs in, the map of his region is shown. The manager can create and modify the map through the MMI and link users to this map.

The MMI can be accessed from different platforms (PCs, phones, tablets etc.) with a secure log in assigned to each user. The MMI allows the users to modify maintenance tasks assigned to his profile, and some fields are editable (scheduling of the task for example) but some are not (failures detected).

The MMI works with its own database (MySQL), used for searching and displaying results, and the input / output files use a specific data schema (automainML, which is based on the railML standard as discussed previously). railML includes three native schemas that are dedicated to infrastructure, rolling stock and timetable. The AUTOMAIN project chose to add a schema dedicated to the maintenance task, keeping the three basis schemas of railML without modification as shown in Figure 30.

Hence, the maintenance task schema uses base types and structures from the railML schemas. But the maintenance task schema remains completely independent from railML and its possible evolutions.

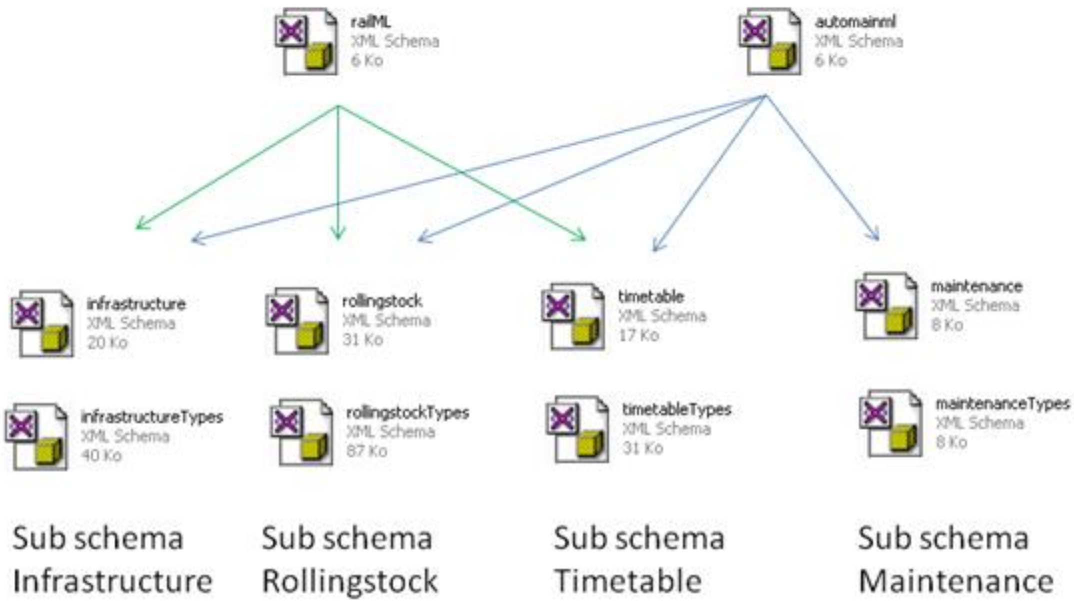


Figure 30 – railML schemas

The "maintenance.xsd" file contains the structure of the main element for automainML, and the "maintenanceTypes.xsd" file describes the types, group of attributes and list of restricted values used by "maintenance.xsd". The three files (automain.xsd, maintenance.xsd and maintenanceTypes.xsd) are available on the web at http://www.automain.eu/schemas.

The following table presents a list of the seven main elements contained in an automainML maintenance task file and their usage is as described below:

- Description – description of the global maintenance task
- Time – time details for the maintenance task
- Risks – list of risks to take into account related to the global maintenance task
- Statuses – list of statuses of the maintenance task
- Users – list of users of the MMI for the maintenance task
- Regions – list of regions of the maintenance task
- Tasks – maintenance tasks details : assets information and failures detected on them

An example railML file in accordance with the "maintenance.xsd" structure is shown in Figure 31 with the Regions section marked in red.

```xml
            <user id="USR2" name="John Easton" email="j.m.easton@bham.ac.uk" role="Administrator" language="en" regionRef="RE
            <user id="USR3" name="Clive Roberts" email="c.roberts.20@universiutyofbirmingham.ac.uk" role="Manager" language='
        &lt;/team&gt;
        &lt;team id="TM3" name="DB"&gt;
            <user id="USR5" name="Gunnar Baumann" email="gunnar.baumann@deutschbahn.com" role="Manager" language="de" regionI
        &lt;/team&gt;
    &lt;/users&gt;
    &lt;regions&gt;
        &lt;region id="REG1" name="Strasbourg"&gt;
            &lt;geoCoord coord="47.1829780 19.8065227"/&gt;
            &lt;geoCoord coord="48.1829780 15.8065227"/&gt;
            &lt;geoCoord coord="49.1829780 17.8065227"/&gt;
            &lt;geoCoord coord="17.1829780 12.8065227"/&gt;
            &lt;geoCoord coord="26.1829780 18.8065227"/&gt;
        &lt;/region&gt;
    &lt;/regions&gt;
    &lt;tasks&gt;
        &lt;task id="TSK143" name="Task n°143" activity="Temporary repair"&gt;
            &lt;description&gt;Grease the rods on the switch_15 (id=15) and switch_20 (id=20)&lt;/description&gt;
            &lt;locationFrom coord="47.1829780 19.8065227" /&gt;
            &lt;locationTo coord="47.1829780 19.8065227" /&gt;
            &lt;assets&gt;
```

Figure 31 – Example XML file

The first version of the automainML extension for railML was published on the AUTOMAIN website in June 2012, but data from live inspection systems has yet to be received / tested.

6.2 Modular Switch Inspection

In order to minimise maintenance times, there is ever increasing interest in the development and use of modular components that can simply be "changed out" when a fault is required, or installed as a single, module as opposed to a kit of parts that need to be built up on site and adjusted. Much of this development has to date concentrated on the actual infrastructure itself, with entire switch panels being transported to site (see Figure 32) and the development of more easily installed switch activation systems.

Figure 32 – Network Rail's tilting wagons for transporting S&C panels

In order for the technologies discussed above to be successful, they too need to be of a modular, and ideally pre-assembled design, for example building sensors into original switch components, as opposed to being a bolt-on extra. A previous AUTOMAIN report looking at the maintenance and repair of S&C suggested that rather than undertaking weld repairs on-site, crossings should be replaced as standard practice. If adopted, it is likely there will be an increased need for such modular technology.

6.3 Energy Harvesting & Communications

In order to support the development of remote inspection systems, there is perceived to be a need for compact, self-powered sensors with built-in short range radio transmission. Such devices are beginning to be seen for on-train application in the UK, with several hundred bearing / axlebox monitoring sensors currently being installed on 148 Electrostar multiple units in operation with Southeastern Railways in the UK. These self-contained units produced by Perpetuum Limited harvest the vibration as the train travels along, storing the energy in a battery. This energy is then used to periodically measure the vibrations and send the results wirelessly to an on train computer. A typical installation is shown in Figure 33

Figure 33 - Perpetuum energy harvesting wireless sensor

It may be possible to apply a similar technology for track installations. However, the key issue is that the vibrations on train are continuous for long periods, whereas the vibration of an on-track installation is sporadic. If a sensor were only required to operate say once a week to gather data, there could still be enough energy harvested from the passage of regular services for such an application.

7.0 Case Study – Camera Inspection System

Any analysis of the potential for self-inspecting infrastructure first involves the investigation of available and possible technical solutions to detect and measure different parameters which must be inspected, as discussed in previous chapters. A further important aspect that needs to be considered is the potential benefit of any new condition monitoring (CM) or inspection system with respect to other types of requirements. It is important to analyse the potential benefits of the system in order choose the right type of equipment with respect to factors such as safety, train delay or cost. But to be able to choose the right type of equipment with the largest benefit, an analysis of possible and critical failure modes of a railway switch must be performed.

This chapter presents a study undertaken by Luleå University of Technology looking at the analysis of failure modes of railway switches in Sweden, and a case study of the possible benefits offered by the contact wire mounted camera system described previously. The study presents an adapted decision support model for choosing appropriate inspection tasks. This model work flow includes the following steps; analysis and selection of critical equipment, risk management, analysis of types of condition monitoring activities, and assessment and decision-making. This section describes what causes the degradation of switches, discusses the potential for using Failure Mode and Effect Analysis (FMEA) to define the inspection tasks required, and concludes with a discussion and proposal for future work.

7.1 S&C in the Swedish Railway System

The railway switch or turnout is an essential component of a railway system, but they need many resources to work properly. In addition, attaining good operational flexibility requires a large number of turnouts; for example, the Swedish railway network has 10 799 turnouts over a track length of 12 000 km. Because of their complexity and because they have a high safety and economic impact on the railway infrastructure, turnouts require careful monitoring. As discussed previously, the inspections of turnouts can be divided into several categories including simple visual inspection, detailed visual inspection, measured inspection and non-destructive testing. Actions resulting from the inspection reports or failures include adjustments, lubrications, cleaning/rinsing, functional checks, repair, replacement, grinding and tamping [1].

Statistics

Of all infrastructure-caused train delays in the Swedish network from 2004 to 2006, 17% were attributed to turnouts [2]. The failure of an individual turnout can cause problems for the railway, including both direct costs and the knock-on impact on train services. Turnouts (i.e. S&C) account for about 13% of the yearly maintenance budget for the Swedish railway infrastructure. The maintenance costs depend on the traffic load, the type of traffic and type of turnout.

The degradation of the turnout has a significant relation to axle load [3]. The highest maintenance costs are for turnouts on the iron ore track in the northern part of Sweden; this cost is due to the higher axle load and the more extreme climate, including cold weather and snow during the winter [4].

The turnouts in Sweden are generally quite old; many have already passed their technical life length, and many more will do so in the next ten years [5]. Therefore, it is likely that there will be higher maintenance costs, combined with increased traffic disturbances in the near future. This calls for more inspection and better condition monitoring of the turnouts.

Manual inspections are expensive and in many cases impossible due to high capacity demands for the track; in any event, the trend is towards fewer human inventions on the track. There are also turnouts in inaccessible terrain where the only access is by the track; problems in these areas can lead to a large loss in the capacity of service. Inspection using a remote camera could facilitate maintenance inspections, thus enhancing the track capacity and saving maintenance costs.

7.2 Decision Support

This section discusses camera inspection of turnouts and what can be measured using a camera.

Cost benefits have previously been studied using condition monitoring equipment and life cycle cost (LCC) calculations in a real case study; the approach includes the consideration of penalty costs and maintenance savings [6]. A well-structured decision support model for defining condition monitoring parameters has yet to be developed or adapted for the railway sector, although their exist similar decision support models in other sectors [7]. Maintenance decisions support model and how to deal with failure consequences can be found for instance, in ref [9] and [10]. These discuss how to choose the right maintenance actions based on failure consequences, and the right maintenance strategy for an item. These articles addressed the following questions:

- Can the item be condition monitored effectively?
- Is this cost effective, and how does this improve maintenance?

However, they do not address how this can be done, how to find the critical measures, and how to be certain that all critical failure modes will be included and documented in a systematic way. Furthermore, the demand for high safety within the railway requires that risk assessment should be well defined and well developed, which has not yet been adequately presented in any decision support model.

7.3 Defining Decision Support Workflow

This section describes the workflow of the decision support model for selecting an appropriate condition monitoring system for a railway switch. It begins with a breakdown of a turnout's characteristics; it then discusses turnout degradation and the function of a turnout on three levels. It shows the work flow and a case study using FMEA to determine what measures can be extracted by one of the suggested monitoring systems in this report, namely the contact wire mounted camera system.

Turnout Characteristics

Before determining if a camera can be helpful, it may be useful to define a turnout and its subsystems, as well as its functions and typical causes of degradation. The breakdown of a turnout includes 14 different sections; see Figure 35a, [10]. The next step is to define the function at each level: level 0, level 1 and level 2. The level 0 function is to "allow vehicles to run along varying routes" and level 1 function is to "support movements of train" and "direct path of train according to signalling commands". This function can breakdown into more detailed levels; see INNOTRACK [11]. Factors influencing degradation at each level are design, manufacturing, maintenance and operation. All have sub-causes that influence degradation as well. Figure 34 provides a fishbone (effect-cause) diagram of the degradation of a turnout.

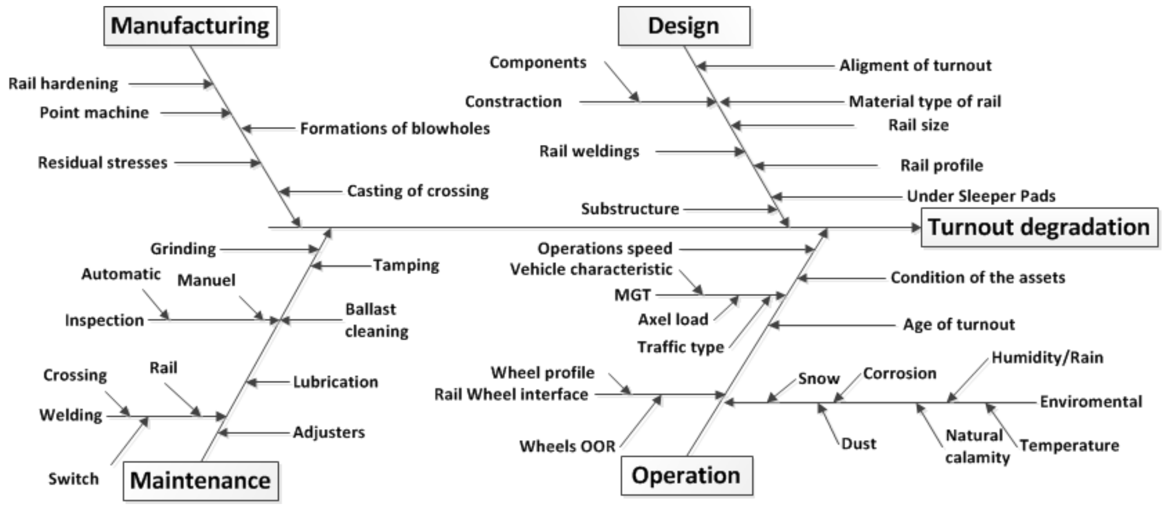


Figure 34 – Fishbone diagram of turnout degredation

The fishbone diagram shows the typical causes of degradation, considering four main areas; manufacturing, design, maintenance and operation.

The Decision Support Model

The first step is to consider the feasibility of performing maintenance inspections with a camera, and to ask whether this can reduce failures and increase capacity. The next step is to define the work-flow process used to select and evaluate a method of condition monitoring. To find the parameters for a turnout and to determine the most appropriate inspection tools, an adapted workflow was used [7]. The four steps are shown in a flowchart in Figure 35b. The difference between the decision support model by ref [7] and the proposed one are: The proposed model considers risk assessment (Step 2), generates a list for all failure modes with an acceptable risk, and brings back the unacceptable risks by new technology and innovations to Step 1, the selection and analysis of equipment and systems. This step covers all failures that will be excluded due to low risk by documentation. No other decision support model takes care of all failure modes in this way.

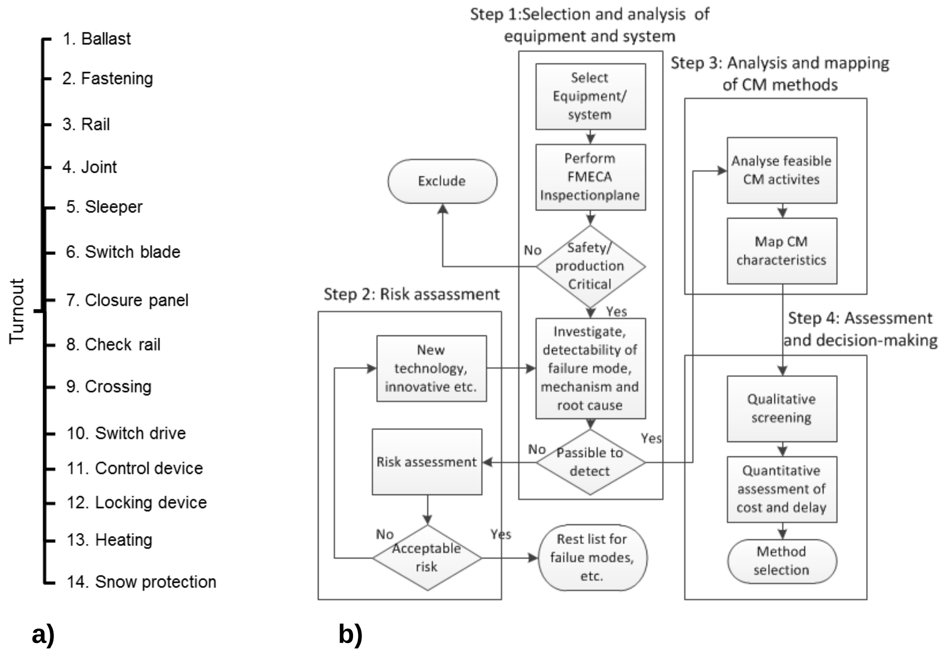


Figure 35 – a) Breakdown of turnout according to BVS811, [11]. b) The decision support model.

This flowchart is adapted to find the inspection tasks; the steps are as follows:

Step 1: Selection and analysis of critical equipment or systems: This step starts by selecting the system to be analysed, in this case, the turnout. Then a Failure Mode and Effect Analysis (FMEA) is performed to determine what must be monitored and how this can affect the maintenance of the system. This stage requires the information above, namely, the breakdown, functions, and degradation of a turnout, so that the investigation of the detectability of failure modes, mechanisms and root causes can take place. All detectable failure modes can be moved to Step 3; the others must be given a risk assessment (Step 2). More details of FMEA are presented below.

Step 2: Risk assessment: This step considers the risk of the failure modes that cannot be inspected or do not require inspection. If the risks are not acceptable, Step 1 is performed again. Because of new technology and innovations, it is important to update the analysis continually.

Step 3: Analysis and mapping condition monitoring methods: This stage finds and evaluates the type of inspection activities for the different levels, failure modes, failure mechanisms and root causes. It studies the feasibility of inspections, finds the characteristics of inspections and selects the most promising inspection methods.

Step 4: Assessment and decision-making: The qualitative evaluation/screening and ranking of the inspection monitoring tasks begins here. The next step is quantitative evaluation, followed by cost analysis. The last step compares the camera inspection to a baseline, allowing the benefits of the camera inspection to be evaluated.

Failure Mode and Effect Analyse (FMEA)

FMEA is a key tool to determine inspection tasks and define system improvements. It was developed for the aerospace industry to improve reliability and safety, but is also used in the chemical and automotive industries to improve safety and product quality as well as production capabilities [12]. There are many other benefits of FMEA, including identifying risks at an early stage, preserving product knowledge, reducing field failures, identifying potential failure modes and effects, rating the severity of the effects, identifying robust design and operation, improving the likelihood of detecting failures early, helping to find diagnostic procedures, prioritising design improvement, finding and identifying the critical characteristics, analysing the service, helping prevent errors, helping to find corrective actions, providing product or process documents [13].

Despite the many benefits, using FMEA requires a great deal of effort from many people with a variety of experience and knowledge. Since this tool was developed for industrial applications and the railway has other characteristics, the process must be modified to fit the railway [14]. Railway systems include signalling, track, substructure, power distribution; in addition, the track system has many sub-systems, such as turnouts, track fastenings, joints and ballast. This means not all possible failure modes can be found; moreover, many systems are huge.

This work applies a large-scale distribution process, whereby the most frequent failure modes are used for the analysis [15]. The FMEA workflow is divided into four main stages: establishing the rules, planning the work and scheduling the time; performing the FMEA in a worksheet, diagrams and fault trees; putting together the information, analysing it and making recommendations; and finally, updating the FMEA when something in the system is updated or developed [16].

Establish Rules and Plan the Work

To establish the rules, the following standards were used: SS-EN, SAE and MIL-STD, [16, 17, 18]. The system boundaries were defined from the stock front joint to the stock rail joint, including the ballast. The turnout used in the FMEA case study is located in the southern part of Sweden on the track section 815 (north of Hässleholm); this turnout has around 10 MBT/year. Before beginning the analysis, it is important to know the following: all problems are not the same; the customer must be known; the function most be known; and the work must be preventive in its orientation [13].

Perform FMEA in a Worksheet

In this step, a FMEA was performed with representatives from the Swedish Transport Administration and Lulea University of Technology. A worksheet was adapted for this purpose, based on the SAE standard [17]. Table 1 shows a portion of the performed FMEA, considering an EV-UIC60-760-1:15 turnout for one component, the switch blade. For more details how to work with the worksheet, see SEA standard [17].

Table 1 – FMEA of a turnout EV-UIC60-760 1:15 for the switch rail.

Part Name	Function of the system/item	No FM	Failure mode	Failure Cause	Frequency		effect on: helth, environm ent, econom	Failure effect		
Switch blade	Carry and guide rolling stock	1	Closes not to support rail	"A switch run-through"						
		1	Top breaking	Fatigue	4	a		-	Damage on rolling stock, sliper and support rail	Derailment
		1	Breaking	Fatigue	2	a		Derailment		Derailment
		1	Switch blade not in position in height (>6mm)	Object in between the gliding plate and switch blade, e.g. snow or ice	2	a		Bad comfort	Damage on switch rail	Derailment
		1	Deformation on the blade Deformerad tunga	"A switch run-through"	3	a		Crowded rail	Wedge the carriages	Derailment
		2	Wear in blade profile	Wear at the curve	5	c		Wear on wheel due to flang contact		To wide gauge
		2	Switch blade not in position in height (<6mm)	Object in between the gliding plate and switch blade, e.g. snow or ice	2	a		-		Damage on switch blade
		2	Switch blade not in side position	Lack of rail anchor(more then 10 mm movements)	2	c		Hard to switch the blade	No swith of the blade	Not in right position
		2	The shape of the switch blade at the movement	High friction at switching, weak	4	d		Slow movement of		

Gather Information, Analyse It and Make Recommendations

This was a necessary step, as it proposed parameters to measure using the camera. At this point, FMEA was ready; all information had been gathered and used to detect the most critical failure modes.

Update FMEA when Something in the System is Updated or Developed

Since FMEA is a living document that can be used in all stages, from the development phase to the service phase, it should be updated every time something changes in the system to ensure that stakeholders will gain from the system's improved reliability and quality. The Transport Administration takes care of the final FMEA to develop the maintenance routines of the turnout.

7.4 Case Study of the Effect of a Camera System

The data in this case study come from turnouts in the centre of Stockholm, on track section 401, and were gathered in 2011; see track layout in Figure 36. This is a strategically important and busy track section with a great deal of passenger traffic. Therefore, a small improvement in this section will provide large gains for local traffic (and global traffic as well) and enhance track capacity.

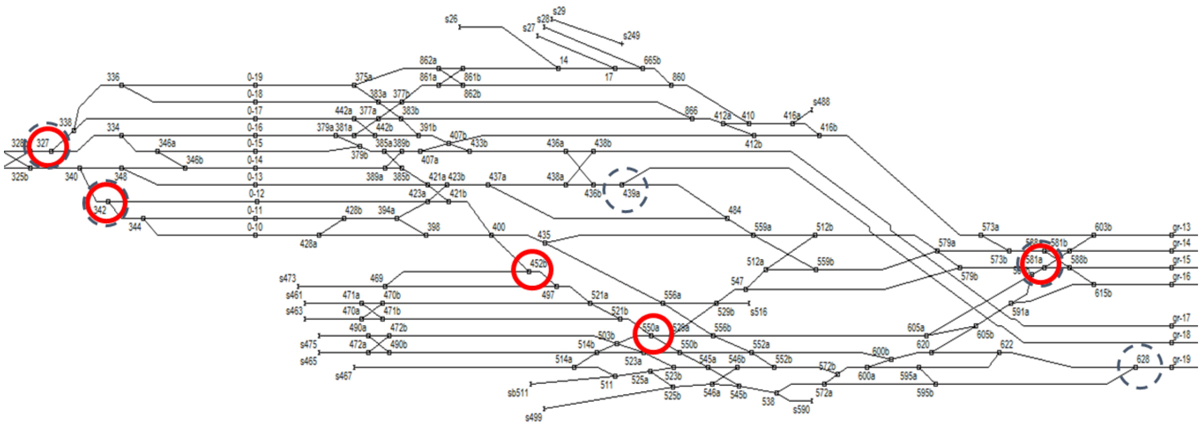
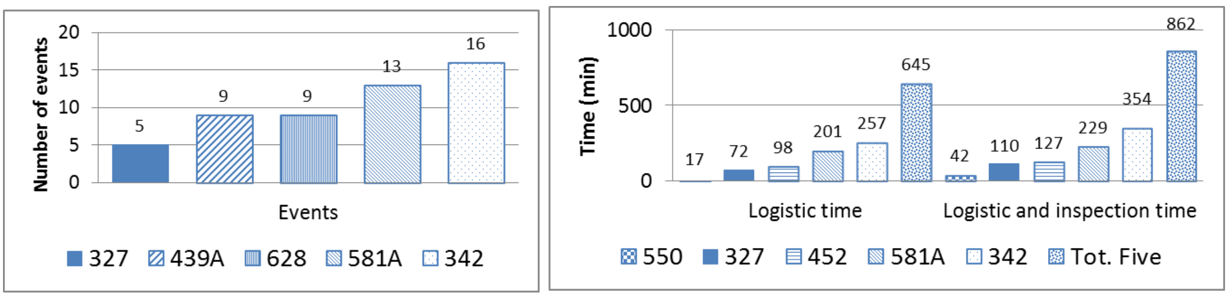


Figure 36 – Track layout from Stockholm city track section 401

In the above diagram, red circles are turnouts with the largest amount of downtime due to maintenance action “check”, and dashed circles are turnouts with the largest number of maintenance events during 2011.

The data show a total of 183 corrective maintenance actions; the five turnouts with the largest amount of corrective maintenance actions are shown in Figure 37a; turnout 342, followed by turnout 581A, shows the largest number of disruptions. When the maintenance action “check” is examined for five turnouts and the total downtime due to logistics and inspection times is added up, this gives 862 minutes, with a logistics time of 645 minutes; see graph Figure 37b. Turnout 342 leads in downtime, followed by turnout 581A.



a) **b)**

Figure 37 – a) Number of corrective maintenance actions for all turnouts in track section 401 for 2011 with all maintenance actions. b) The downtime of five turnouts on track section 401 for 2011 when maintenance action “check”

The total train delay for all events is 19 minutes. The downtime could be reduced if the "check" were done by camera inspection, thus enhancing the capacity of the line. Altogether, 21 of 327 turnouts performed the action "check" on this particular track section. Table 2 shows the information for the turnouts with the most downtime due to the maintenance action "check".

Table 2 – Turnouts with the largest amount of downtime due to maintenance action "check"

Turnout	Type	Instalations year	Inspection class	Max speed diverging track	Radius	Rail type
327	ST	2006	3	80	760	60
342	ST	2008	3	50	300	60
452b	ST	1985	2	40	190	50
550a	DT	1986	2	40	-	50
581a	DT	1985	3	40	-	50

7.5 Results and Discussion

Usually, no well-structured decisions support model is used for finding condition monitoring measures within the railway sector. Decision support model presents some advantages when implemented: finding critical parameters, high performance of condition monitoring, good control and documentation, obtain as high safety level as possible with the condition monitoring. This work has presented a useful model which can be adapted in specific cases in the railway sector. Furthermore this work shows that this model is practical since it has been demonstrated for the acquisition of the camera monitoring system for turnout. This can be adapted for defining condition monitoring for different items, parts, subsystems and systems.

The decision support model can be used to find and define measures for different items and systems. The analysis shows that FMEA plays an important role in defining the system, what can be inspected and potential gains resulting from the action. The case study suggests that many turnouts have a large number of events; maintenance "checks" are common and cause a great deal of downtime while they are being performed. In addition, some turnouts are simply "bad actors"; this needs more research.

Using camera inspections for turnouts could enhance the capacity on the track; for instance, if an object falls from a passing train and blocks the blade, there is no way to know this before trying to switch the turnout and then noticing that the blade will not go into position. With camera monitoring, this will be noticed before switching the blade, thus providing more reaction time. In other words, an advantage of camera inspection of a turnout is faster diagnostics and better knowledge of the failure before entering the site. This earlier and better knowledge can reduce the maintenance logistics time and save money (for both contractors and infrastructure managers) and enhance track capacity. Camera inspections should be used on the most critical turnouts, like those on busy lines or those placed far away, with poor maintainability capability. The ability to note trends and make predictions will also increase, improving maintenance planning and enhancing track capacity.

7.6 Conclusions

This process can be used to define condition monitoring measurements for all kinds of systems and items within these systems on a railway. It can also be used more widely to find appropriate condition monitoring parameters or measurements in other systems. FMEA plays an important role in finding weak spots and improving the performance of a system or item within the system. In this work, five turnouts are shown to gain from camera inspections using the prototype described above. In short, using camera inspections can enhance the capacity of track section 401.

7.7 References

[1] Nissen, A. 2009, Development of life cycle cost model and analyses for railway switches and crossings, Division of Operation and Maintenance Engineering, Luleå University of Technology.
[2] Granström, R. 2008, "A system and stakeholder approach for the identification of condition information: a case study for the Swedish railway", Proceedings of the Institution of Mechanical Engineers, vol. 222, no. F4, pp. 399-412.
[3] Zwanenburg, W.-. 2006, "Degradation Processes of Switches & Crossings", Railway Condition Monitoring, 2006. The Institution of Engineering and Technology International Conference on, pp. 115.
[4] Nissen, A. 2009, "Classification and cost analysis of switches and crossings for the Swedish railway: a case study", Journal of quality in maintenance engineering, vol. 15, no. 2, pp. 202.
[5] Trafikverket 2011, The Swedish Transport Administration - Annual Report 2011, Trafikverket.
[6] Marquez, F., Lewis, R.W., Tobias, A.M. & Roberts, C. 0811, "Life cycle costs for railway condition monitoring", TRANSPORTATION RESEARCH PART E-LOGISTICS AND TRANSPORTATION REVIEW, vol. 44, no. 6, pp. 1175-1187.
[7] Utne, I.B. 2012, "A structured approach to improved condition monitoring", Journal of Loss Prevention in the Process Industries, vol. 25, no. 3, pp. 478.
[8] Horner, R. M. W., El-Haram, M. A., & Munns, A. K. (1997). Building maintenance strategy: a new management approach. Journal of Quality in Maintenance Engineering, 3(4), 273-280.
[9] Kim, J., & Jeong, H. Y. (2013). Evaluation of the Adequacy of Maintenance Tasks Using the Failure Consequences of Railroad Vehicles. *Reliability Engineering & System Safety*.
[10] Trafikverket 2009, The Swedish Transport Administration - System Structure BVS811 (Banverkets Anläggningsstruktur), F 08-11909/OR30, Trafikverket.
[11] INNOTRACK 2008, D3.3.1 – List of key parameters for switch and crossing monitoring, INNOTRACK TIP5-CT-2006-031415.
[12] McDermott, R., Mikulak, R. & Beauregard, M. 1996, "The basics of FMEA, Productivity", Inc., Portland, OR.
[13] Stamatis, D.H. 2003, Failure mode effect analysis: FMEA from theory to execution, ASQ Quality Press.
[14] Duque, O., Zorita, A., García-Escudero, L. & Fernández, M. 2009, "Criticality determination based on failure records for decision-making in the overhead contact line system", Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, vol. 223, no. 5, pp. 485-494.
[15] Goodfellow, J. 2000, "Applying reliability centered maintenance (RCM) to overhead electric utility distribution systems", Power Engineering Society Summer Meeting, 2000. IEEE, pp. 566.
[16] MIL-STD-1629A 1980, Procedures for Performing a Failure Mode, Effects and Criticality Analysis", MIL-STD-1629A, November 24, Department of Defence Washington DC 20301.
[17] SAE J-1739 2001, Potential Failure Mode and Effects Analysis in Design (FMEA), Reference Manual, Ford Motor Company.

[18] SS-EN-60812 Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA), European Committee for standardization (CEN).

8.0 A Suggested System for Key S&C

Table 3 shown below summarises the main inspection requirements and the technologies that could be employed to replace manual inspections.

Table 3 – Summary of Self-inspection Technologies

Inspection Category	Components	Proposed Inspection Technology
Visual Condition	Rails Fastenings Ballast Vegetation	Remote inspection using video cameras mounted on measurement vehicles, in-service trains, at the trackside or between the running rails.
Rail Profile	Switch blade Stock rails Crossing Wing / check rails	Laser measurement from measurement vehicles, in-service trains or at trackside. Lasers on trains have higher accuracy as closer to the measurement point.
Track Geometry	Gauge Cant / cross level Twist	Inertial or displacement measurement combined with laser measurement.
Component Security	Stretcher bars Drive bars Fishplates	Locking mechanism to extend inspection intervals or intelligent washer technology to monitor tightness.
Rail Flaw / Crack Detection	Railhead	Ultrasonic / Eddy currents are of limited value over S&C - likely that no automated solution available in the next 10 years.

It can be seen that in order to replace current manual inspections, a range of technologies would be required, but that it ought to be possible to largely automate S&C inspection with the right combination.

8.1 Suggested Commercially Available Solution

The following combination of commercially available technology could be used to replace (or at least minimise) the common manual inspection tasks:

- SIM wagon to undertake Video Inspection, Rail Profiling and Track Geometry tasks
- locking nuts to greatly extend manual inspection intervals and satisfy the Component Security requirements
- point machines such as the Vossloh and Bombardier in-sleeper designs to extended inspection intervals similarly

The one aspect that requires considerable further investigation is crack and flaw detection. It is arguable that current video inspection technology would enable a similar level of inspection to be undertaken to current practice. However, there is a need to be able to assess surface cracks more thoroughly and to detect sub-surface cracks, with current techniques being very limited over S&C components.

8.2 Alternative Solutions

The SIM wagon is a great step forward for automatic inspection of S&C and offers an excellent solution where there is a high density of S&C. However, in terms of covering an entire network, train paths need to be carefully programmed in order to maximise coverage, particularly as the maximum measurement speed is limited to 40 kph.

For the inspection of a small number of golden assets, the laser inspection trolley described is likely to be a lower cost solution, combined with some form of CCTV inspection. For network wide coverage, the laser trolley technology has the potential to be installed on in-service or track maintenance vehicles running at line speed. The lasers would need to be combined with sufficient elements of in-service track recording to record cross level as a minimum, and a more compact form of video inspection would also be required.

8.3 Demonstration System

It is suggested that both the commercially available solution and alternative solution described above ideally need to be demonstrated as part of Work Package 6. If possible, this would ideally include a live trial of the SIM wagon, or at least a computer terminal showing actual data gathered by the system previously. In terms of the alternative system, the demonstration would ideally include:

- a live demonstration of the laser inspection trolley
- an infrastructure mounted camera system (CCTV or overhead), ideally demonstrating that S&C condition and measurements such as track gauge can be made reliably and accurately
- a computer terminal showing data previously gathered from in-service track geometry measurement across S&C

It is understood that a trial site has already been selected for this demonstration.

8.4 Remaining Challenges

There are a number of current inspection tasks associated with S&C which are not directly addressed by the solutions described above, as shown in Table 4.

Table 4 – Remaining Inspection Challenges

Inspection task	Comments
Check for cracks beneath switch rail fittings using a mirror	Inspection is normally done visually and neither a overhead line camera nor a vehicle mounted camera can necessarily inspect these features from an appropriate camera angle with sufficient resolution.
Check drainage system for vegetation, sand and dirt	
Check for voiding by observing passing trains	
Check for vegetation of approved walking routes	
Measurement of voiding through S&C	Different technological solutions may be appropriate: - Vossloh's vibration sensor - trackside sensors including geophones, lasers & cameras - vehicle based measurement (under investigation at UoB)
Inspection of insulated joints: measurement of joint width, vertical wear, lipping and resistance at 100 kHz	Some measurement may be achieved using digital cameras although the accuracy of the result may be hard to assure. Joint resistance may be measured remotely if consideration is given to the track circuits. More advanced signalling & control systems do not require insulated joints.
Inspection of fishplates for deformation, hoist and material migration	
Inspection of welds, lipping in particular	

But as indicated in Table 3, the key technologies for self-inspecting infrastructure are already available, with the notable exception of crack / flaw detection according to the definition of self-inspection in Section 2.4. The current solution depends heavily on the ability to operate the SIM wagon or similar inspection vehicle, which is expensive equipment that still needs to be programmed into special train paths. There is also significant work remaining to prove that manual inspections can be fully replaced. But at least with the technology on offer, manual inspection intervals could be greatly extended from weeks to months, or quite possibly to an annual inspection.

The ultimate aims should be to minimise the technology and make it cheap enough to install on in-service vehicles, rather than having a specialised wagon. Towards this end the work being done by UoB on the inspection trolley and the in-service track recording technologies being developed by DB and UoB are interesting and helpful.

There is also the need to bring all of the data together. The development of railML is helpful in this respect and the development system is going in the right direction, but further development work is required to generate a complete system. However, the greatest challenge for the future is crack and flaw detection, which can currently only be undertaken by trolleys or hand-held equipment.

9.0 Conclusions

This report describes a number of technologies that together can form the basis for self-inspecting infrastructure, particularly in relation to S&C.

9.1 Key Findings & Developments

The study of inspection requirements showed that these are broadly similar across the railway administrations who participated in this study. These requirements can be categorised into one of five categories as shown in Table 5. Existing inspection technologies have been investigated and evaluated in terms of their ability to support self-inspection and a summary of technologies and their Technology Readiness Levels is presented in Table 5.

Table 5 – Summary of Self-Inspection Technologies & TRLs

Inspection Category	Components	Proposed Inspection Technology	Technology Readiness
Visual Condition	Rails Fastenings Ballast Vegetation	Remote inspection using video cameras mounted on measurement vehicles, in-service trains, at the trackside or between the running rails.	**Good.** Technology proved by Strukton, and more camera angles and better resolution may improve the system further. Overhead line cameras currently under research. **TRL 9**
Rail Profile	Switch blade Stock rails Crossing Wing / check rails	Laser measurement from measurement vehicles, in-service trains or at trackside. Lasers on trains have higher accuracy as closer to the measurement point.	**Good.** Laser technology used in existing railway application for inspection & condition mon. SIM wagon proven to measure key S&C parameters, but grease remains an issue in UK. **TRL 8 / 9**
Track Geometry	Gauge Cant / cross level Twist	Inertial or displacement measurement combined with laser measurement.	**Medium / Good.** Belgium & Netherlands use data from geometry measurement cars, but more research needed to improve systems for S&C. SIM can measure key geometry. **TRL 7/9**
Component Security	Stretcher bars Drive bars Fishplates	Locking mechanism to extend inspection intervals or intelligent washer technology to monitor tightness.	**Good.** Tracksure and Hardlocks already in use. Smart washers are currently under development, but validation necessary. **TRL 8/9**
Rail Flaw / Crack Detection	Railhead	Ultrasonic / Eddy currents are of limited value over S&C - likely that no automated solution available in the next 10 years.	**Poor.** Current NDT techniques for S&C only available in manually operated equipment. Further development needed for reliable, automated solution. **TRL 3/4**

There exists a commercially available means of undertaking self-inspection which relies upon the use of a SIM wagon (or similar bespoke measurement vehicle). The SIM wagon offers the ability to perform comprehensive inspections at up to 40 kph. While this could be a significant limitation on higher speed lines, for many freight routes this would be sufficient with the measurement vehicle only slowing through S&C.

Ultimately, the functionality such vehicles offer will be replaced by in-service monitoring devices fitted a number of passenger vehicles, freight vehicles, locomotives or maintenance machines. It may also be possible to upgrade existing track recording cars such as the NMT to undertake such inspections.

However, while a SIM based solution is valuable for dense groupings of S&C or for key assets on mainlines, there is also scope for a smaller scale solution based on reducing the frequency of manual inspections and speeding up the inspection process. In this case, a combination of CCTV, an in-service version of the laser trolley, and in-service track geometry measurement would appear to be an attractive solution, although further development and validation work is required.

9.2 Implications for AUTOMAIN

The core aim of this element of the AUTOMAIN project was to avoid the need for staff to go on or near running lines in order to check whether S&C conforms to required standards. The investigation undertaken demonstrates that there are commercially available solutions to achieve this aim for all areas of inspection, with the notable exception of rail flaw / crack detection.

One of specific aims of Task 3.2 included the development of a low-cost inspection solution. It is arguable that, although the investment required to operate a SIM wagon is high, it can be used to inspect several hundred switches on a regular bases. Therefore the cost per switch becomes more reasonable, depending on the number of switches covered. An alternative low-cost solution has been developed (the trolley based profile measurement system), but the system is only at TRL level 4, with considerable further work required to turn it into an in-service based solution.

9.3 Recommendations

The trial of the SIM wagon on DB should continue to be followed closely, particularly to the point where the periodicity of manual inspections is extended, or when they done only on an as-needed basis to take a closer look at problems highlighted through self-inspection. This, along with the service experience gathered in the Netherlands, will provide a significant indication to other railway networks that manual inspection of S&C is either no longer required, or at least required far less frequently. It is suggested that this report be re-issued once the results of the trials on DB are available.

Support needs to continue for the development of a common standard for exchange of data (i.e. railML), and suppliers of infrastructure inspection equipment should continue to be encouraged to export data in the “automainML” schema. Work should continue to develop in-service equipment capable of replicating the SIM wagon’s functionality, and further assessment of the ability of in-service track geometry measurement to work over S&C is also required. It terms of other developments, railway administrations should be encouraged to install locking nuts, and point machines with long inspection intervals.

Appendix A – Requirements Investigation Spreadsheet

An Excel spreadsheet was constructed to record, compare and classify the different inspection tasks of participating railway administrations. This table is shown over the following pages.

Category		Country	Inspection task	Network Rail inspection standards	ProRail inspection standards	DB inspection standards	Current method of inspection	Typical inspection frequency	Inspection Type						Solution Gap
									Visual	Profile & Position	Track Geometry	Crack Detection	Cmponent Security	Point Machine	
Visual inspections	Switch rail inspections	UK, DE	**Switch Rails** - check for broken, cracked, defective, worn, sideworn, affected by lipping or sharp gauge switch rails (UK); loose, not tight, periodical indentation, single indentation, black/brown spots, broken, rupture, corrugation, head-checks, shelling, spalling, wheel burns, clay pumping (DE)	NR/L2/TRK/001/A01, Chapter 8.8 (d); NR/L2/TRK/001/E01, A.10 (6); NR/L2/TRK/0053, Chapter 13.4.3 (lipping)		RilF 821 - Oberbau inspizieren, page 124-126	1. Visual inspection by track patrol 2. Remote inspection behing a desk using video recording trains (VST-05 and SIM in Netherlands)	weekly to monthly	X						
		UK, NL	**Flangeways** - obstructions in switches and flangeways or evidence of wheels striking the back of the open switch rail (check for scar signs that prove flange back contact) (UK); obstructions between the two rails (NL)	NR/L2/TRK/001/A01, Chapter 8.8 (d); NR/L2/TRK/001/E01, A.10 (6); NR/L2/TRK/001/D01, Chapter 8.4.1	UIC Working Group Switches & Crossings, page 23				X						
	Stock rail inspections	UK, NL, DE	**Stock rail checks** - sideworn stock rail towards heel or at switch tips (UK); check for rolling contact fatigue condition (NL); rigidly fixed, broken, rupture, head-checks, corrugation, wheel burns, shelling, black or brown spots, indentations AND if closure rail, then also: defects in rail foot, short/long waves, baseplates pushed down into sleepers (DE)	NR/L2/TRK/001/E01, A.10 (6)	UIC Working Group Switches & Crossings, page 31	RilF 821 - Oberbau inspizieren, page 108, 114 and 118 for closure rail			X						
		UK	**False Flange Damage**	NR/L2/TRK/001/D01, Chapter 10					X						
		UK	**Stock rail lipping** - check for the presence of lipping on the stock rail throughout the movable part of the switch rail (UK)	NR/L2/TRK/0053, Chapter 13.4.3					X						
		NL	**Heel baseplates**		UIC Working Group Switches & Crossings, page 23				X						
	Crossing inspections	UK, NL, DE	**Crossing check** - for broken, cracked, defective or worn, especially nose battering or wheel strikes damage (UK); for flaws, cracks or sinking of it (NL); for exfoliation, head checks, wheel burns, periodical indent, single indent, shelling, spalling, black/brown spots and condition of frog holes (DE)	NR/L2/TRK/001/E01, A.10 (6)	UIC Working Group Switches & Crossings, page 27	RilF 821 - Oberbau inspizieren, page 112 and 113(frog holes)			X						
		UK	**False Flange Damage**	NR/L2/TRK/001/D01, Chapter 10					X						
		DE	**Frog bolting mechanism** - check for missing, broken or not tight			RilF 821 - Oberbau inspizieren, page 109			X						
		NL	**Swing nose obstruction** - check for obstructions between the wing rail and the swing nose		UIC Working Group Switches & Crossings, page 26				X						
		NL	**Swing nose crossings slide chairs/plates and movable point** - visual check		UIC Working Group Switches & Crossings, page 25				X						
		NL	**Swing nose heating** - check correct functionality of point heating for the swing nose (visual inspection)		UIC Working Group Switches & Crossings, page 26				X						
	Wing and check rails inspections	NL	**Check rail chairs** - visual inspection		UIC Working Group Switches & Crossings, page 25				X						
		DE	**Check rail** - loose, not tight			RilF 821 - Oberbau inspizieren, page 116			X						
		DE	**Wing rail** - loose, broken, torn, bent, squashed, black/brown spots			RilF 821 - Oberbau inspizieren, page 112			X						
	Switch rail fittings inspections	UK	**Stretcher bars, lock stretcher bars and its associated brackets** - cracked, broken, loose, missing (bolts), distorted stretcher bar/brackets or damaged	NR/L2/TRK/001/E01, A.10 (6); NR/L2/TRK/001/D01, Chapter 9					X						X
		UK, DE	**Slide chairs and baseplates** - check for cleanliness and lubrication (UK); check for broken, bent or squashed (DE)	NR/L2/TRK/001/D01, Chapter 11		RilF 821 - Oberbau inspizieren, page 109			X						
		UK, NL, DE	**Rolling area of switch blade** - check for adequate lubrication; lubricate if necessary (UK); roller systems / lubrication, free slideplate (NL); check for missing, broken, loose or dirty (DE)	NR/L2/TRK/0053, Chapter 15	UIC Working Group Switches & Crossings, page 22	RilF 821 - Oberbau inspizieren, page 110			X						
	Track fittings inspections	UK	**Soleplate** - damaged, cracked or broken soleplate gauge stock block weld	NR/L2/TRK/001/E01, A.10 (6); NR/L2/TRK/001/D01, Chapter 9					X						
		UK, NL, DE	**Bolts** - for loose, broken or missing (UK); loose or missing (NL); broken, missing, worn, force fit and if the foot is grooved (DE)	NR/L2/TRK/001/E01, A.10 (6)	UIC Working Group Switches & Crossings, pages 22, 25, 28	RilF 821 - Oberbau inspizieren, page 110			X						
		DE	**Rail clips** - missing or broken			RilF 821 - Oberbau inspizieren, page 110			X						
		UK, NL	**Blocks** - missing, cracked or broken blocks (UK); distance blocks (NL)	NR/L2/TRK/001/E01, A.10 (6)	UIC Working Group Switches & Crossings, page 22				X						
		NL	**Baseplates** - visual check		UIC Working Group Switches & Crossings, page 28				X						
		NL, DE	**Anti-creep device** - for missing or loose (DE)		UIC Working Group Switches & Crossings, page 22	RilF 821 - Oberbau inspizieren, page 110			X						
	Other inspections	NL	**Switch point heating**		UIC Working Group Switches & Crossings, page 23				X						
		NL	**All fasteners (in switch, crossing, closure panel and transition zones)**		UIC Working Group Switches & Crossings, pages 24, 27, 29				X						
		NL	**Voiding** - vibration at the driving by passing train (visual check of vertical movement)		UIC Working Group Switches & Crossings, page 24										X
		NL, DE	**Welds** - visual deformation of welds (NL); exfoliation, loose, broken, rupture, longitudinal cracks, lateral cracks (DE)		UIC Working Group Switches & Crossings, page 30	RilF 821 - Oberbau inspizieren, page 119			X						
		DE	**Rail joint** - check for broken, loose, black/brown spots			RilF 821 - Oberbau inspizieren, page 122, 123			X						
		DE	**Fishplate of rail joints** - check for loose or broken fishplate, missing or not tight bolts						X				X		
		NL	**Cables** - check for cables to be fastened		UIC Working Group Switches & Crossings, page 31				X						
		NL, DE	**Ballast, gravel** - check the condition and the profile of the ballast (at least 55cm outside sleeper) (NL); check to see if it is too much or too less (DE)		UIC Working Group Switches & Crossings, page 31	RilF 821 - Oberbau inspizieren, page 111			X						
		DE	**Sleepers** - various visual checks			RilF 821 - Oberbau inspizieren, page 120			X						
		NL, DE	**Drainage** - check for good functioning of drainage (NL); check for vegetation, sand and dirt (DE)		UIC Working Group Switches & Crossings, page 31	RilF 821 - Oberbau inspizieren, page 111									X
		DE	**Walking path** - check for vegetation or if too small												X

Category		Country	Inspection task	Network Rail inspection standards	ProRail inspection standards	DB inspection standards	Current method of inspection	Typical inspection frequency	Inspection Type						
									Visual	Profile & Position	Track Geometry	Crack Detection	Cmponent Security	Point Machine	Solution Gap
Measured inspections	Gauge and geometry measurements	UK, DE, NL	**Track gauge** at various points throughout the switch and crossing	NR/L2/TRK/001/D01, Chapter 8.1, 8.3 and 8.4.2	UIC Working Group Switches & Crossings, page 33-34	RilF 821 - Oberbau inspizieren, page 101	1. Manual measurements using gauges 2. Digital trolley (ProRail) 3. Track recording car from VolkerRail (ProRail)			X	X				
		NL, DE	**Gauge, cant, twist, levelling, alignment** - together with free wheel passage and checkrail distange (NL)		UIC Working Group Switches & Crossings, page 33	RilF 821 - Oberbau inspizieren, page 124		every 2 months to every 6 months			X				
	Switch rail inspections	NL	**Free wheel passage** - measurement of free wheel passage at the switch rails		UIC Working Group Switches & Crossings, page 23, 35		manual measurement with gauge	monthly to every 6 months		X					
		UK	**Toe openings** in switches	NR/L2/TRK/001/D01, Chapter 6						X					
		UK	**Flangeway gap** measurement through the moving parts of switches	NR/L2/TRK/001/D01, Chapter 8.4.1						X					
		UK, NL, DE	**Switch toes position** - measurement of the position of switch toes (UK, NL); longitudinal height error (DE)	NR/L2/TRK/001/D01, Chapter 7	UIC Working Group Switches & Crossings, page 23	RilF 821 - Oberbau inspizieren, page 124				X					
		UK, NL	**Rail profile** - check to see if the profile of switch rail tip with gauge (UK); horizontal and side wear measurement with gauge (NL)	NR/L2/TRK/0053, Chapter 8.5, Chapter 13.5.2	UIC Working Group Switches & Crossings, page 22					X					
		DE	**Top and side wear** - top and side wear of the switch blade			RilF 821 - Oberbau inspizieren, page 126				X					
		DE	**Lipping** - measured in mm							X					X
		UK, NL	**Rail damage** - check to determine whether or not any damage or chipping of the running surface to the switch rail is safe or otherwise (UK); inspection of the nicks in the tongue blades (NL)	NR/L2/TRK/0053, Chapter 8.3	UIC Working Group Switches & Crossings, page 22				X	X					
		NL, UK	**Cracks** - check for cracks in the switch rail	NR/L2/TRK/001/B01, Chapter 4.2	UIC Working Group Switches & Crossings, page 20		ultrasonic manually	every 2 to 12 months				X			
	Stock rail inspections	UK, NL, DE	**Side wear** - measurement of plain rail side wear using NR4 gauge (NR); only in closure panel and transition zones (NL); measured in mm (DE)	NR/L2/TRK/0053, Chapter 8.4, Chapter 13.1	UIC Working Group Switches & Crossings, page 28	RilF 821 - Oberbau inspizieren, page 108	manual measurement with gauge	monthly to every 6 months		X					
		NL, DE	**Top wear** - measurement of plain line top wear in closure panel and transition zones (NL); measured in mm (DE)							X					
		DE	**Lipping** - measured in mm							X					X
		NL, UK	**Cracks** - check for cracks in the stock rail	NR/L2/TRK/001/B01, Chapter 4.2	UIC Working Group Switches & Crossings, page 20		ultrasonic manually	every 2 to 12 months				X			
	Both switch and stock rail inspections	UK	**Profile** - check for wheel flange contact below 60º within the first 4000 mm of the switch rail using a P8 wheel profile	NR/L2/TRK/0053, Chapter 8.2			manual measurement with gauge	monthly to every 6 months		X					
		UK, DE	**Rail heights** - check to determine whether or not the tip of the switch rail is at least 15 mm below the top surface of the stock rail.* (UK); relative height between stock rail and switch rail (DE)	NR/L2/TRK/0053, Chapter 8.3, Chapter 13.3.2		RilF 821 - Oberbau inspizieren, page 124				X					
		UK, NL	**Residual switch opening**	NR/L2/TRK/001/D01, Chapter 8.4.2	UIC Working Group Switches & Crossings, page 22					X					
		UK	**Stock rail side worn** - check if the tip of the switch rail projects above the bottom of the stock rail side wear.	NR/L2/TRK/0053, Chapter 13.1						X					
	Standard crossing inspections (inspections that apply for all crossings)	UK, NL, DE	**Side wear and top wear** - assesment of crossing profile using a straight edge (NR); side and top wear of the crossing (NL); is measured in mm (DE)	NR/L2/TRK/054	UIC Working Group Switches & Crossings, page 25	RilF 821 - Oberbau inspizieren, page 112 and 113	manual measurement with gauge	monthly to every 6 months		X					
		DE	**Flangeway gap in frog** - measured in mm							X					
		DE	**Lipping** - measured in mm							X					X
		UK	**AMS cracks** - Check for cracks in Austenitic Manganese Steel crossings	NR/L2/TRK/054			manually (dye penetrant)	every 3 to 12 months				X			
		UK, NL	**Bainitic steel cracks** - Check for cracks in bainitic steel crossings	NR/L2/TRK/054	UIC Working Group Switches & Crossings, page 20		manually (ultrasonic)					X			
	Swing nose specific inspections	NL	**Actuation, locking and detection** - check correct functionality of actuation, locking and detection mechanisms		UIC Working Group Switches & Crossings, page 26		manually; involves trowing the switch and placing a gauge between rails	every 3 to 12 months						X	
	Wing and check rails inspections	UK, NL	**Flangeway Gap** - measurement at the check rail and wing rail in crossings (UK); check rail flangeway gap only (NL)	NR/L2/TRK/001/D01, Chapter 8.1, Chapter 8.5.3;	UIC Working Group Switches & Crossings, page 25, 34		manual measurement with gauge	monthly to every 6 months		X					
		UK, NL	**Check gauge** measurement at crossings fitted with a check rail (measurements done against the check rail) (UK); measurement is taken at both the entry of the check rail	NR/L2/TRK/001/D01, Chapter 8.1, Chapter 8.5.2	UIC Working Group Switches & Crossings, page 33-34					X					
		DE, NL	**Check rail** - horizontal wear of the check rail		UIC Working Group Switches & Crossings, page 25	RilF 821 - Oberbau inspizieren, page 116				X					
		DE	**Wing rail** - horizontal wear, vertical wear and lipping; all in mm			RilF 821 - Oberbau inspizieren, page 112				X					X
	Switch rail fittings inspections	UK	**Bolts and fastenings within S&C assemblies** - check for correct torque, integrity and any signs of weakening	NR/L2/TRK/001/D01, Chapter 12			manual with torque wrench	monthly to every 6 months					X		
	Other inspections	UK	**Voiding** - void measurements	NR/L2/TRK/001/D01, Chapter 12			manually using a voidmeter	on demand							X
		NL	**Insulation joints (glued)** - Measurement of the joint width, vertical wear, lipping and resistance at 100Khz		UIC Working Group Switches & Crossings, page 30		manually			X					X
		DE	**Rail joint** - lipping, material migration and hoist; all measured in mm			RilF 821 - Oberbau inspizieren, page 122 and 123	manual measurement with gauge			X					
		DE	**Fishplate of rail joints** - measured in mm: bent, deformed, hoist and material migration							X					
		DE	**Welds** - lipping measured in mm			RilF 821 - Oberbau inspizieren, page 119				X					
		DE	**Insulation bracket** - wear measured in mm							X					
		DE	**Tightness of nuts** - various nuts and bolts must be checked for adequate tightness			RilF 821 - Oberbau inspizieren, page 109, 110, 116, 117 and 123	manual check						X		

	Category	Country	Inspection task	Network Rail inspection standards	ProRail inspection standards	DB inspection standards	Current method of inspection	Typical inspection frequency	Inspection Type						
									Visual	Profile & Position	Track Geometry	Crack Detection	Cmponent Security	Point Machine	Solution Gap
Point inspections	Generic point inspection	UK	**Visual checks**: obstructions, correct fitting of the switch rail against the stock rail, stretcher bar and brackets distortion and functionality of the point heating equipment	NR/SMS/PA11			visual inspection	weekly to monthly	X						
	Point machine inspections	UK, NL	**Regular tests** - Facing point lock test, fluid level and RKB 222 padlock; lock doesn't engage for a 3.5mm gauge and it engages for a 1.5mm gauge (UK); actuation, locking and detection equipment is checked (NL)	NR/SMS/PC05, NR/SMS/PB11	UIC Working Group Switches & Crossings, page 23		manually using 3.5 mm and 5 mm gauge	twice a month to monthly						X	
		UK	**Service A** - a detailed inspection that is specific to the type of point machine	NR/SMS/PC05, NR/SMS/PB11			various inspections including visual and with gauges	every three months						X	
		UK	**Service B** - a detailed inspection that is specific to the type of point machine	NR/SMS/PC05, NR/SMS/PB11			various inspections including visual and with gauges	every year						X	
	Point fittings inspections	UK	Various inspections are carried out to ensure that **insulations, nuts, bolts, lock nuts, brackets, bars, bracket fasteners, bolt holes, drilled holes, lock stretcher bars, adjustable stretcher bars, welds and brushes** are, if applicable, **in place, securely fitted, tight, properly adjusted, doesn't have signs of cracking or surface deterioration, not bent and have adequate clearances**.	NR/SMS/PF01			various inspections including visual and with gauges	every three months	X				X		
		UK	**Tightness of nuts** - nuts and lock nuts must be checked for correct torque using a calibrated torque wrench	NR/SMS/PF01			manual with torque wrench	every three months					X		
	Mechanical supplementary drive inspections	UK	Various inspections are carried out to ensure that **crank bases, cranks, sleeve on cranks, cotter pins, rodding, roller assemblies, drive pin and lock nuts** are, if applicable, **in place, securely fitted, tight, and they are not worn, seized, loose, bent or broken**.	NR/SMS/PF02			various inspections including visual and with gauges	every three months					X		
		UK	**Functional test** to see correct movement of the switch rails.	NR/SMS/PF02			check operation of the switch		X						
	Switch rollers inspections	UK	Inspections to ensure that all the parts are secure and don't have signs of damage. Other visual checks are carried out to ensure that the switch rails are moving properly over the switch rollers.	NR/SMS/PF03			visual inspection	every three months	X						