

# 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

### **Demonstration of modular, self-inspecting switch technology**

Deliverable Reference No: D 6.2

Due Date of Deliverable: 31/01/2014

Actual Submission Date: 31/01/2014

| Dissemination Level |                                                                                       |   |
|---------------------|---------------------------------------------------------------------------------------|---|
| PU                  | Public                                                                                | X |
| PP                  | Restricted to other programme participants (including the Commission Services)        |   |
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## Document Summary Sheet

This document demonstrates the research and test trials carried out for the development of a “Modular, self inspecting switch” as part of WP3, Task 3.2. After a brief introduction in Chapter I, Chapter II presents the objectives of the work and Chapter III the approach taken to achieve this. Chapter IV describes the tests and results of the innovations. Chapter V provides information regarding the cost of using these innovations while Chapter VI describes the estimated reduction in inspection time as well as the technology readiness level of the innovations. Finally Chapter VII provides a few conclusions.

| <b>Additional information</b>    |                                               |
|----------------------------------|-----------------------------------------------|
| <b>Subproject / workpackage:</b> | <b>WP6</b>                                    |
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| <b>Document date:</b>            | <b>27/01/2014</b>                             |
| <b>Status:</b>                   | <b>Final, Approved by consortium</b>          |

| <b>History</b> |                   |                               |                                                                                          |
|----------------|-------------------|-------------------------------|------------------------------------------------------------------------------------------|
| <b>V0.1</b>    | <b>31/01/2014</b> | <b>1<sup>st</sup> version</b> | <b>In Power Point format</b>                                                             |
| <b>V0.2</b>    | <b>14/04/2014</b> |                               | <b>Revision after feedback from Project Officer.<br/>Standard document format added.</b> |

## Table of Contents

|       |                                                                   |    |
|-------|-------------------------------------------------------------------|----|
| I.    | Introduction .....                                                | 1  |
| II.   | Objectives.....                                                   | 1  |
| III.  | Approach.....                                                     | 1  |
|       | Identification of inspection requirements .....                   | 2  |
|       | Identification of existing solutions for inspection .....         | 2  |
|       | Solution development to cover S&C inspection gaps.....            | 2  |
| IV.   | Results .....                                                     | 3  |
|       | a) Test results .....                                             | 3  |
|       | b) Encountered issues .....                                       | 11 |
|       | c) Exploitable results, conformity with the Grant Agreement ..... | 11 |
| V.    | Costs.....                                                        | 11 |
| VI.   | Potential exploitation .....                                      | 11 |
| VII.  | Conclusions .....                                                 | 12 |
| VIII. | Appendix A.....                                                   | 13 |

## **Executive Summary**

This document demonstrates the research and test trials carried out for the development of a “Modular, self inspecting switch” as part of WP3, Task 3.2. As initially agreed, different parts of the solution have been demonstrated in different countries under laboratory and/or test track conditions. The objective is to reduce the inspection time of S&C as much as possible by moving towards condition based inspection and remote / automatic inspection. In order to do this a three step approach is followed: (1) identification of inspection requirements, (2) identification of existing solutions for inspection and (3) development and testing of S&C inspection solutions. Initial research identified five key inspection categories which have been addressed. Chapter IV provides details of the innovations and test trials which have been demonstrated. The final three chapters provide other information addressing issues surrounding the test trials, including the possibility of exploiting the research findings and details of the cost of the innovations.

## I. Introduction

The aim of WP6.2, and hence Demonstrator Scenario 2, was to build on previous switch and crossing inspection demonstrator work within Innotrack and other EU and national projects. The primary objective was, therefore, to identify the current gaps in switch inspection technology, and develop and demonstrate solutions to address these gaps.

It was initially agreed, as it could be difficult to demonstrate some technological innovations on the same specific switch, a 'modular' approach to switch inspection would be conducted. This has meant that different parts of the solution have been demonstrated in different countries; some on live railways, and some under laboratory and/or test track conditions.

## II. Objectives

The main objective is to analyze the inspection requirements of S&C, explore current gaps in switch inspection technology and develop, explore and test solutions that have the potential to improve the maintenance of S&C by reducing possession time and improving inspection reliability. This can be achieved through the use of maintenance techniques such as on-condition based maintenance and remote/automatic inspection.

## III. Approach

As switches and crossings are safety-critical assets (i.e. the safe running of trains depends on the condition of S&C) it is important to distinguish between condition monitoring and inspection. Table 1 below provides a brief comparison between the two terms.

**Table 1 - Differences between inspection and monitoring**

| Condition monitoring                                                                                                                                                                                                                                                                                                                                                                           | Inspection                                                                                                                                                                                                                                                                                                                                                     |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>A system which is directed at the fault:</p> <ul style="list-style-type: none"> <li>▪ <u>fault detection</u>: the system is able to detect a fault which is happening</li> <li>▪ <u>fault diagnosis</u>: the system is able to diagnose the fault</li> <li>▪ <u>fault prediction</u>: the system is able to predict a fault a certain amount of time before it will <u>occur</u></li> </ul> | <p>A system designed for safety:</p> <ul style="list-style-type: none"> <li>▪ identify the assets which do not meet safety standards</li> <li>▪ carry out inspections as specified in inspection standards</li> <li>▪ carry out inspections in a way which satisfies inspection requirements (e.g. precision of measurement, reliability assurance)</li> </ul> |

In conclusion, condition monitoring techniques generally offer a way of identifying potential faults in the infrastructure. However, the accuracy of the information provided by condition monitoring systems is often limited, which can lead to safety assurance being compromised (this generally applies where accurate measurements are necessary in order to assure safety).

The work followed a three step process to identify S&C inspection gaps and develop appropriate solutions.

1. Identification of inspection requirements

- Understanding inspection standards
  - Understanding inspection specifics (e.g. resolution)
2. Identification of existing solutions for inspection
    - Identify products that may be able to meet inspection tasks
    - Develop tests to confirm capabilities
    - Identify gaps for technology development
  3. Development and testing of S&C inspection solutions to cover the gaps (either where technology does not exist, is not cost effective or does not meet the requirements)

### Identification of inspection requirements

The S&C inspection standards of three countries were analysed: United Kingdom, Netherlands and Germany. These have been collated into an excel spreadsheet to allow for easy understanding and categorization as well as comparison between different countries.

| Part of S&C            | Countries  | Inspection task                                                                                                                            | UK inspection standard that defines it    | NL inspection standard that defines it          | DE inspection standard that defines it  | Average frequency of inspection | Current method used to carry out the inspection |
|------------------------|------------|--------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|-------------------------------------------------|-----------------------------------------|---------------------------------|-------------------------------------------------|
| 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 | RiF 821 - Oberbau inspizieren, page 108 | once a month to once a year     | manually with a gauge                           |
|                        | NL, DE     | Top wear - measurement of plain line top wear in closure panel and transition zones (NL); measured in mm (DE)                              |                                           | UIC Working Group Switches & Crossings, page 29 | RiF 821 - Oberbau inspizieren, page 109 | once a month to once a year     | manually with a gauge                           |

Figure 1 - A sample of current S&C inspection tasks mapped against S&C inspection solutions

### Identification of existing solutions for inspection

It has been found that most S&C inspection requirements fall under one or several of the following five key S&C inspection categories:

1. Switch rail fittings
2. Point machine inspection
3. Cracks in rails and crossings
4. Visual inspection
5. Shape, size, gauge

The above classification is based on the type of technology that is likely to cover the inspection requirements. Figure 2 below shows the association between the inspection categories and the most relevant inspection technology.

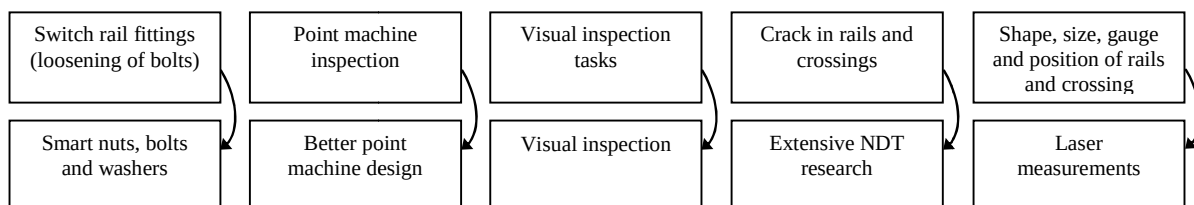


Figure 2 - Inspection categories and potential solutions

### Solution development to cover S&C inspection gaps

The following is a summary of the research solutions for each of the five inspection categories.

1. Switch rail fittings

- development of smart washers and nuts to ensure safety-critical components are secure and in place (in collaboration with NR and Huddersfield University)
- 2. Point machine inspection
  - develop and use point machine designs which require infrequent inspection regimes due to their improved reliability (e.g. the Bombardier point machine used by Strukton, ProRail require a yearly inspection)
- 3. Cracks in rails and crossings
  - demonstration of a novel NDT system (University of Birmingham)
- 4. Visual inspection
  - overhead camera and Switch Inspection and Measurement wagon (SIM) (developed by Strukton, Damill AB, Lulea, TV)
- 5. Shape, size, gauge
  - demonstration of laser inspection (developed by Strukton – train-borne, and University of Birmingham with NR – handheld)

## IV. Results

### *a) Test results*

#### **1. Overhead camera inspection**

A prototype camera was mounted to the OHL above a S&C for remote inspection. The main benefits are: extremely good eagle eye perspective of S&C, dimension measurement from images, basic resolution: 1600x1200 pixels, features lateral tilt, possibility of adding optical zoom.



Figure 3 - Overhead camera



Figure 4 - Sample image



Figure 5 - Test site operator

## 2. Train-borne switch inspection

Strukton's Switch Inspection and Measurement (SIM) system was trialed in Germany. Further analysis of the results was carried out using DB developed software. RFID technology was used for switch identification.

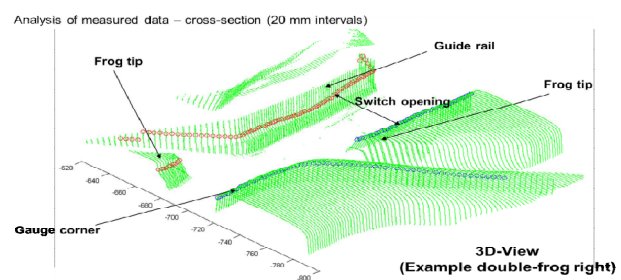


Figure 6 - SIM (left side) and crossing inspection results (right side)

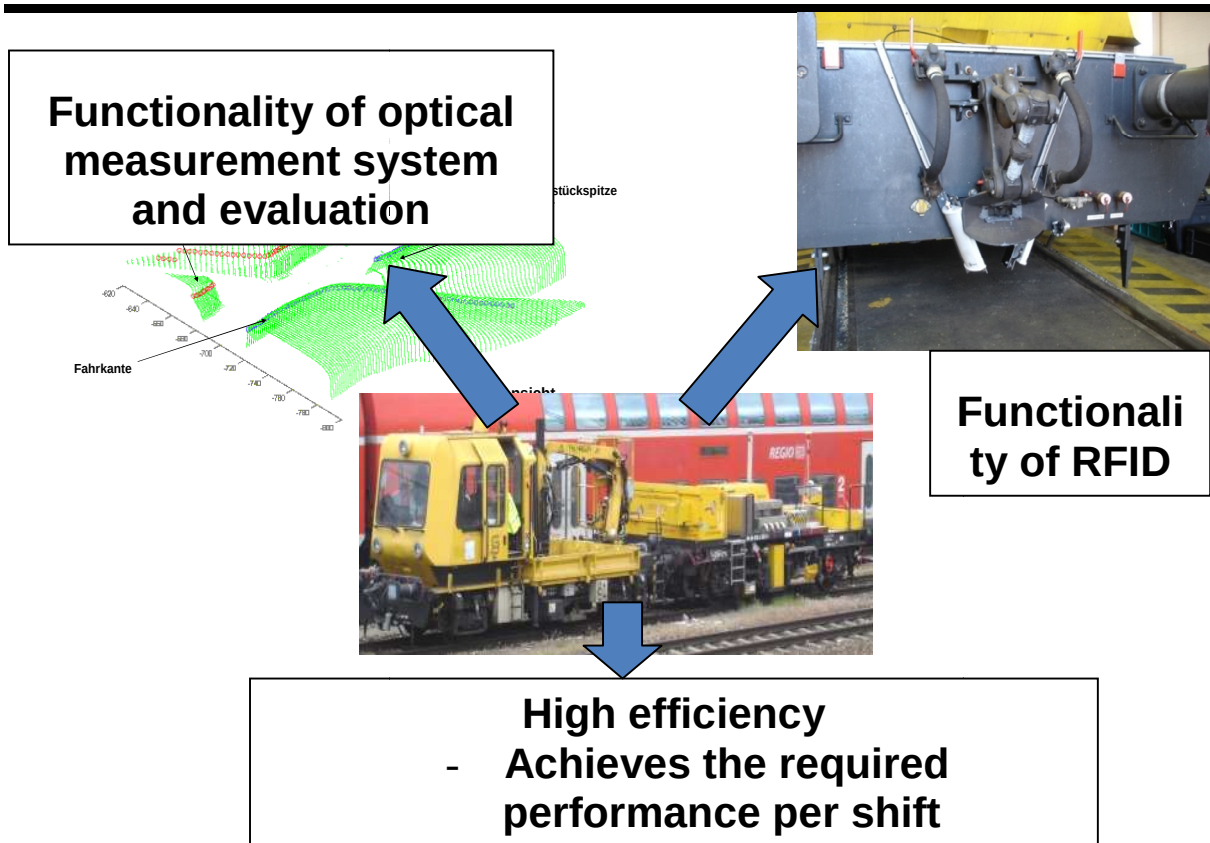


Figure 7 - SIM trial

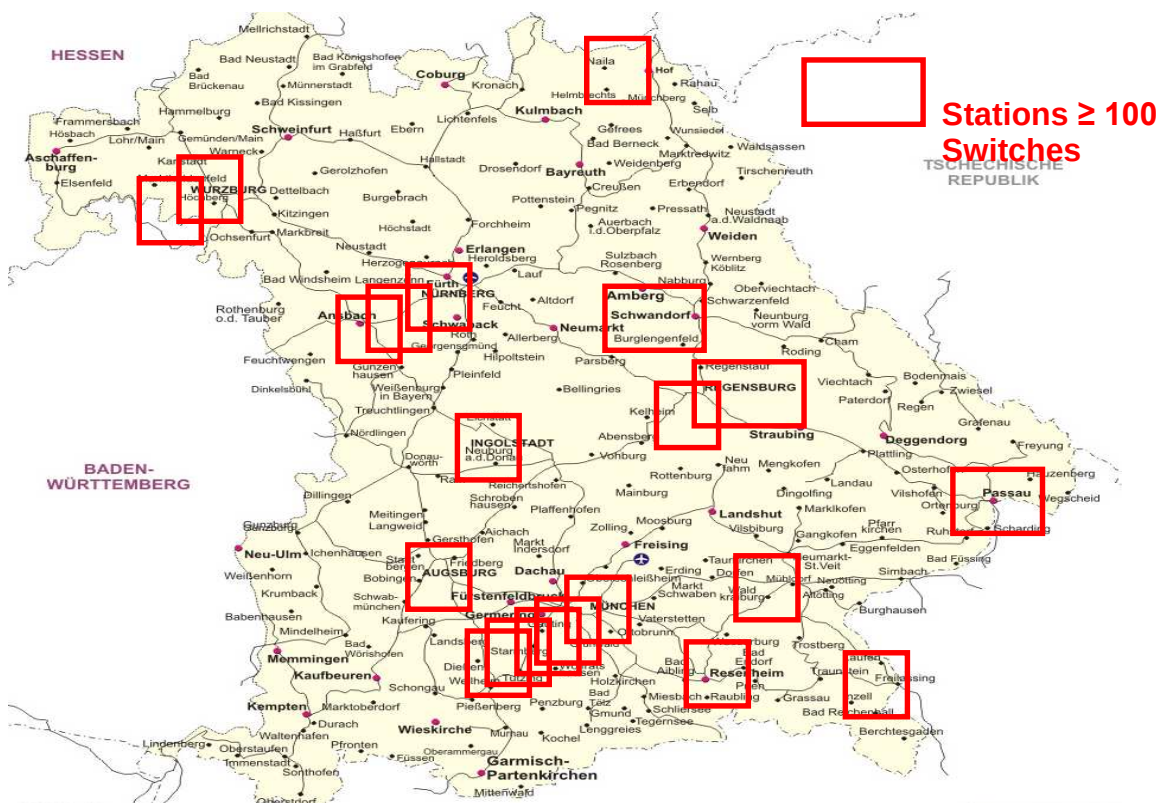


Figure 8 - Stations with over 100 switches in Germany

**Table 2 - Stations with over 100 switches in Germany**

| <b>Bahnhöfe <math>\geq</math> 100 Weichen</b> | <b>Anzahl</b> |
|-----------------------------------------------|---------------|
| Nürnberg Rbf                                  | 101           |
| Nürnberg Hbf                                  | 267           |
| Nürnberg-Hgbf                                 | 101           |
| München Hbf                                   | 393           |
| München Nord Rbf                              | 326           |
| München Ost                                   | 155           |
| München Pasing Bbf                            | 101           |
| München Pasing Pbf                            | 104           |
| Augsburg Hbf                                  | 327           |
| Regensburg Hbf                                | 197           |
| Regensburg Ost                                | 124           |
| Würzburg Hbf                                  | 195           |
| Würzburg Rbf                                  | 131           |
| Ingolstadt Hbf                                | 189           |
| Mühlhof                                       | 137           |
| Passau                                        | 135           |
| Bamberg                                       | 133           |
| Hof Hbf                                       | 121           |
| Freilassing                                   | 105           |
| Schwandorf                                    | 103           |
| Rosenheim                                     | 99            |
|                                               |               |
| Gesamt                                        | 3544          |
| <b>pro Bahnhof durchschnittlich</b>           | <b>169</b>    |

**Table 3 - Test results of some of the SIM trials in Germany**

| <b>Station</b> | <b>Switches</b> | <b>Time</b> | <b>Number</b> | <b>Night / Day</b> |
|----------------|-----------------|-------------|---------------|--------------------|
| Nürnberg       | 266             | 14:59       | 239 Sw        | N+D                |
| Ingolstadt     | 210             | 14:38       | 174 Sw        | N+D                |
| München        | 392             | 06:56       | 170 Sw        | N+N                |
| Rosenheim      | 95              | 09:48       | 2x85 Sw       | N+D                |

Overall Performance: 963 Switches in 46:21 h (with no possessions)

### 3. Hand held switch inspection

The hand held S&C inspection system developed by the University of Birmingham allows maintenance teams to rapidly assess the true condition of the shape of S&C rails. Several derailments have occurred in the UK because of the poor shape of S&C rails. The Railway Accident Investigation Branch supports the rewriting of the standards and introduction of new inspection technologies (e.g. laser) that can eliminate human errors.

The system can also assist the repair team to accurately repair the profile of the S&C to the correct shape. This increases the quality of the repair and decreases the life cycle cost of the S&C.

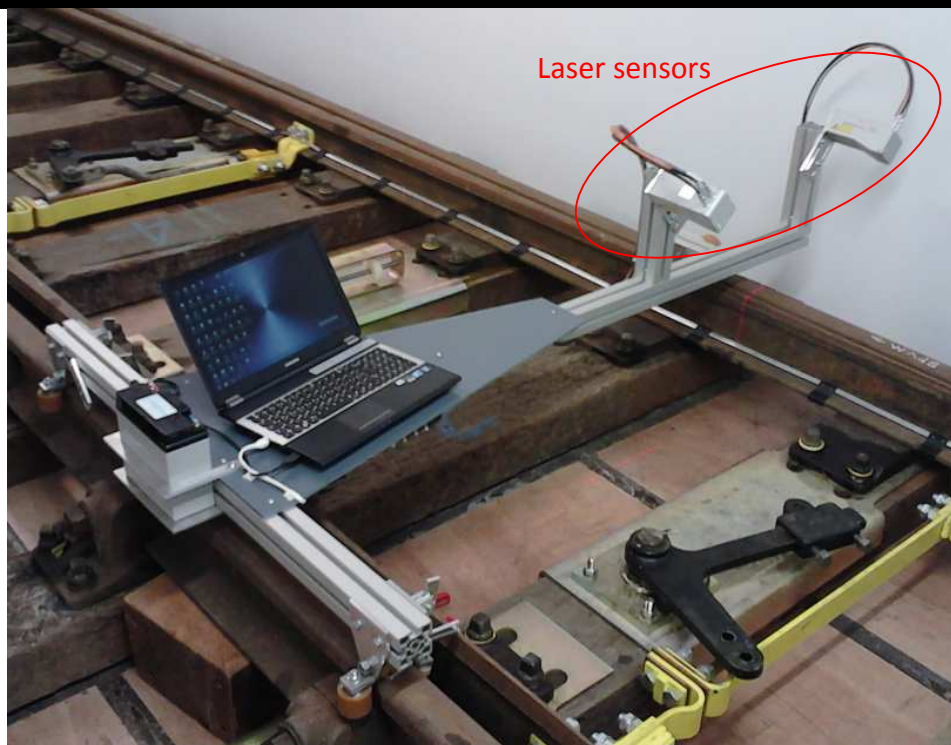


**Figure 9 - Hand held S&C inspection at University of Birmingham**



**Figure 10 - Hand held S&C inspection trial at Long Marston Test Track, UK**

Several switches were measured at the Long Marston Test Track in the UK. The system is able to assess the shape of S&C according to Network Rail S&C inspection standards. The images below provide sample pictures of the inspection results.

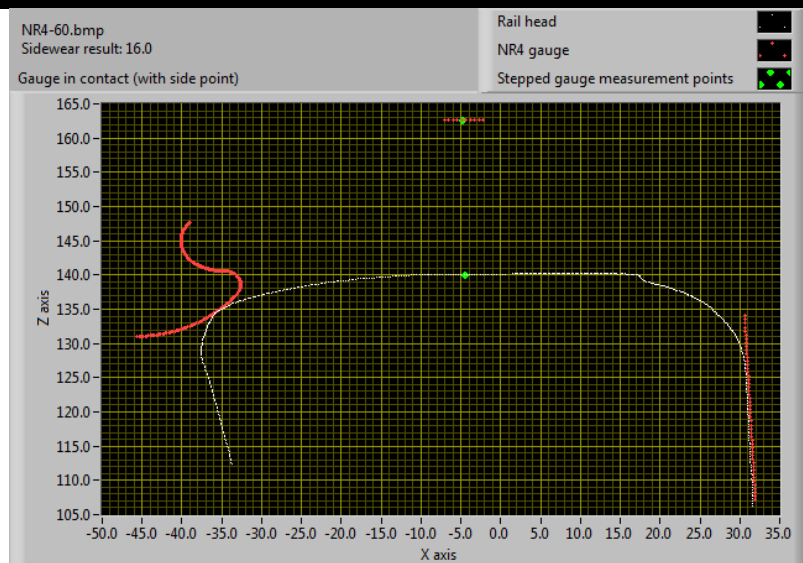


Figure 11 - NR4 side wear measurement

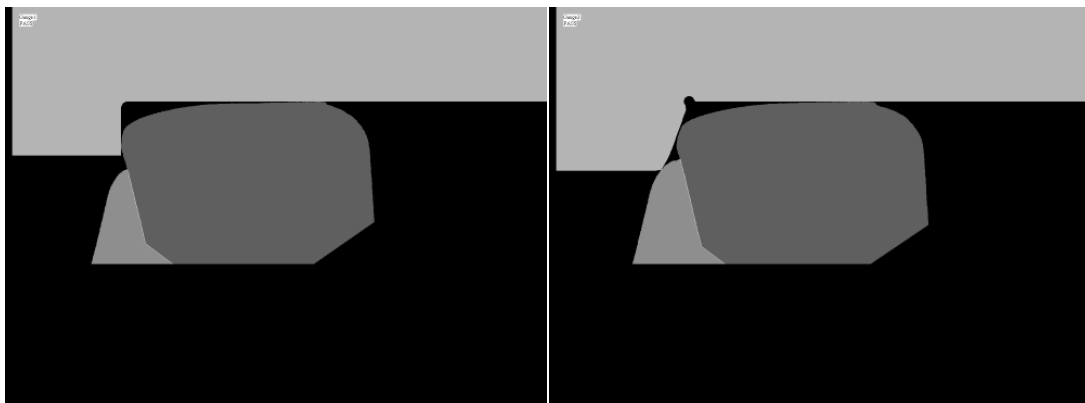


Figure 12 - Gauge 1 test (left) and Gauge 2 test (right)

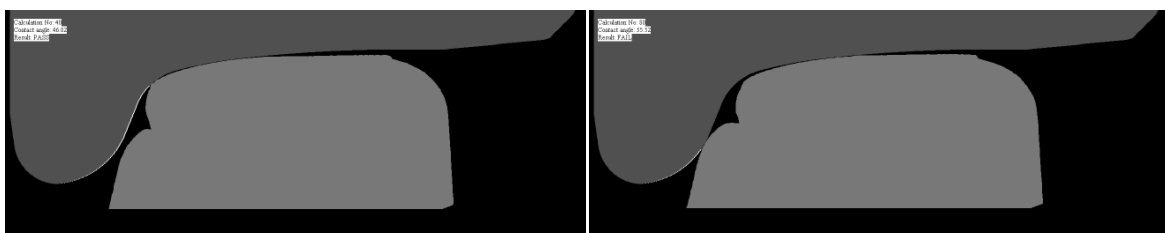


Figure 13 - P8 contact angle test; PASS example (left), FAIL example (right)

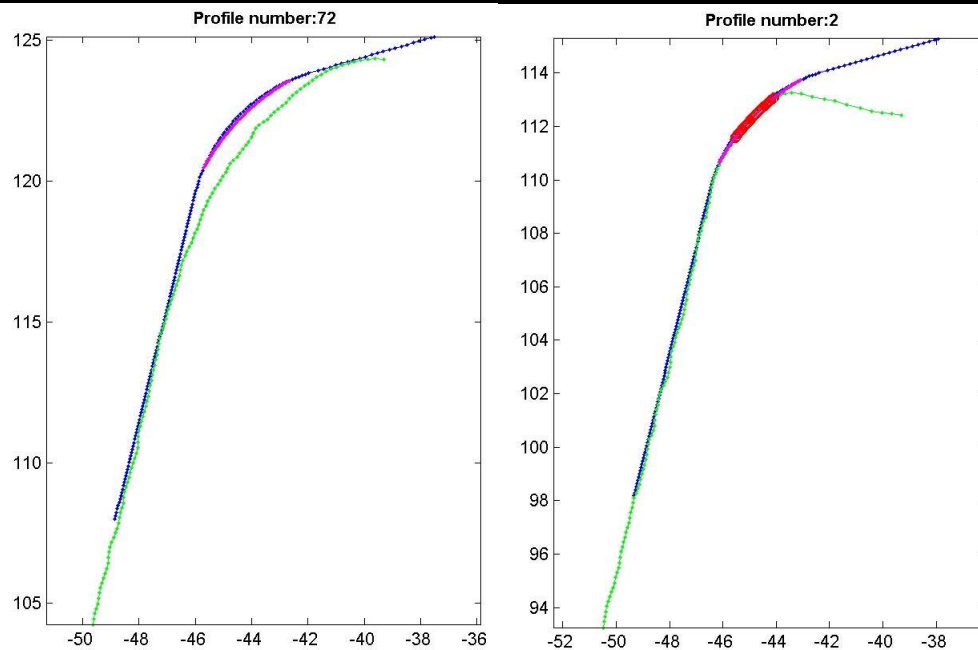


Figure 14 - Switch rail radius check, PASS example (left), FAIL example (right)

#### 4. Smart washer

Due to the fact that locking mechanisms cannot guarantee that minimum locking force will be maintained over an unlimited period of time, they have to be regularly inspected. Smart washers are installed on critical joints and can measure joint tightness. This information is then automatically sent out to a receiver which collects the data. By using this principle periodic inspection is not necessary.

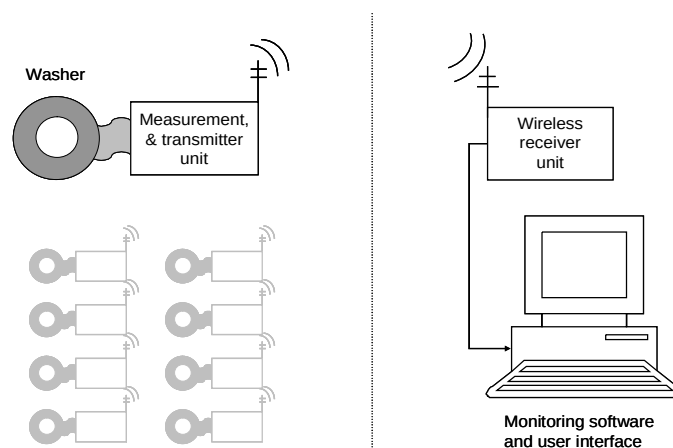


Figure 15 - Smart washer architecture

Figure 15 shows the basic principle of smart washers.



Figure 16 - Test example of a smart washer at the University of Birmingham

Early prototypes were tested and, although a complete solution was not designed, research shows that the principle is feasible.

## 5. Non-Destructive Testing

Current NDT technologies are very unreliable at detecting cracks in S&C. Figure 17 shows a NDT system developed at the University of Birmingham which uses a robotic arm in order to accurately measure cracks in rails. The accuracy of the measurements is higher than known commercially available NDT systems.

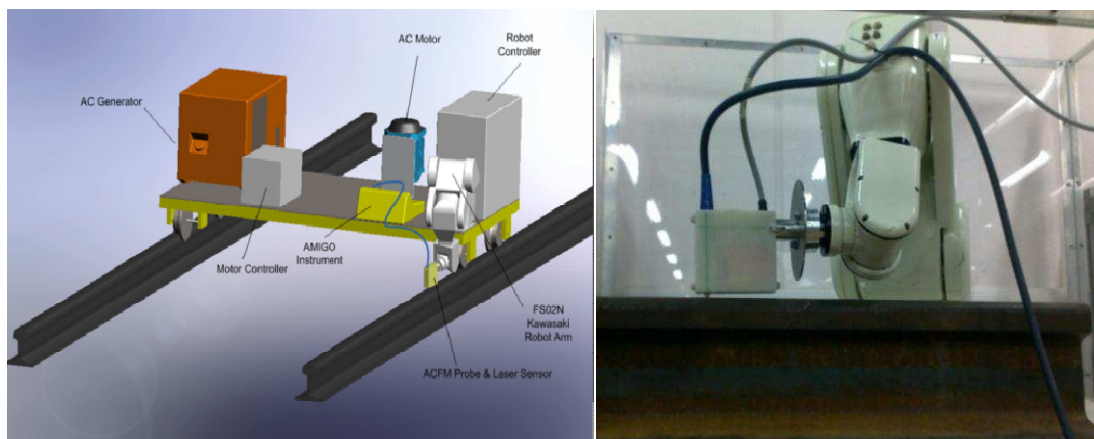


Figure 17 - Robotic arm NDT (left: model, right: robot arm)

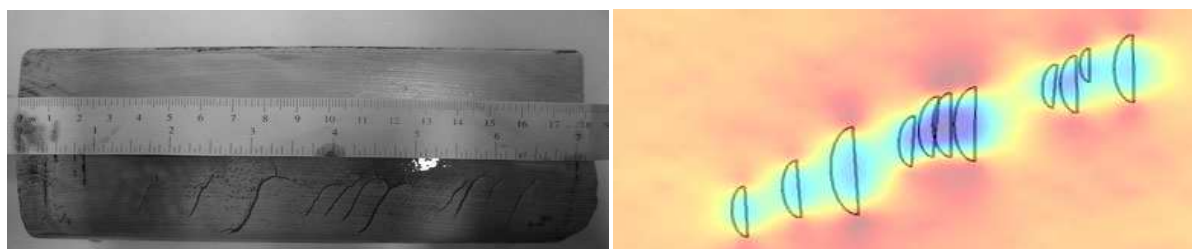


Figure 18 - NDT test (left: inspected piece of rail, right: results)

## ***b) Encountered issues***

### **Overhead camera inspection**

The main challenges of this innovation are: high voltage areas, powering, low weight (catenary dynamics), maintenance accessibility, wind stability, communication and cost.

### **Hand held switch inspection**

Laser inspection does not work in every environment. Very bright sunlight can make the data unreliable, therefore a housing for the lasers with absorbent interior had to be used in some cases. Other challenges include: assuring the algorithms are perform as expected on any switch of the network, reducing size and weight of the system and cost.

### **Smart washer**

The issues around smart washers are the optimization of sensor, transmitter, harvester circuit and receiver in order to increase its performance (measurements per day, transmission distance, size and cost).

## ***c) Exploitable results, conformity with the Grant Agreement***

The technologies developed and tested as part of the Automain project were chosen in order to support the idea of a “self-inspecting switch” which tries to reduce maintenance to the minimum possible. Most technologies can be carried forward and be exploited in a railway environment.

## **V. Costs**

### **Train-borne switch inspection**

The Switch Inspection and Measurement system is estimated to cost at least 500 000 Euros. Other running and maintenance costs also have to be factored in. However, the high output of this system can balance its cost. as the system can scan 100 switches (around a single station) within a few hours at night when services are not running.

### **Hand held switch inspection**

The prototype version of the hand held switch inspection system costs around 16 000 Euros, although the actual production cost would be less than this.

## **VI. Potential exploitation**

### **Overhead camera inspection**

New possession time / reduction percentage: 0 min / 100%.

Technology readiness level estimated at TRL 7. System prototype has been demonstrated in a railway environment in Boden, Sweden.



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### **Train-borne switch inspection**

New possession time / reduction percentage: 0 min / 100%

Technology readiness level estimated at TRL 8. Train-borne innovations have been demonstrated at four locations (963 switches) in Germany.

### **Hand held switch inspection**

New possession time / reduction percentage: 5 min / 83%

Technology readiness level estimated at TRL 7. Prototype has been demonstrated in a railway environment at Long Marston Test Track, Stratford-upon-Avon, UK.

This innovation could be further explored by a private company that specialises in rail and track measuring equipment. The University of Birmingham runs Knowledge Transfer Programmes which facilitate the transition from research to production.

## **VII. Conclusions**

An approach to understanding inspection requirements has been developed. A number of switch inspection innovations have been developed from first principles or further developed during the project. Demonstrations have taken place in the UK, Germany and Sweden.

Work will be taken forward by a number of infrastructure managers:

- Overhead camera inspection (Damill and Trafikverket, Sweden)
- Train-borne switch inspection (DB, Germany and ProRail, Netherlands)
- Hand held switch inspection (University of Birmingham and Network Rail, UK)

## VIII. Appendix A

### AUTOMAIN Demonstration 6.2 - Modular, self inspecting switch

|                                                                                                                                                                                                  |                                                                                                                                                                                                                      |                                                                                                                                                                                          |                                                                                                                                                                                                                  |                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Scenario location type</b><br/>A high capacity switch that is difficult to access, e.g. at a busy station, inside a tunnel, high speed location, high density route, complex junctions</p> | <p><b>Problem features</b><br/>Switch difficult to access<br/>Safety issues with access<br/>Loss of capacity during access<br/>Significant possession time required for access<br/>Access limits 24 hour running</p> | <p><b>Technology to demonstrate 1</b><br/>Visual inspection from overhead camera (DAMILL) at Boden, Sweden</p>                                                                           | <p><b>Enabling technology 1</b><br/>MMI (Vossloh, France)</p>                                                                                                                                                    | <p><b>KPI 1</b><br/>Reduction in inspection time – i.e. a reduction in the non-availability of the network due to inspection</p>   | <p><b>Story line Part 1</b><br/>The inspection technology is in place, together with the MMI which shows a visualisation of the current (or recent) state</p>                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|                                                                                                                                                                                                  |                                                                                                                                                                                                                      | <p><b>Technology to demonstrate 2</b><br/>Laser switch inspection (UoB) in the laboratory at the University of Birmingham, UK</p>                                                        | <p><b>Enabling technology 2</b><br/>Modular capability (i.e. the ability to have all or some of this technology and also the ability to build sensors into the original switch components) (Vossloh, Sweden)</p> | <p><b>KPI 2</b><br/>Reduction in maintenance time - i.e. a reduction in the non-availability of the network due to maintenance</p> | <p><b>Story line Part 2</b><br/>A fault occurs, e.g. (i) a bolt becomes loose; (ii) the alignment through the switch degrades; (iii) the switch rail becomes damaged</p>                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|                                                                                                                                                                                                  |                                                                                                                                                                                                                      | <p><b>Technology to demonstrate 3</b><br/>SIM (Switch Inspection Measurement) system (Strukton/DB) in Germany</p>                                                                        |                                                                                                                                                                                                                  |                                                                                                                                    | <p><b>Story line Part 3(i)</b><br/>The MMI shows a degradation on force on the washer, and hence maintenance can be scheduled in non-peak time (using WPS tools) for corrective maintenance to occur. The possession time is less. Humans have not had to access the track to assess this. The dependability of detection is high. Continuous monitoring means that any fault is detected in a timely manner.</p>                                                                                                                                                                                        |
|                                                                                                                                                                                                  |                                                                                                                                                                                                                      | <p><b>Technology to demonstrate 4</b><br/>In-service inspection of switches (DB/UoB) on the Rotterdam (Netherlands) to Dillingen (Germany) line and the London to Brighton (UK) line</p> |                                                                                                                                                                                                                  |                                                                                                                                    | <p><b>Story line Part 3(ii)</b><br/>The in-service train automatically identifies a degradation of alignment over time. Degradation rate can be observed in the MMI (i.e. a priority can be calculated). Optimal corrective maintenance can be scheduled (using WPS tools). The quality of the work can be assessed, and the rate of degradation to the next fault can be observed (i.e. if the fault reappears within a few weeks a more fundamental underlying issue is present). Possession time is less. Humans do not have to access the track to assess this. Detection dependability is high.</p> |
|                                                                                                                                                                                                  |                                                                                                                                                                                                                      | <p><b>Technology to demonstrate 5</b><br/>Smart washer (UoB/NR) in the laboratory at the University of Birmingham, UK</p>                                                                |                                                                                                                                                                                                                  |                                                                                                                                    | <p><b>Story line Part 3(iii)</b><br/>(a) The SIM system is ideal for groups of switches in a large complex junction/station. SIM inspection will be scheduled so that all switches are inspected at once. System accurately measures all geometry. (b) The overhead camera system is ideal for a single switch located a long distance from maintenance personnel. The camera is able to visualise large defects (i.e. detectable by eye). (c) The laser measurement system is used after maintenance has been carried out. It can also be used in locations where it is not feasible to use SIM.</p>    |