In2Rail

Project Title:	**INNOVATIVE INTELLIGENT RAIL**
Starting date:	01/05/2015
Duration in months:	36
Call (part) identifier:	H2020-MG-2014
Grant agreement no:	635900

Deliverable D2.7

Self Inspecting / Adjusting S&C: Systems Concept Design Report

Due date of deliverable	Month 14 (GA) - Month 26 (EC review)
Actual submission date	30-06-2017
Organization name of lead contractor for this deliverable	NR
Dissemination level	PU
Revision	FINAL – Updated after EC review

Authors

		Contribution
Author(s)	**Network Rail (NR)** Tara Scott	Providing expert S&C knowledge, existing asset data and guidance on current standards and policies. Defining selection and evaluation criteria.
Contributor(s)	**Ansaldo STS (ASTS)** Federico Papa, Enzo Sorrentino	Research S&C Control Principles & Monitoring Required
	Trafikverket (TRV) Arne Nissen	Providing expert S&C knowledge, Inspection work for S&Cs, failure and maintenance data sent to ERT Failure Data and Cost
	Luleå Tekniska Universitet (LTU) Matti Rantatalo	Investigate a method for detecting the switch blade position
	Deutsche Bahn AG (DB) Franz Löffler	Providing expert S&C knowledge, existing asset data and guidance on current standards and policies. Defining selection and evaluation criteria.
	Systra (SYSTRA) Nicolas Lestoille	Expertise and knowledge in innovative design and development of new concepts for railway infrastructures
	University of Huddersfield (UoH) Yann Bezin	Multibody system simulation of selected new S&C systems to predict wear or rail components requiring monitoring and adjustment. Consideration for material, vehicles and traffic and their effect on wear.
	University of Southampton (UoS) Louis Le Pen, Taufan Abadi, William Powrie	Area of sensors and consideration of degraded sub-structure
	Vossloh Cogifer Patrick De Lavallee	Evaluate Technologies Capable of Monitoring Key Parameters Concept Evaluation and Selection for Further Development
	Loughborough University (LU) Roger Dixon, Chris Ward, Tim Harrison	Input in terms of control and mechatronic systems, fault tolerant design, condition monitoring to help identify and exploit opportunities for using modern control systems science in order to improve S&C mechanisms
	Network Rail Chris Rowley Pauline Reith	Checking the document

Review Comments

Following the In2Rail midterm review on Tuesday 28th February 2017, this deliverable was requested for revision by the European Commission in the assessment report #Ref. Ares(2017)1734456 - 31/03/2017, In2Rail can confirm that the review comments have been duly considered and this modified report contains revisions to address these specific points.

The below table provides an index to Sections of the revised document that contain the responses to the review comments.

Revision Requested from EC	Revision Reference Number
System design concept is needed to be clearly expanded on in the report.	• Section 5.1: A new section 5.1 has been inserted to describe the current concept and illustrate (in S5.2) how that concept is modified with the proposed closed-loop approach. • Section 5.2: Section 5.2 (formerly 5.1) has been expanded and relates the approach to the open-loop approach to conventional S&C (of which HPSS is one approach and will be used to demonstrate the concepts as the work progresses)
Explanations needed of how to apply the system design concepts / approach.	• Section 5.1 • Section 5.2: the changes above are also intended to make this clearer. • Section 5.2.3.1: a new section 5.2.3.1 “**Task 2.4 System Design Concept / Approach”** has been added to describe how the simulation of a HPSS will be used to compare the conventional (open-loop control) with the proposed closed-loop design approach. • Section 5.2.4: changes have been made to the structure some parts of text with the aim of understanding what the different approach is in terms of redundancy. • Section 5.5: an extra list of bullet-pointed steps going forward to make it clearer what work will be done (to be reported on in the future)

Revision Requested from EC	Revision Reference Number
The CBA (Cost Benefit Analysis) in Ch.4 needs to be carried out following standard CBA methodologies (comparing scenarios; the “do something” scenario is not defined or unclear in the report, and therefore no cost of implementation of new systems and no benefits are assessed).	• Section 4.1.4 • Section 4.2.3 • Section 4.3 • A discussion of the two pieces of work is added in 4.1.4 to link the common themes and show how the way forward was identified. Section 4.3 has been added to identify the next steps
Ch.5 Control Process Analysis: There should be more focus on specific conceptual applications to S&C and on the research into new S&C control principles as well as on how the “possibilities for further explorations” described at the end of section 5.4 go beyond the current state of the art.	• Section 5.1 • Section 5.2 • Section 5.5 In the changes mentioned in response to the first two comments (top of this table) we have tried to relate what we plan to do and demonstrate on HPSS. More was also added to give more detail in 5.5 (formerly 5.4) to show the detail of what we will compare.

Executive Summary

The aim of this deliverable document is to explain the initial steps that Task 2.4 has taken to address the remit to deliver new control and monitoring principles for Switches & Crossings (S&C) to allow for automated self-adjustment of switches within acceptable tolerances that provide for safe and reliable operation.

In order to understand the remit research was carried out into understanding basic control systems theoretical principles, and what the safety and performance requirements are. This developed into an understanding the current S&C control principles, and a case study investigating S&C Point Operating Equipment to be analysed in detail. The case study has been carried out using information gathered from the current Network Rail type HPSS points system. This data aided the identifying the specification requirements for advanced switch control that included the functionality for self-adjustment. As part of this task the S&C was treated as a system so there is a requirement to take the track substructure data into account as this will increase the understanding of the parameters and magnitudes of the self-adjust that is required.

The reduction in the amount of manual interaction will have both a safety and financial benefit. The safety benefit will be related to the reduced amount of time that work force staff are exposed to the track environment. .

The financial benefits calculated in this report took the assumption that there would be a reduction in the volume of service affecting failures that required some form of remedial adjustment as part of the failure mechanism. There was also a calculation on the amount of money saved by reducing one of Network Rails standard tasks of regularly checking and re-adjusting of S&C motion and locking mechanisms.

The potential savings using Network Rail and Trafikverket information shows that on average EUR 11,1 and EUR 2.3 million per year could be saved respectively.

From these figures, the business case for self-adjusting railway switches is clear. The remaining work being tackled in Task 2.4 is the technical challenge of how to achieve this. Future work, which will be reported in the final deliverable (D2.8), is to look at various control systems science based concepts and to test these against current switch control technology. This will then inform a full and accurate cost benefit analysis prior to making further recommendations to Shift2Rail (*i.e.* the Annual Work Plan 2018 Members Project and the S-Code IP3 Open Call Project).

TABLE OF CONTENTS

Abbreviations and acronyms

Abbreviation / Acronyms	Description
MTBSAF	Mean Time Between Service Affecting Failure
FPL	Facing Point Lock
HPSS	High Performance Switch System
NR	Network Rail
S&C	Switches and Crossings
POE	Point Operating Equipment
ECU	Electrical Control Unit
HPSA	High Performance Switch Actuator
AC	Alternating Current
DC	Direct Current
EMC	Electromagnetic compatibility
LVDT	Linear Variable Differential Transformer

1 Background

The present document constitutes the second issue of Deliverable D2.7, Self-inspecting and adjusting S&C, Systems concept design report in the framework of the Project titled "Innovative Intelligent Rail" (Project Acronym: In2Rail; Grant Agreement No 635900).

This task requires research into new principles for S&C control and monitoring to allow for automated self-adjustment of switches within acceptable tolerances for safe and reliable operation. It will require the design of self-inspecting, correcting and adjusting systems and sub-systems. The ambition of WP2 Task 2.4 is to investigate the feasibility of implementing advanced control systems, to both existing and radical switch designs, using virtual testing and verification to encompass all possible variations in operating conditions to establish safety limits (TRL3).

Failures associated with S&C currently account for some 25-30% of all infrastructure failures on European railways. Experience dictates that there is a common issue around reliability of Points Operating Equipment (POE) lock and detection functions and a distinct lack of redundancy built into this safety critical asset. There is also a requirement to reduce or eliminate the amount of manual maintenance required to improve staff safety.

The development of innovative solutions will be performed using state-of-the-art design, computer simulation and visualisation for the assessment of a number of innovative new S&C solutions.

2 Objective / Aim

The primary aim of this objective is to describe the basic control systems that are currently in use in other industries and investigate whether such feedback control systems might be used within the existing S&C control.

The focus will then be on taking the principles of feedback control (and associated control systems science idea) forward to determine how they can be implemented on current S&C systems. The following step is to then see how with further mods to the hardware (being considered in other parts of the project), the control concepts for rail might be further improved in the future and added to the novel radical S&C design concept developed within In2Rail WP2 Task 2.3.

The overall aim is to reduce or eliminate the number of failures and reduce the amount of manual intervention required to adjust switches during maintenance. This will also lead to a reduction in the amount of faults requiring teams to manually adjust switches as a result of failure.

3 Scope of Work

The following table shows what is in scope within this Task 2.4:

In Scope	**Out of Scope**
Switch Locking Mechanism(s)	Power Supply (This will be in scope at the detailed design stage – *i.e.* within Shift2Rail).
Switch POE Detection System(s)	Uncommon, Low Population and Low Failure Rate Switch Designs
All Major European Rail Profiles, Switch Designs and Constructions	Designing to Withstand the Loads associated with Run-throughs
Interface with Existing Signalling Systems	
Consideration of Degraded Sub-structure	
Interaction with Other Systems (*i.e.* Points Heating)	
Weather Resilience	
Compliance with Existing European and Individual Infrastructure Manager Standards	
Existing Switch Actuation	

Table 3.1: Specific Extent of Scope

As a baseline for this deliverable it has been decided that the task will use information gathered from a Network Rail Point Machine, HPSS (High Performance Switch System). The decision was made as the data, which is the switch position location from the LVDT (Linear Variable Differential Transformer) is readily available and can help form the base that this task will take forward and improve upon. This will be used as a Case Study. However, it should be noted that the conclusions are expected to be general (not just applied to HPSS) and that any principles learnt can be adapted to other switch types and to meet the requirements of radical S&C designs emanating from Task 2.3.

3.1 Network Rail HPSS

The system was first trialled in Tamworth in 1998 to 2001, and it gained its product acceptance in 2001. Currently there are about 500 units installed across the UK network which makes up 2.6% of the S&C systems within the UK. The other types of systems are:

- HW Point Machine – 42%;
- Style 63 Point Machine – 5%;

- Clamp Lock MK2 – 47%;
- Hy-drive Mechanical – 2.6%.

For the purpose of this deliverable the mechanical point systems in the UK have been excluded.

Table 3.2 shows the HPSS summary statistics:

Actuation	Electro-mechanical
Supplementary Drive	Torsional Tube
Number in service	500
MTBSAF	3.5yrs
Strengths of HPSS	Drive System
Vulnerable to	Detection Failure
Initial Cost	High

Table 3.2: Summary of HPSS

Figure 3.1 shows an overview of the HPSS system:

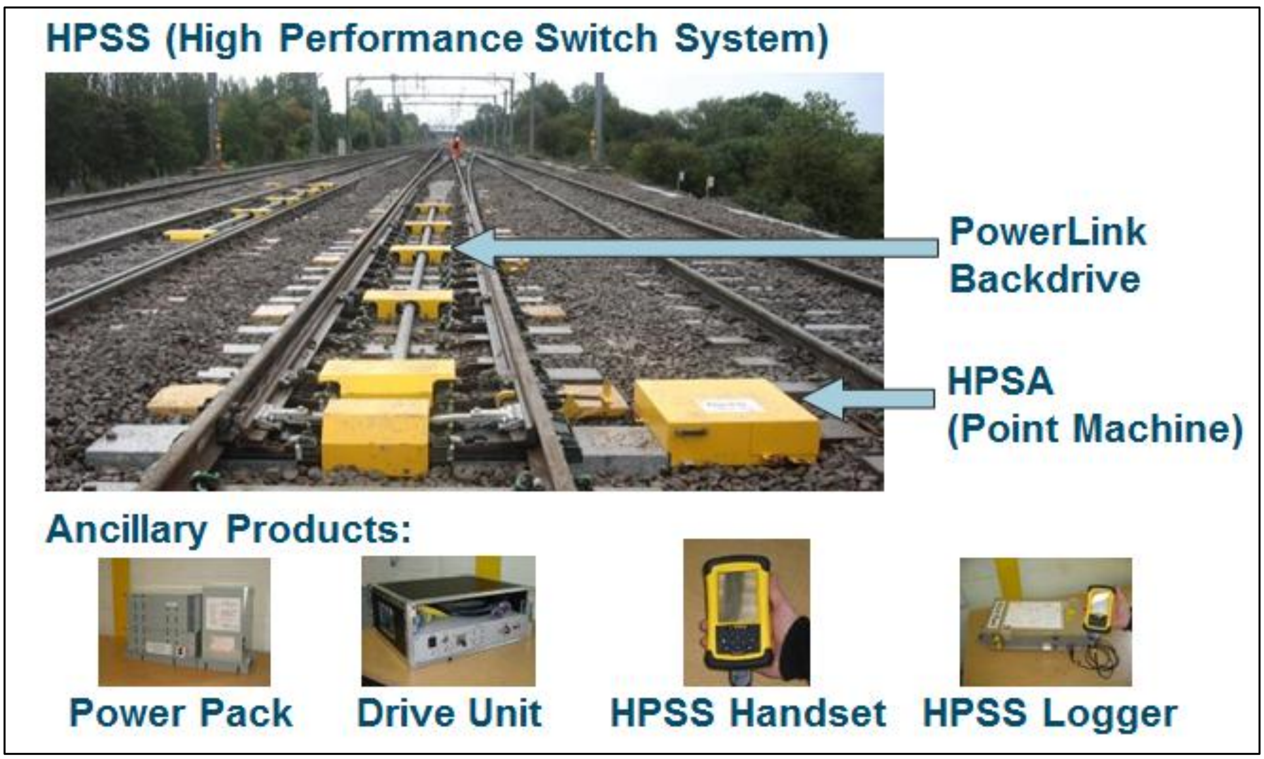


Figure 3.1: HPSS Outline

The HPSS has Rail Position Sensors within the system used to detect the position of the switch rail relative to the adjacent stock rail. The system has two position sensors, the primary sensor at the switch toe, and a secondary found at the supplementary drive position. The position sensor consists of a Linear Variable Differential Transformer (LVDT), which has a continuous measurement range, compared to conversational limit switches.

Powered operation of the HPSS is achieved via standard relays in a location case or relay room. The High Performance Switch Actuator (HPSA) is designed to integrate with AC, DC or Solid State Signalling systems.

The HPSA is an electromechanical unit that provides the Actuation, Locking and Detection functions for the S&C system.

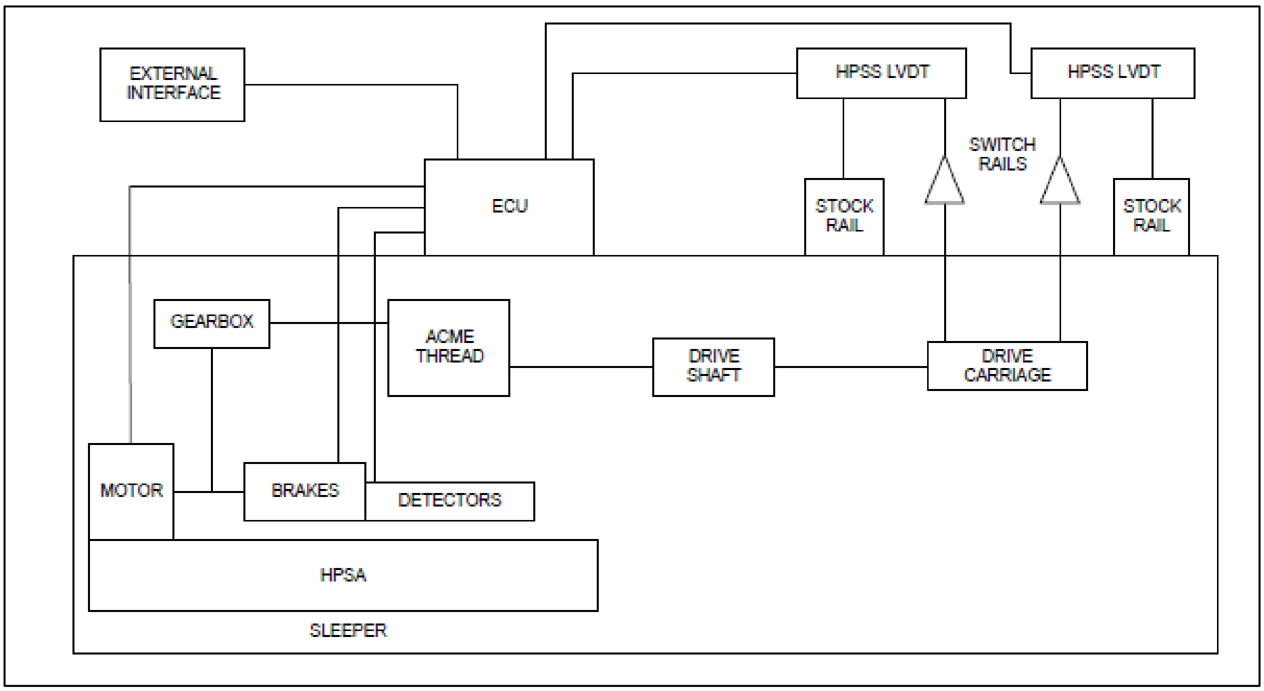


Figure 3.2: HPSA Block Diagram

Command and Detection cables are the 10 Core and 4 Core types commonly used for Point Machines.

The entire HPSS is controlled and monitored by an Electronic Control Unit (ECU) that receives external demands, controls the actuation and locking sequence, provides detection output to the external signalling system, and contains the Condition Monitoring circuits and data storage. By designing the ECU as a number of discrete circuit boards contained within a fully waterproof, EMC compliant housing, the HPSS design is compatible with any signalling system and importantly offers the ability to be upgraded to contain additional circuitry for any new signalling system interfaces, or enhanced remote Condition Monitoring that is required in future.

On receipt of a valid command, the ECU energises the duplex brake to release the Switch Rails and then operates the motor until a stall condition is detected via the motor sensors, (that is the closing Switch Rail is assumed to have driven hard up against its mating Stock Rail).

When the Switch Rail has stalled out against the Stock Rail, motor power is removed and the brake is de-energised, restoring both friction plates within the brake allowing the spring to return them to the holding position. The friction plates positions are monitored by two independent proximity sensors, which are located within the Brake assembly.

The ECU sets a valid detection output, with the points in either the 'Normal' or 'Reverse' position, when it has confirmed that all rail sensor positions are within their specified tolerances, that is when the Switch Rails are in a safe and secure position, and both brake friction plates are in their holding position.

As a safety check, an internal timer, within the ECU removes power from the Motor if the rail positions have not reached their specified tolerances within 6.5 seconds from receipt of a demand, and consequently will not give a valid output to the signalling system thereby maintaining a 'safe state'.

Once the ECU has set a valid detection output, all rail sensor positions and brake friction plate positions are continuously monitored to ensure that a valid detection outputs remain.

The position of each Switch Rail relative to its associated fixed Stock Rail is monitored using a Linear Variable Differential Transformer (LVDT), being clamped directly to the foot of the Stock Rail at the Toe of the Switch. This provides an absolute position measurement of each Switch Rail relative to its adjacent Stock Rail in both the open and closed positions. To ensure absolute system safety, the rail positions are cross-validated by the detection circuits (i.e. the closed rail detector also confirms the position of the open rail and vice versa). This is a fundamental safety feature and in key installations that have Condition Monitoring set-ups, may be constantly monitored for any signs of system degradation.

The principle of operation of an LVDT is similar to a Transformer, where an electrically energised primary winding generates electrical output from the secondary coil(s). The axial movement of an iron core, located co-axially within the cylindrical coil housing, provides a linear variation between output signal and rail position.

LVDTs are also used to monitor supplementary rail positions in order to meet Network Rail's 15mm (RT60) Obstruction Detection requirement as defined in Company Standard 'Requirements for Powered Point Operating Equipment' (RT/SRS/2001).

4 Cost / Benefit Analysis

The following section follows an evaluation of existing switch failure modes and maintenance activities that can be reduced and / or eliminated through the introduction of advanced switch control systems for self-adjustment.

4.1 Failure modes associated with switch adjustment

4.1.1 Failure Data :-UK Rail Network (Network Rail)

The Network Rail failure data for the year 15/16 was filtered to only include failures where an adjustment of the system was subsequently required. These were also classed as Service Affecting Failures as they had disrupted the train service in some way. The table below shows the number of failures categorised by cause.

Failure Types	Number of Events
Actuation	70
Detection	116
External Factors	40
Locking	73
No Fault Found	8
Grand Total	**307**

Table 4.1: Overall Failures

Examples of types of failures recorded per categorised cause:

Actuation	• Backdrive Mechanism including out-of-adjustment, loose and worn components • Point Motor including adjustment of clutch, springs and incorrectly set up components • Points failing to move including incorrectly set up components
Detection	• Incorrect detection assembly • Points failing to detect • Supplementary detection failure
Locking	• Clamplock Mechanism requiring adjusting • Locking mechanism requiring adjustment
External Factors	• Ballast within the points which then requires the switch to be adjusted • Poor Track Quality which requires the switch to be adjusted • Thermal expansion which requires switch to be adjusted
No Fault found	• Each failure required the switch to be re-adjusted to sign the S&C back into operation.

Table: 4.2: Types of failures recorded per categorised cause

4.1.2 Delay costs associated with switch adjustment failures - NR

For the NR Failure Data the following costs are the rates of performance failure costs, not the cost of the resource to repair the failure. Performance failure costs are calculated by the Schedule 8 payment method. This process sets out the basis for compensation to train operators for the impact of unplanned lateness and cancellations on their' revenues. The process is calibrated to be financially neutral to Network Rail, provided they hit their regulatory performance targets. Benchmarks and payment rates are specific to each service group and bonus payments are made at the same rate as compensation payments.

Failure Type	Number of Events	Cost
Actuation	70	£613,820.12
Detection	116	£1,233,129.06
External Factors	40	£470,129.91
Locking	73	£1,151,822.20
No Fault Found	8	£10,229.62
Grand Total	**307**	**£3,479,130.91**

Table 4.3: Cost Associated to Failures Year 15/16

4.1.3 Failure Data :-Swedish Rail Network

The analysis included switches constructed with 60 kg/m rail (UIC60), which are typically installed in main line track with traffic levels varying from 1-32 MGTPA. From a population of 12,000 switches, those analysed makeup approximately 2000 of the most important S&C on the Trafikverket network. There are approximately 1500 other S&C in main line track with 50 kg/m rail, which have a traffic level of 1-12 MGTPA and have excluded from the analysis. Failure data is taken over a 3 year period from 2013 to 2016. Trafikverket has divided the S&C into six sub-systems. Four of these dominate the failure statistics:

- Point machine;
- Heating system;
- Detection system;
- Switch panel.

The normal failure rate for S&C in Sweden is 1.0 – 1.1 failure/switch/year. In winter, the number of failure increases resulting in over 40% of failures on S&C with 8-12 MGT/year being winter related. Winter related failures are connected to the heating system and sometimes to the switch panel, see Figure 4.1. Over the year there is also an increase of failures during summer.

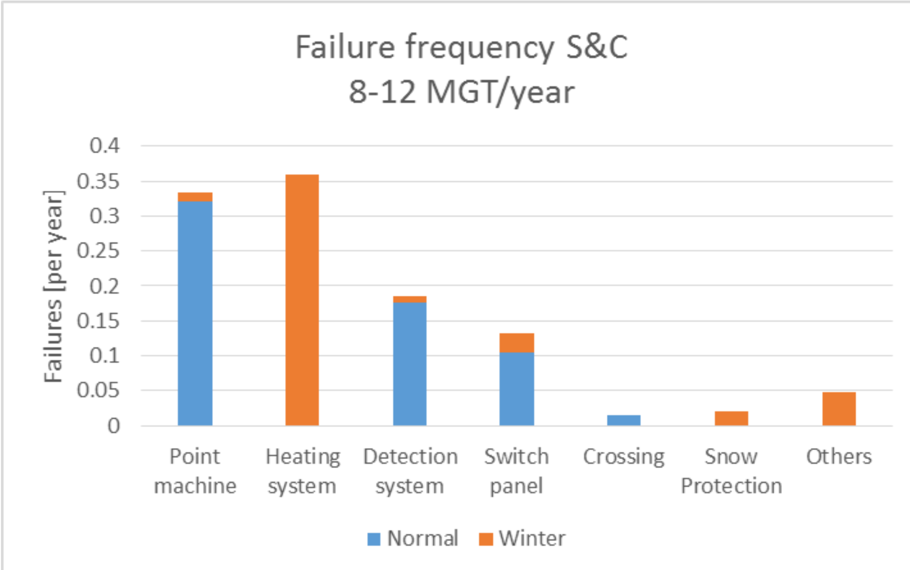


Figure 4.1: Failure for UIC60 S&C with traffic of 8-12 MGT/year and total traffic load of 50 - 350 MGT. The failures are divided into normal condition and winter related

For the point machine there is a possible correlation to the traffic load per year and total traffic load. For switch panel and crossing there might be a correlation to total traffic load, but for the other subsystem there is no obvious correlation, see Figure 4.2 and Figure 4.3. For heating system it is a high value in the interval 350-450 MGT which corresponds too many of the S&C located with lines that are dominated by freight traffic (iron ore line). There is significantly different weather on the iron ore line in the north of Sweden compared to the UK. Therefore figures are higher due to the extremes of weather.

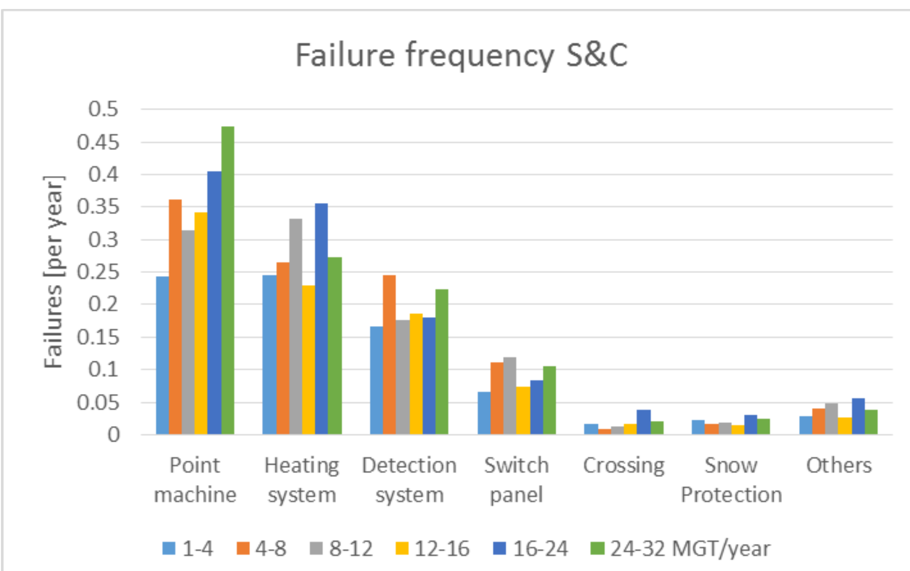


Figure 4.2: Failure for UIC60 S&C with traffic of 1-32 MGT/year

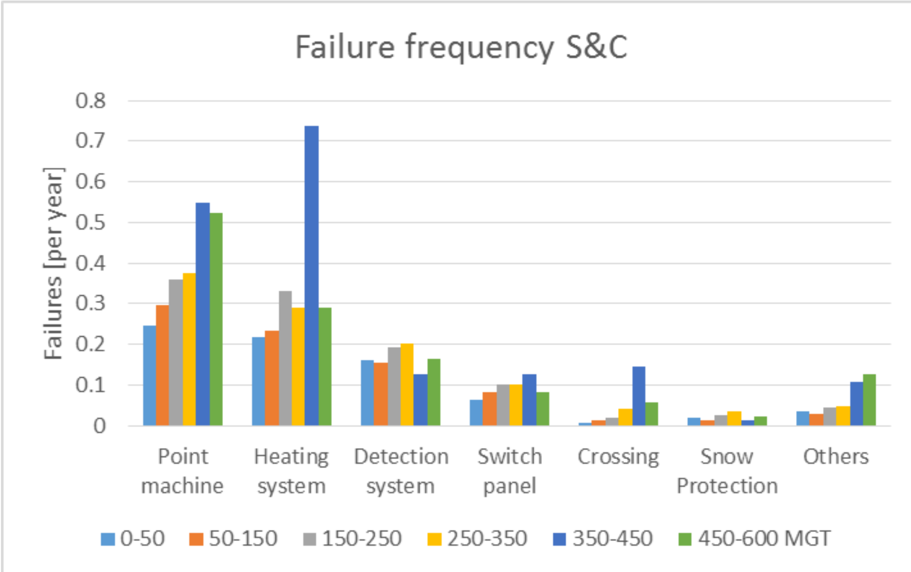


Figure 4.3: Failure for UIC60 S&C with total traffic load of 0-600 MGT/year

In the failure report the S&C system is given proposed actions and by choosing those actions that contain reference to "adjustment or check" it is possible to find the failure modes that can be decreased by self-adjusting systems. Failures that have taken a long time to adjust were omitted as these where outliners. About 0.2 failures/S&C per year whereas 0.07 failures/S&C per year were service affecting. Each service affecting failure gives an average of 30 minutes delay time.

Part of S&C	Frequency train stopping	Frequency	Delay time per train stopping failure
Point machine	0.04	0.12	31.03
Detection system	0.02	0.05	31.29
Switch panel	0.00	0.01	11.00
Others	0.01	0.02	36.22
Totals	**0.07**	**0.21**	**30.81**

Table 4.4: Failure frequency for UIC60 S&C that can be decreased by self-adjustment

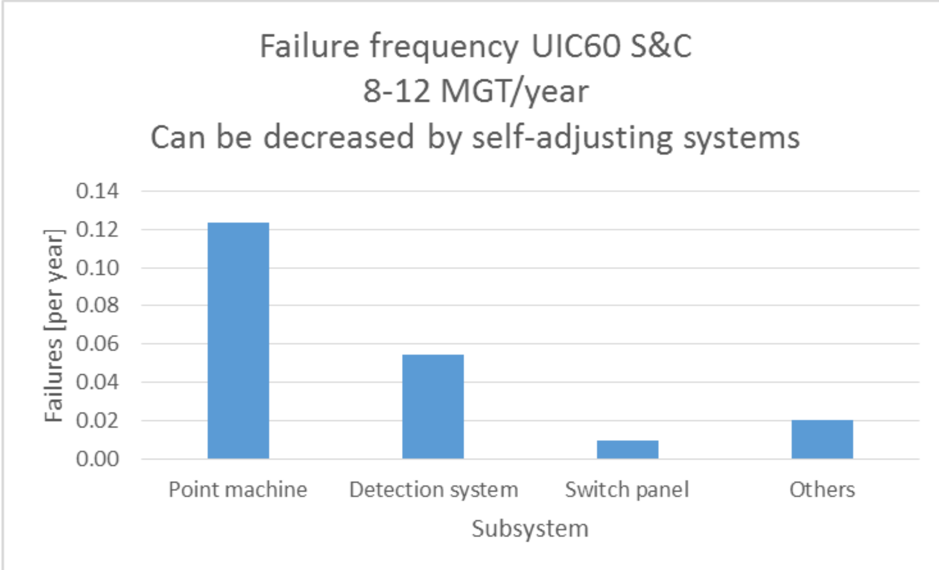


Figure 4.4: Failure frequency for UIC60 S&C that can be decreased by self-adjustment

The cost for performing maintenance is estimated to 200 €/h per maintenance team. A typical time including travel and preparation for these types of failures is 3 hours. That would give about 400 000 €/year in maintenance cost for 3500 S&C (UIC60, BV50 and SJ50). The cost for failures is estimated by the delay times that affect the passenger. There is no general delay cost that is in regularly use at Trafikverket, as the delay cost should be calculated for each track section separately. For the Western and Southern main line 130 €/minute has been assumed and has been used in the calculation. The mean delay time per S&C is 2.1 minute which gives approximately 1 million Euro in delay cost per year.

4.1.3.1 Analysis of inspection remarks for Trafikverket

Preventive maintenance is registered in a database separate from the system for corrective maintenance system. Some of the actions performed after inspection remarks are considered as failures (corrective maintenance), but Trafikverket very seldom show these figures together with failure statistics as they are taken from different databases.

In the data extracted from a limited number of track sections, 20 % of the inspection remarks was coded as corrective maintenance, as shown in Figure 4.5.

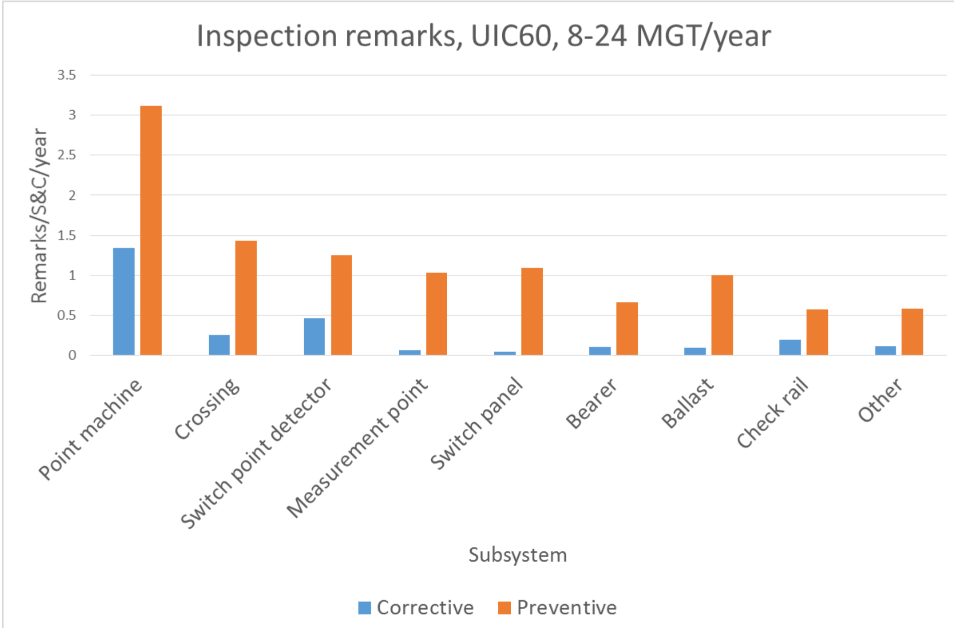


Figure 4.5: Inspection remarks for selected UIC60 S&C

Adjustment is a common action for point machine and switch point detectors giving in total 3.6 actions per S&C per year, see Figure 4.6. The cost for these adjustment can be estimated to 1.3 M€/year assuming that each action takes approximately 30 minutes to complete including planning and travel.

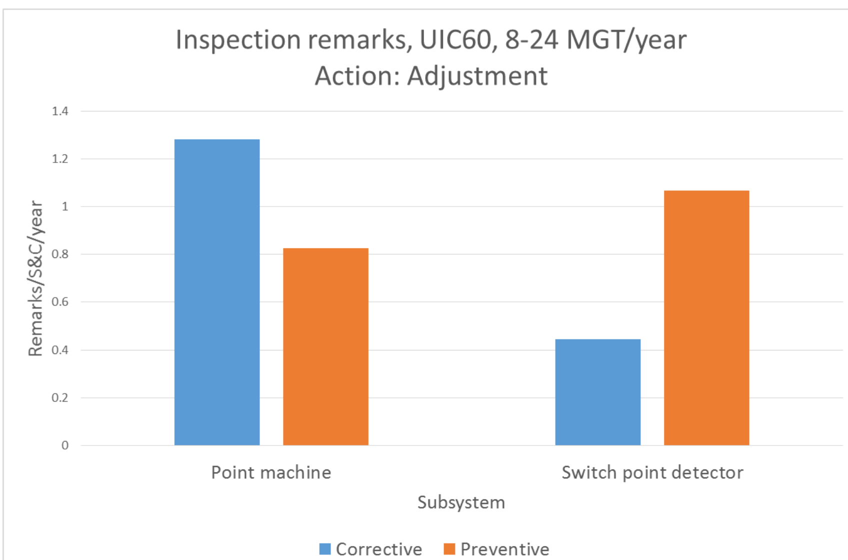


Figure 4.6: Inspection remarks for selected UIC60 S&C with the action adjustment

4.1.4 Potential Benefits

Looking across the failure information in 4.1.1 - 4.1.2, it is clear that faults related to detection and actuation represents a large proportion of issues with S&C. Based on this, a significant proportion of failures could be avoided and inspection could be reduced, if (through use of improved control design) self-adjustment can be implemented that would remove some of these faults.

4.2 Maintenance requirements for switch adjustment

To enable a true reflection of the amount of switch adjustment required it is useful to look at the whole track structure as a system. There could be a relationship between the amount of movement in the subsystem and the amount the S&C units requiring to be adjusted.

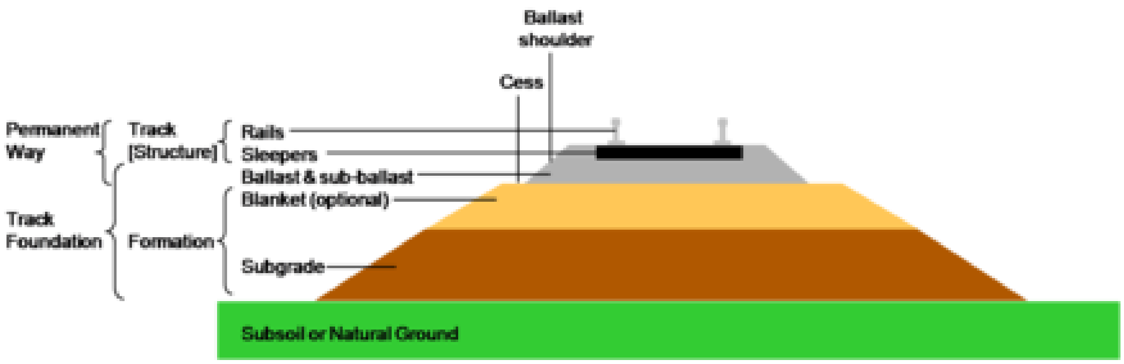


Figure 4.7: Track Structure

The Subsystem is all off the system under the ballast layer as shown above.

4.2.1 Subsystem of Track Structure

The previous section highlighted external factors contributing to switch failures which are related to poor/degraded support and worn/degraded mechanical components. Switch panels are subject to high dynamic loadings because of the variable wheel-rail contact conditions leading to non-linear load amplifications (see Fig 10) on both high and low rails (not shown here). This leads to a progressive geometrical deterioration in the switch panel designed installation (its vertical and/or lateral alignment) which has an impact on the satisfactory operation of the Point Operating Equipment (POE) and lock mechanism as well as generating gradual wear and tear in their moveable components.

Wear and fatigue damage of the running surface of the rail, variation in support stiffness due to variation in bearer length, rail numbers and component strengths will also lead to a variation over time of the contact conditions and associated dynamics loads, as well as introducing risks of plastic flow migrating from the stock rail into the mating face with the switch rail. This can affect the closing gap and proper detection of the switch position. Fig 11 shows the Hertzian contact band on the high rail (viewed from the top) for the leading and trailing wheels. The colours correspond to the type of damage, showing areas of high wear in the gauge corner of the switch blade as well as rolling contact fatigue on the stock rail.

Maintenance actions are designed to accommodate for the above deviations from ideal and restore the system conditions to acceptable levels to ensure reliable operation.

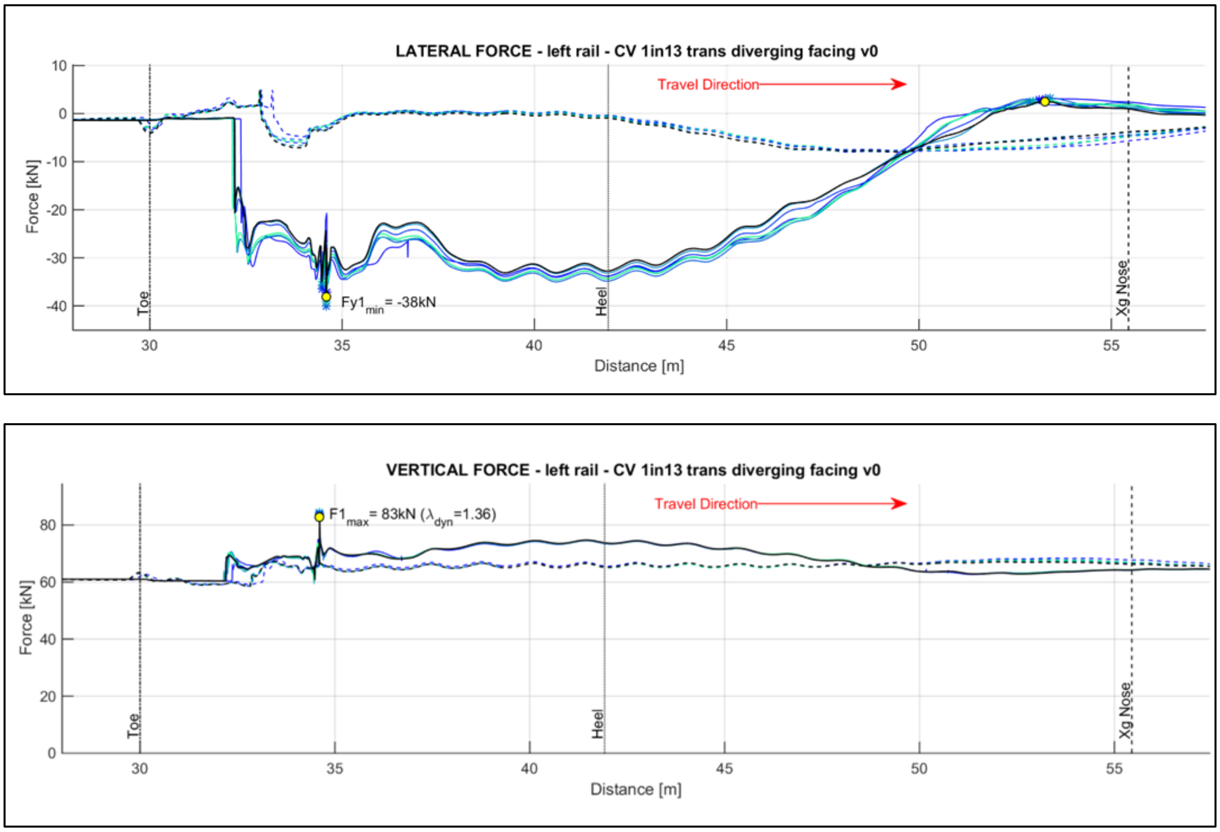


Figure 4.8: Lateral (top) and vertical (bottom) load on high rail in UK CEN56 CV type switch at maximum turnout speed of 40km/h for a range of wheel shapes for leading (solid line) and trailing (dashed line)

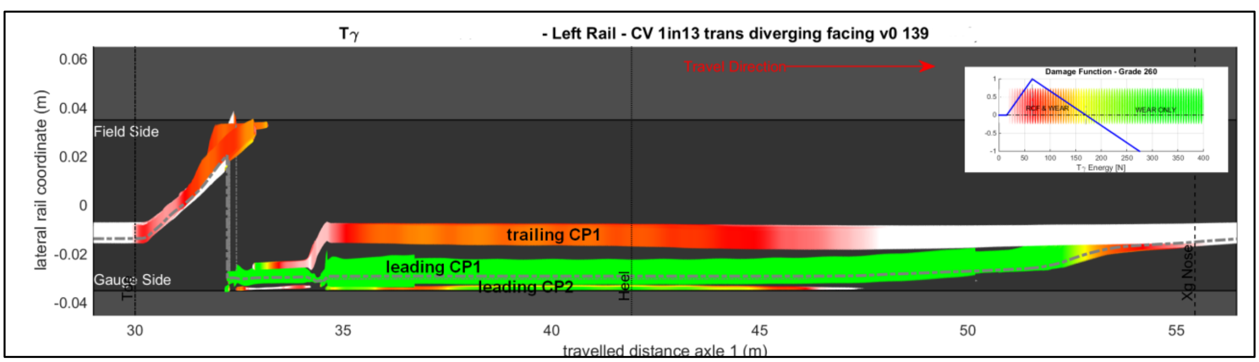


Figure 4.9: Tγ damage function and contact band representation from leading and trailing wheel on high rail in UK CEN56 CV turnout showing areas of RCF damage (red) and of wear (green)

4.2.1.1 Consideration of degraded substructure

The track substructure for S&C, as for plain line, is intended to provide a stable and uniform support to the track superstructure (bearers and rails) and should be able to drain freely. Generally the substructure is provided by a ballast layer typically 300 mm deep consisting of (in a modern railway) a crushed angular igneous rock, such as granite, relatively uniformly graded with grains in the size range 20 mm to 65 mm. The ballast layer may be underlain by a sand blanket, typically 100 mm thick and a prepared or natural formation. Geogrids and/or geotextiles may also be used to provide strength, separation and filtration. The combined depth of ballast and any sand blanket present should be specified so as to reduce the stresses transferred to the underlying soils to acceptable levels for millions of load cycles. Owing to variations in regional geology, the historical stock of existing earthworks/cuttings and changing construction practices, the quality of the ballast, presence of a sand blanket and quality of the subgrade/natural ground may be highly variable with some sections of track needing more frequent maintenance. At S & C, even where the substructure has been prepared to the highest initial quality, a number of factors may lead to a requirement for more frequent maintenance than plain line and contribute to failures of S & C. In particular:

1. The presence of switch rails and the use of elongated bearers to tie crossing routes together mean that restoring track line and level is more difficult to achieve using normal tamping maintenance practices, (e.g. are both lines tamped together? If not, is one raised relative to the other? Are tines inserted around crossing rails?). This means that geometry at S & C may be maintained to a lesser quality and/or cost more to maintain than nearby plain line;
2. Dynamic increments of vertical and horizontal load (Figure 4.8) on the track from trains either continuing and passing a crossing or using a crossing are more onerous than on plain line. The loads may lead to localised increased rates of track substructure degradation and track superstructure component damage;
3. Train load transmitted as stress to the ballast surface are more variable at S & C. This is a result of changes in rail bending stiffness particularly near the crossing nose, elongated bearers see-sawing between adjacent tracks rather than uniformly deflecting vertically, and the dynamic increments of vertical and horizontal load that occur both by design changes and through wear and tear on the wheel/rail running surface.

Although the factors that can lead to points failures are most obviously categorised under the heading external factors (Figure 4.9), these factors also lead to enhanced vibrations and loss of geometry at S & C and could play a role in other types of failure,(e.g. detection).

Higher vertical impact loads will cause higher accelerations which will result in higher shock loading. This higher shock loading will be damaging to components such as LVDTs which are susceptible to impact and vibration damage over time. Therefore it is critical that we use this modelling in further research.

4.2.2 Example of Maintenance Activity

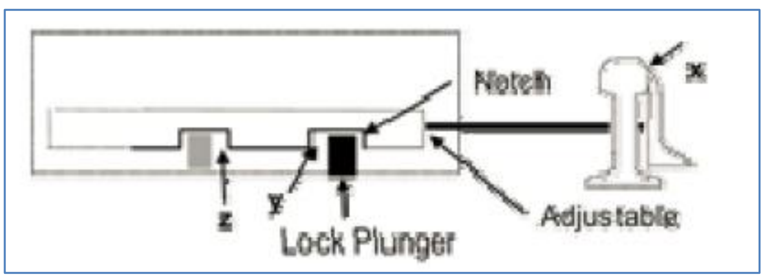
There are many tasks within the Network Rail's Signalling Maintenance Specification which requires the S&C components to be reset and adjusted. One of the most important activities is the Facing Point Lock (FPL) Inspection.

The inspection is as follows and requires a 3.5mm and 5mm point checking gauge and a 1.5mm gauge. Below is an extract from the Network Rail standard NR/L3/SIG/10663 Signal Maintenance Specifications, NR/SMS/Part/B, NR/SMS/Test/001. The same basic inspection is carried out for all types of S&C. With some additional checks for HPSS which are found in Appendix A.

In other parts of Europe this tolerance can be 4mm (in Italy) or 3.5 to 5mm (in Switzerland).

Process for a Network Rail FPL Inspection

1. For each closed switch position:
   a. Place the 3.5mm end of the FPL gauge between the switch and stock rail at a point in line with the bolt securing the stock rail to the first slide chair,
   b. Manually operate the points and Check that the lock will not enter the notch in the lock slide,
   c. Repeat item 1(i) using the 1.5mm gauge,
   d. Manually operate the points and Check that the lock will enter the notch in the lock slide;



Note: With point switch fully closed (x), there should be a 1.5mm clearance on each lock face (y & z).

2. Adjust and retest as necessary to achieve the requirements of (ii) and (iv);
3. Record the results and details of any adjustments made on the FPL Test Record;
4. Restore the points.

The final check before completion of the work is to ask the signaller to operate the points to normal and reverse positions (twice if possible). Observe correct operation.

4.2.2.1 Cost Associated with the FPL Inspection

On average an FPL Inspection is carried out at either a 6 week or 13 week interval. This interval is decided by the local maintenance Engineer with risk factors being taken into account. Within Network Rail Managed infrastructure there are about 19,000 S&C units which require an FPL.

The "norm times" is the average time it takes to carry out a single maintenance task, which for the FPL test is stated to take on average 0.5 hrs with two members of staff. The average cost per visit based on the norm times is £42.

The current staff cost is £42 per hour but this does not take into account the cost of planning the visit, nor the cost of time spent travelling to site.

The table below shows the average cost based on the required frequencies.

6 week interval				
Number of Points	**Number of Visits**	**Total Number of Visits**	**Average Cost Per Visit (£)**	**Total Cost (£)**
19,000	9	171,000	42	7,182,000
13 week interval				
Number of Points	**Number of Visits**	**Total Number of Visits**	**Average Cost Per Visit**	**Total Cost**
19,000	4	76,000	42	3,192,000

Table 4.5: Calculation of total cost for 6 week and 13 week inspection scenarios

Averaging out the inspection interval and average cost per year for the 19000 S&C units is £5,187,000.00. Taking the failure cost with the cost of carrying out an FPI the potential average saving is £8,666,130.91 (this assuming 100% savings).

4.2.3 Overall Potential Benefits

Currently without the full modelling and understanding of the possible design solutions the implementation costs associated with the new technology cannot be fully established and hence an accurate Cost Benefit Analysis cannot be done. The above chapters indicate that there are the potential savings that could be made if S&C became self-adjusting. This could be achieved by reducing the amount of service affecting failures and therefore delay cost and by reducing the amount of cyclical maintenance activities that would no longer be required. This information forms the bases for the next deliverable and will be part of the case study included in this stage. Section 4.3 goes into some more detail.

4.3 Requirements for future Cost Benefit Analysis

4.3.1 Scenario Testing

In order to assess the potential benefits of implementing self-adjustment within the S&C system, a number of scenarios will be tested using the HPSS case study (refer to section 5.5).

The variables that will be studied within the 'scenario testing' have been described within section 4.2 and can be summarised as:

- **Switch obstructions –** how will a closed-loop control system cope with trapped ballast?
- **Switch / Stock Rail Wear –** can the closed-loop control system help to reduce detection and lock faults by automatically adjusting within a defined set of switch to stock rail tolerances?
- **Track Gauge –** can the closed-loop control system accommodate changes in track gauge to avoid lock and detection failures?
- **Degraded Track Sub-grade –** How will the closed-loop control system cope with degraded track condition (i.e. significant voiding at the switch tips)?
- **Facing Point Lock Test** – is it possible for the closed-loop control system to enable relaxation of the FPL test frequency to 26 / 52 weekly?

The above variables will be used to assess performance of the advanced, closed-loop control system against the existing, open-loop system.

4.3.2 Cost of Implementation

To complete the full cost / benefit analysis, the cost of implementation will need to be established. This is a key activity to help inform the future investment decision to either enhance existing switch designs or integrate the additional hardware and software into next generation systems. However, it is first necessary to understand the performance of different types of advanced S&C control to then start designing the hardware and software required to deliver the most viable solution. This deliverable addressed the very early stages of concept development (i.e. up to TRL2) and therefore completion of the full cost / benefit analysis will form a key part of the future deliverable D2.8.

5 Control Process Analysis

This section describes the research into new principles for S&C control and monitoring to allow for self-adjustment of S&C tolerances within a system of adaptive control.

5.1 Current switch machine operating principles

Switch machine design has changed little in recent decades. Some designs in service today are over 50 years old. The control system consists of push-rods attached to the switch rails opening and closing electrical contacts.

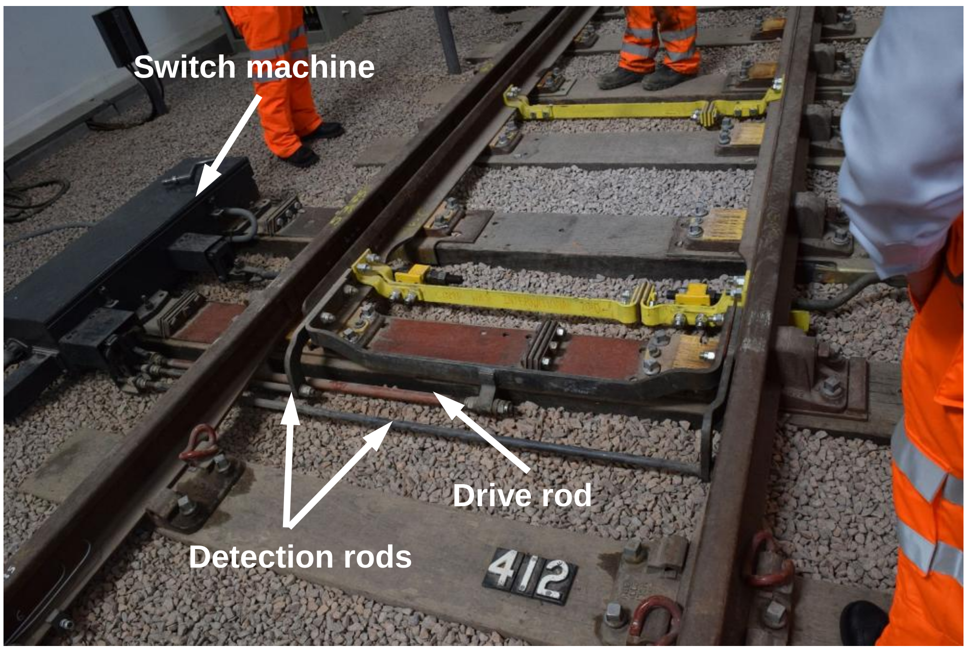


Figure 5.1: Current Point Operating Equipment

The drive, lock and detection mechanisms are housed within the switch machine on the left of Figure 5.1. When commanded to move, the motor starts. Through a cam mechanism, the lock is withdrawn; the drive rod moves the switch blades and the lock is inserted in the new position. Motor power is cut off when the switch blades AND the lock are detected in the correct position. If the correct position is not achieved, the power supply is cut-off after 7 seconds to prevent possible motor damage. The system is set up through careful adjustment of the drive and detection rods so that the switch blades are moved to the correct position and the closed switch blade can only be detected as closed when the gap between switch and stock rail is within 3mm.

In the UK, the check (and if necessary adjustment) of the system is required every 12 weeks and represents a significant maintenance burden.

More recently, the UK developed HPSS has taken this open loop control a little further. The motor drives a ball screw to move the switch blades to the new position. The motor is driven until it stalls (*i.e.* is mechanically baulked as the switch rails close). The switch rail position is detected by LVDTs at the switch toe and backdrive. If the switch rails are seen to be within a pre-set range when the motor stalls, the switch is considered to be in the correct position. That pre-set range is set for each switch installation during an inspection and adjustment check every 12 weeks. The process is given in Appendix A. From this it can be seen that the control of track switches is quite primitive in its reliance on simply logic, binary drive signals and 'three state' measurements. This is contrary to the developments and adoption of advanced control engineering systems in other transport sectors such as aerospace and automotive. Indeed in these sectors designs are not thought of as mechanical or electronic, but mechatronic, where advanced functions and condition monitoring can only be generated by including the control system design as part of the package from the outset, not as an enabling technology for a fixed mechanical design as has been implemented to date on track switches. Thinking in this way can lead to much more robust and functional designs.

The HPSS switch (although specific to the UK) represents a track switch system that is closest to a design that incorporated these concepts, as such it will be used (in modelling form and with collected data) to demonstrate how control engineering can be used to improve the functionality of established design. But any results should be seen in the context as outlined above and the true benefits of control will only be realised with a bespoke 'designed for control' track switch. The following sections cover the basic principles of control engineering and how this will be applied to the HPSS switch in the modelling environment.

5.2 Basic Principles of Control Systems

5.2.1 Motivation

If we are to introduce self-inspecting / self-adjusting capability to existing S&C, we must accept that there is a need to take measurements (continuous in nature rather than the absolute sensing usually employed on track switching), and then to take action should those measurements differ from the ideal situation. The system needed to be put in place would:

- Interface with the sensors that take those measurements (link to In2Rail WP2 Tasks 2.1 and 2.2);
- Compare those measurements to an ideal situation (currently those identified within existing standards, although advance, closed-loop control of track switches may enable existing standards, tolerances and limits to be challenged);

- Report any difference between the measured and ideal;
- Make adjustments to drive the measured situation towards the ideal.

Once such a system is in place, additional benefits can be introduced:

- Redundancy: Introduction of multiple sensors, actuators, drive mechanisms, etc. to allow continued operation in the case of single mode failure;
- Condition Monitoring: Examining the measured parameters for unusual trends, or differences between similar equipment, in order to detect problems before they progress to failure.

The HPSS switch is different in this context (as stated above) that it is equipped with LVDT measurement devices so that a relative measurement of the switch rail measurement to the stock rail can be taken. Currently though this measurement is used in system alignment and used in a very limited way during operation. Adding additional LVDT sensing would allow significantly improved operation that can self-adjust for operating temperatures and self-alignment. The processing for this would require a computational device beyond the robust but simplistic data logger devices now employed. The precedent for performing this kind of computation was set by the solid state interlocking signalling systems now widely employed where multiple channel computation is used to virtually eliminate the risk of failure from the controller.

5.2.2 Basic Control Systems Design

5.2.2.1 Open Loop

The simplest form of control is defined as "open loop" and is essentially how the majority of track switches are controlled. It has a command or required situation, a controller that converts that requirement to an input to the system. The system then responds and there is an output, which, if the controller is functioning well should correspond to the command.

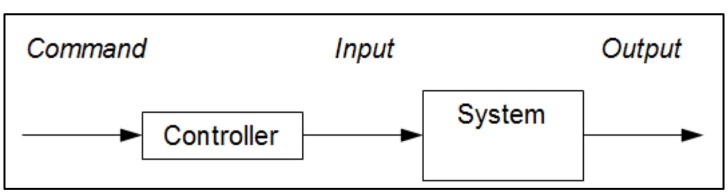


Figure 5.2: Simple Control - Open Loop

An example from the automotive sector would a cars speed (or 'cruise') control. The command is the speed required (i.e. 100 kph). The controller takes this command and converts it to an input to the system (in this case a throttle angle). This may be achieved using a lookup table of throttle angle for a given speed as defined by experiment during development. With the throttle set to an angle known to correspond to 100 kph, then the car accelerates to 100 kph.

One problem with open loop control is that it is susceptible to *disturbance* and *uncertainty*. Disturbance is an unknown or unmeasured from factor outside the system that can affect the output. Uncertainty is a factor within the system that can affect its operation.

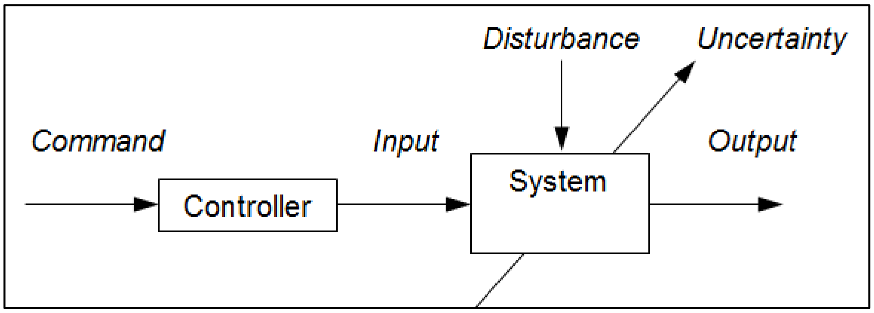


Figure 5.3: Open Loop showing disturbance and uncertainty

In the car example, when the car begins to descend a hill, a disturbance is introduced. The car may accelerate, despite the control system maintaining a constant throttle angle. The open loop control system is unable to take the effect of the disturbance into account when controlling the system.

Uncertainty is an unknown or unmeasured variation in parameters (and / or the structure of the dynamics) describing the system to be controlled. Returning to the car example, ageing of the transmission may increase friction, introducing uncertainty to the throttle angle required to maintain a given speed also what gear you are in. Again, the open loop control system is unable to take the effect of the uncertainty into account when controlling the system.

To date, the vast majority of point operating equipment installed has open loop control. The system is commanded to move; the position is detected, and passed to the signalling system. Any disturbance or uncertainty in the system can and may affect the output, i.e. the switch position. The control of critical positions in the system requires manual inspection and adjustment to maintain the required tolerances. The switch control system cannot directly quantify the gaps between switch blade and stock rail and must rely instead on driving until a limit switch is closed or the drive system stalls. This is similar to Open Loop control, although one could consider the manual intervention to be a slow feedback loop.

5.2.2.2 Closed Loop

In closed loop control, we aim to reduce the effect of disturbance and uncertainty by taking the output from the system, by taking the output as *feedback*, comparing it to the command to give an *error*. This error is then fed back into the controller and the controller aims to adjust the input to reduce the error to zero.

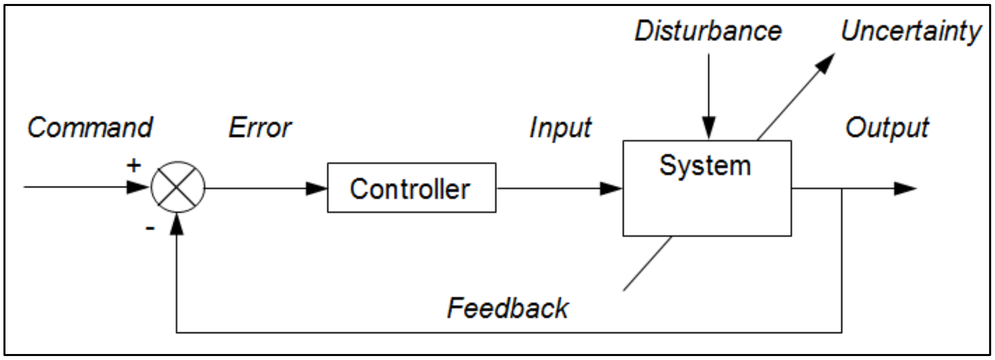


Figure 5.4: Closed Loop

In the case of the car, if the car slows down as it begins to climb a hill, the output speed, say 45 mph, and the command speed (50mph) will differ. The difference between the output and the command are used to create an error. The controller can increase the input (throttle angle) to increase speed and reduce the error towards zero.

The design aims for the controller are to ensure that the output follows or *tracks* the command as closely as possible, even in the event of disturbances or uncertainty. The controller reacts in a timely manner to *regulation*, i.e. a change in the command. Closed Loop control has the following benefits over Open Loop control:

- improved command tracking performance;
- disturbance rejection (such as unmeasured external loads);
- reduced sensitivity to system changes (parameter variations);
- unstable processes can be stabilized.

However, careful design is needed to ensure that the system is stable.

Whilst all existing track-switches are effectively open-loop, the Network Rail HPSS does have the capability to measure the position of the switch blades throughout their travel, however, that position is used only to confirm the switch blades are in the correct position once the motor stalls. There is the potential to close the loop in the control system by feeding back the switch rail position to allow the controller to adjust for disturbances and uncertainty. The 'disturbance' in this case is represented by: climatic conditions that will cause expansion and contraction of the components; wear of the components that will mean a variation in the switch movement size is required; and possible contamination blocking or slowing the movements of the system.

5.2.3 Outline Control System Design Process

In order to design a closed-loop control system, the first step is to understand the system (including the requirements) and develop a Design Model. This is usually a mathematical model of the system, including disturbances and uncertainty. Ideally, this model should be validated against engineering and/or test data.

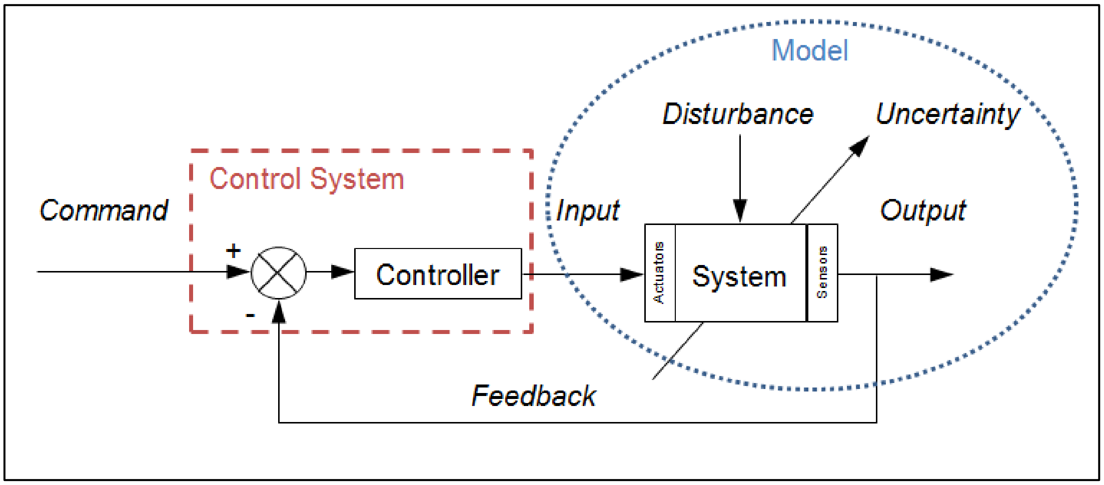


Figure 5.5: Control System Design Process

Analysis of the design model in the time and frequency domains provides data for the initial design of the controller. Assessment of the design is accomplished with reference to a number of key performance parameters (or performance requirements) as described below:

- Steady State Error – difference between command and output in a steady state, i.e. unchanging, situation;
- Rise time – time taken to for the response to move from 10% to 90% of the command following a step change in command;
- Settling time – time taken to become within 2% of the new steady state value following a step change;
- Overshoot – expressed as a percentage of the final value over the steady state value;
- Stability.

A final design will depend on the system requirements. From example, overshoot may not be acceptable, therefore the project may have to accept a slow rise time.

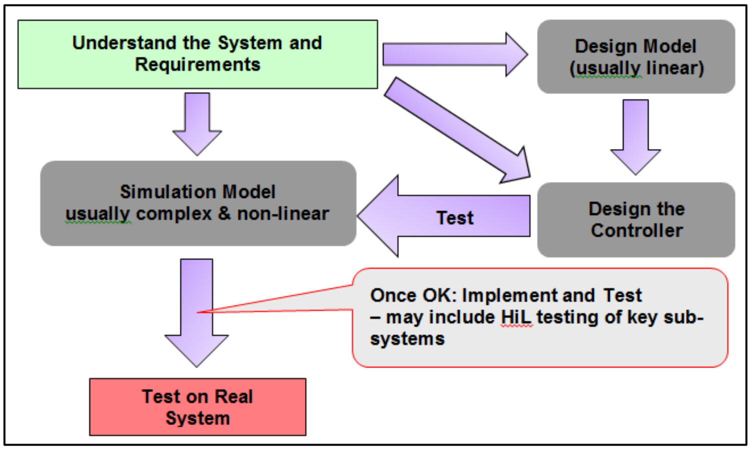


Figure 5.6: Example of Final Design

Once a suitable controller design is achieved, testing is undertaken using a (usually complex and non-linear) Simulation Model. Dependant on the application some Hardware in the Loop (HiL) testing of key sub-systems may be necessary before implementation on the real system.

5.2.3.1 Task 2.4 System Design Concept / Approach

For the work in this project a dynamic simulation model will be developed in order to test the efficacy of the proposed control schemes. The simulation model will be built in a suitable multi-body physics package (such as Simpack) that can be used to include all of the complex non-linear mechanics (track bending, rotational kinematics, discontinuities). This model will be validated against data that is collected from an operational HPSS switch (though it should be noted that at the low sample rates available it will not be possible to validate any of the high frequency dynamics present). A simplified control design model (or set of models at differing operating points if the HPSS exhibits strongly nonlinear behaviour) will be created (either from first principles physical modelling or using system identification from the MBS model data).The two stages of modelling will then determine the appropriate controller design method to apply (classical, modern, robust, adaptive, etc.) and the high level logic. This will be compared to the current functionality of the HPSS with open loop control.

5.2.4 Hardware Redundancy

Current S&C installations have no built in redundancy. Should any part of the mechanism fail, the system fails. And traffic must be stopped and a maintenance team attend the site before service can be restored. However, redundancy of sensing and actuation is used in many similar safety-critical applications in other industries and may be of benefit to S&C. There are a number of options to consider when determining which form of redundancy to apply.

5.2.4.1 Sensor Redundancy

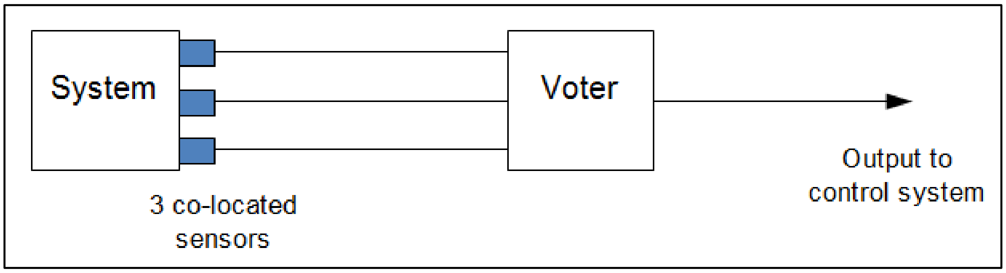


Figure 5.7: Hardware Redundancy

For measurement systems, Static Redundancy requires three or more sensors, see the schematic in Fig 5.6. To measure something a device is needed to convert the measurement into an electronic signal that represents the measurement this is usually called a sensor. Should the state of any one disagree with the other two, the voter disregards the sensor(s) in the minority. Three sensors allow one fault to be tolerated. In general, a voting system with n sensors can tolerate m faults, where m = n – 2.

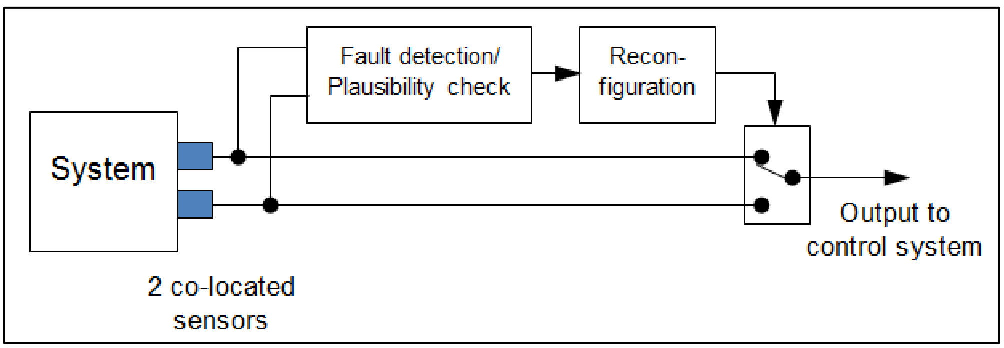


Figure 5.8: Dynamic Redundancy

For dynamic redundancy, it is possible to reduce the number of sensors to two, however, we need the capability to run some form of self-test or diagnostic, see Figure 5.8. Dynamic redundancy using 2 sensors allows 1 fault to be tolerated. In general a dynamic system with n sensors can tolerate m faults, where m = n -1.

A further step would be to introduce analytical redundancy, in which one sensor is used. In order to understand whether the sensor is functioning correctly, analysis of other available data is done in real time to check the plausibility of the output from that one sensor. The work of Grewal et al.[1] at Loughborough University has been published in this field.

5.2.4.2 Actuation Redundancy

Actuator redundancy functions in a similar manner. Using several actuators in a given situation will allow for continued operation despite the failure of any one. There are however some difficulties with redundant actuation. All of the actuators must be powerful enough to drive the system individually and back drive the failed actuator(s). For redundancy to work, a failed or jammed actuator must not be able to lock the system in position. Some of these points may require careful consideration if the system should be required to lock a switch in a given position or fail safe. Work on High Redundancy Actuation that may be applicable to this application has been undertaken at Loughborough University by Steffen et al. [2]

The models used for the controller design will be used as a test bed to explore these ideas.

5.3 Research S&C Control Principles and Monitoring Required

5.3.1 Relation between S&C and Interlocking systems

The scope of this section is to briefly describe existing interlocking systems and, more in details, their links with S&C to provide a state of the art analysis to be used for the further developments foreseen for this task. It must be noted that part of the information reported below could be also found inside the deliverable D2.3 “Embedded & integrated sensor: Systems design hierarchy report”.

5.3.1.1 Interlocking high level description

In the railway signalling sector, the computer-based interlocking is an arrangement of signal apparatus that prevents conflicting movements through a combination of tracks such as junctions or crossings. An interlocking is designed so that it is impossible to display a signal to proceed unless the route to be used is proven safe. The typical architecture of the Interlocking is characterized by:

1. A central post, which implements the safe management of the railway traffic;
2. A peripheral post, which manages the interface with the field devices. The peripheral post (CdE) equipped with a module that does not perform interlocking functions but:
    a. Dispatches the commands received from the central post to the field devices distributed in stations and along the lines;
    b. Collects the state of these devices and sends the extracted information to the central post.

Computer-based Interlocking is currently in use all around the world, including the most demanding High Speed networks on Main Lines and also in metros. Existing interlocking systems are mainly focused on safety/vital related information and, in some cases, could also manage non safety/non vital information which are in any case related to the diagnosis of the interlocking components.

The diagram below aims to visually describe how the interlocking system works and needs to interface with its respective automatic control system it.

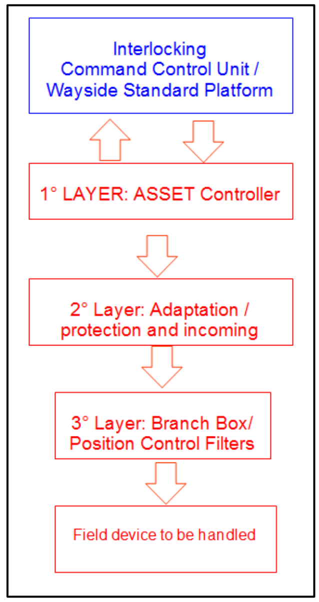


Figure 5.9: Simple Diagram Showing how interlocking system works

5.3.1.2 Link between interlocking and Switches

With an interlocking system it is possible to control the field devices (e.g.) railroad switch or Light Signal) through the CdE module that monitors the devices status and their availability. In particular, in relationship with the switches, the CdE module allows :

- Provision of the required power supply to the electric motor when it has to make the switch operation;
- Generation of and sending to the field device a FSK signal (square wave with 166Hz and 250Hz frequencies) used to detect the status of the switch between an operation and another one;
- Provision of galvanic isolation of the supply voltage from the outputs;
- Limitations of the output current in the case of faults;
- Provision of diagnostic information by visualising signals (LED) on the module and using the diagnostic tool;
- Measurement of the voltage and current absorption;
- Checking of the position control of the switch.

Meanwhile the CdE module provides the following information:

- the device's ID;

- the status of the switch operation i.e. whether it is in progress and the routing position (normal or reverse);
- if the switch is in control or not;
- Vital Errors: in case of vital errors the switch becomes unavailable because the fault involve an inside component of the CdE;
- Non-vital errors: In case of non–vital errors the fault is linked to external components not directly linked with the CdE.

In particular, the errors can be:

- operator errors;
- reversed cables;
- control loss;
- serial bus communication error;
- interior Warning;
- warning on communications.

5.3.1.3 Possible developments of Interlocking, linking with future self-inspecting/self-adjusting S&C

On the subject of possible future self-inspecting/adjusting switches it is considered beneficial from an Interlocking perspective, if these new switch designs are able to automatically detect and adjust at least some of the vital errors introduced above in a certified way. This solution will provide to the next generation of interlocking the possibility to automatically re-acquire the control of switches, after becoming unavailable due to the occurrence of vital-errors without having to wait for an intervention in the field by the maintenance teams. It must be noted that, taking into account all the possible different type of switches actually installed, it is difficult to identify a “standardised” list of vital-errors but the list below contains the most common/relevant parameters to be checked/adjusted to avoid vital errors:

- Switch points must be within 4 mm of tolerance;
- Lubrication status of the components;
- Electrical isolation of the switches
- Geometrical parameters (gauge, linear expansion etc).

5.4 Determine Safety and Performance Requirements

Work conducted at Loughborough University by Bemment et al. has drawn on industry Standards and requirements to derive a list of top level requirements for track switch systems. This splits the requirements into 4 broad categories:

1. Support vehicles and guide vehicles
2. Direct vehicles along the route set by the interlocking
3. Confirm the route to the interlocking
4. Communicate back to a maintenance organisation the future ability to perform requirements 1, 2 and 3.

Existing designs adequately provide for requirement categories 1, 2 and 3. More detailed requirements for these categories should be available from Infrastructure owners and managers.

Category 4 has some overlap with the requirement for self-inspecting/correcting/adjusting S&C.

Current S&C require significant inspection and adjustment intervention. In order to automate this process self-inspecting/correcting/adjusting S&C would, in the first instance, require instrumentation, and then the necessary actuation to make adjustments where necessary. For In2Rail purposes, additional sensing is considered outside the scope of Task 2.4.

The partners will work with an existing switch design to introduce an element for self-inspection/correction/adjustment. The majority of installed S&C operate using limit switches, and do not have the ability to log or report any data pertaining to the operation of the system. The High Performance Switch System (HPSS) can log data. It should be possible to remotely obtain position information from the LVDT and potentially motor voltages and currents. The HPSS (and other modern switch machines) currently has a setup/adjustment mode to set the reference/datum range for the normal and reverse switch positions. This process is currently done on-site by visually ensuring the switch is in the normal or reverse position and setting the reference positions to match. It may be necessary to retain some form of visual check of the switch position and integrity before setting the reference position. One solution would be to provide a camera system to allow that visual check to be performed remotely.

5.5 Specification for advanced switch control for self-adjustment

The partners propose to construct a multi-body physics model of an HPSS installation in SIMPACK. Ideally this would be a model of an installation for which operating data is available, to allow validation of the model. The current logic of the HPSS control system would be modelled in MATLAB/Simulink and linked to the SIMPACK model to give a baseline co-simulation environment.

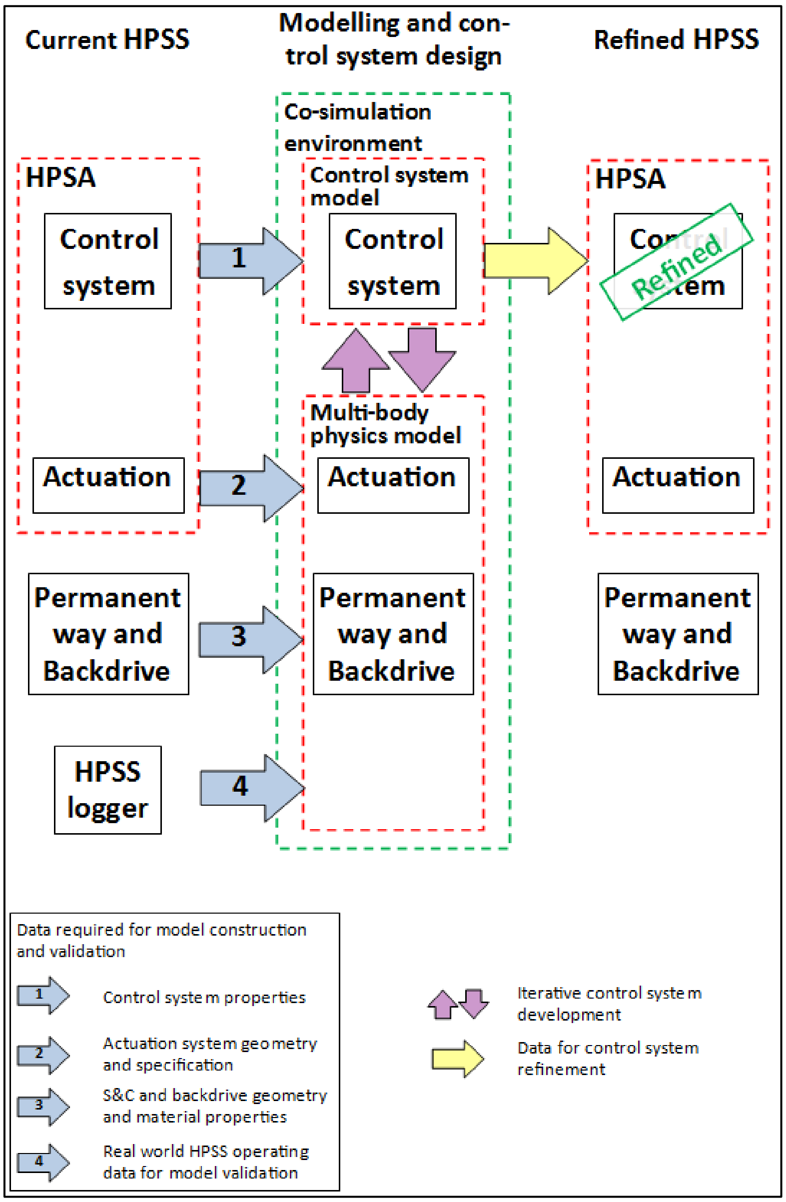


Figure 5.10: MATLAB/Simulink - SIMPAC co-simulation environment and data requirements

This co-simulation environment will be available to test modern/robust control methodologies, sensor concepts (in collaboration with partners working on task 2.2) and methods of calibration.

The possibilities for further exploration given such a model configuration may include:

- Prediction of friction in the system from the available switch position and motor current/voltage data;
- Modelling the effect of temperature and thermal expansion on the switch and whether/how this affects the detected switch blade position;
- Monitoring trends in the switch position at motor stall with the aim of predicting if/when the switch positon detection will fail;
- Comparing changes over time between the toe and mid-position LVDT outputs, with the aim of understanding whether geometry or back drive problems or excessive friction can be predicted.

Concepts will be benchmarked against the existing HPSS configuration, to demonstrate the improvement over a current state of the art system and quantify the available benefit.

5.6 Concept Evaluation

Work package 2.4 aims to deliver concepts for self-inspecting and self-correcting/adjusting S&C.

A case study of HPSS is taking place, whereby the existing design is modelled and validated against in-service data, to enable control system practice from other industries to be applied virtually, modelled, and evaluated in simulation. In the first instance this will allow an understanding of what can be achieved with the existing hardware, sensors etc., to reduce the maintenance/inspection burden by increasing automation in the inspection process. Building on this foundation, further steps will be to model improvements that can be made by incremental (rather than revolutionary) changes to existing design. Architecturally, redundancy (in the form of extra sensors) could be modelled to understand the influence on reliability. Possibilities for additional sensing that may be required to introduce self-inspection can be explored through modelling in conjunction with the work in Task 2.1 and Task 2.2.

The process going forward:

a) Modell the HPSS;
b) Validate the model;
c) Define a series of scenarios to support a cost / benefit analysis (see section 4.3);
d) Apply current HPSS (open-loop) control;
e) Apply closed-loop control;
f) Compare 4 and 5 during the test defined by 3.

Concerning item c) above, consideration has already been given to the potential test scenarios to be used during the final cost / benefit analysis. These will almost certainly include stock and switch rail wear, track gauge variation, switch rail obstruction and degraded track sub-grade scenarios. However, these cannot be fully defined until the HPSS switch co-simulation model has been fully validated against 'live' asset data. This exercise will inform Task 2.4 on how the co-simulation model can be used to simulate and predict the overall system performance of the 'enhanced' HPSS case study.

6 Analyse other Technology Sectors

6.1 Hardware in the Loop Testing

Hardware in the loop testing is a process whereby components, sub-systems and systems can be tested in a simulated environment without the need to have the complete system or product available for test.

Figure 6.1 uses a vehicle analogy. In order to test a completed engine control unit (ECU), we can connect the complete ECU to a test system designed to simulate the inputs from sensors etc. and to run a test cycle under a variety of conditions. It is safe to test the ECU under various failure conditions as there is no risk to a complete vehicle. Taking this one step further, a complete engine test brings in the engine hardware, controlled by the ECU. The engine test facility provides a resistance designed to simulate typical use. Again tests can be performed that it may not be safe or financially viable to perform on the complete vehicle.

As hardware maturity improves, then a more complete vehicle is tested and the simulation element is reduced, to the point where we reach full product test.

A track switch example may involve testing a point motor while applying a load to the output lever. That load would be calculated to represent the load required to overcome friction and operate the points. If we need to understand the interaction of the point machine with the interlocking and signalling systems, these could be simulated and connected to the point machine under test.

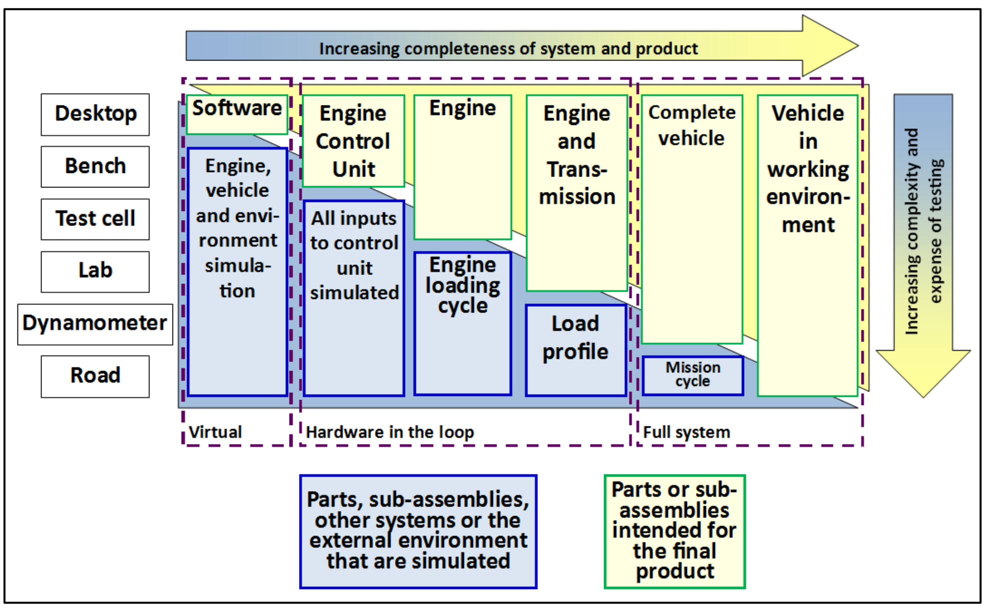


Figure 6.1: Vehicle Analogy

6.2 Landing Gear extension/retraction control for large civil aircraft

Similarities between aircraft landing gear extension/retraction control with railway track switching include:

- Bi-position system;
- Safety critical;
- Heavy actuation;
- High integrity outputs to interfacing systems;
- Environmental Factors.

Control is provided by Boolean logic written on Field Programmable Gate Arrays (FPGA). There are 2 identical control units, with independent power supplies for redundancy. Each unit is capable of controlling the system. Control is switched between the control units once per cycle. The monitoring part of the control unit is implemented in software. This cross checks inputs and outputs and interfaces with other systems. It does not provide any control function, however it can disable the outputs should it detect a problem with the sensors or control logic. All sensors are duplicated and cross checked. Wiring continuity is monitored.

Hydraulic power is provided by one system, however that system has multiple pumps. At the actuation level there is only 1 actuator and selector valve per function. However, there is an emergency backup system to mechanically release the uplocks and allow the landing gear to extend under gravity and lock down with the assistance of springs.

For a rail or track switching application, the redundancy and integrity at the sensing and control level of this aerospace application would seem a good match for the reliability and redundancy targets for track switching. The actuation architecture may be insufficient for a rail application where redundancy of actuation would be desirable.

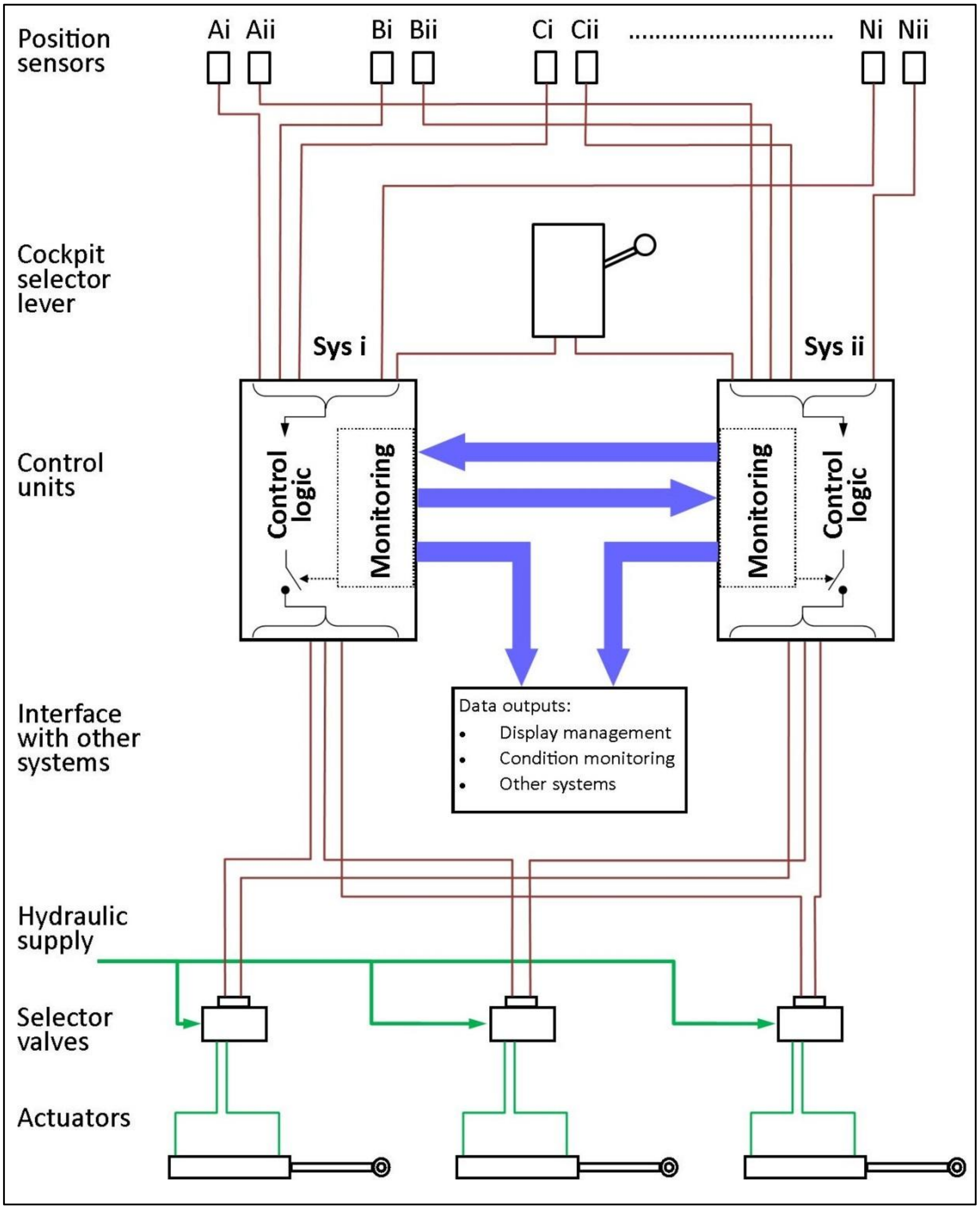


Figure 6.2: Landing Gear Extension/Retraction

7 Conclusions

This report has investigated the basic principles of control systems and how these can be taken forward to solve the following areas:

- Reduce or Eliminate the amount of manual maintenance required to adjust switches;
- Reduce or Eliminate the amount of manual intervention before or after a switch has failed.

The work has confirmed the potential to develop a system that will have a significate positive impact on work force safety, by reducing the need for manual inspection and adjustment.

The potential benefit of this has been calculated as EUR 11,188149.24 per year for Network Rail and EUR 2.3 million per year for Trafikverket. There is a difference in savings between Network Rail and Trafikverket, and this is due to more data being available to work out savings in Network Rail.

The next stage of the task is to gather the data from LVDT sensors to enable further modelling/ analysis to be performed specifically by Loughborough, Huddersfield and Southampton Universities. After this is done, control can be implanted leading to looking into what other sensors could be used.

8 References

1. Grewal, K.S., Dixon, R. and Pearson, J., 2011. Model-based Fault Detection and Isolation applied to a Pneumatic Actuation System. International Journal of Condition Monitoring and Diagnostic Engineering Management, 14(4), p.40.
2. Steffen, T., Schiller, F., Blum, M. and Dixon, R., 2013. Analysing the reliability of actuation elements in series and parallel configurations for high-redundancy actuation. International Journal of Systems Science, 44(8), pp.1504-1521.
3. Bemment, S.D., Ebinger, E., Goodall, R.M., Ward, C.P. and Dixon, R., 2016. Rethinking rail track switches for fault tolerance and enhanced performance. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, p.0954409716645630.
4. Network Rail's Standard - NR/L3/SIG/10663 Signal Maintenance Specifications, NR/SMS/Part/B, NR/SMS/Test/001
5. Network Rail's Standard - NR/L3/SIG/10663 Signal Maintenance Specifications, NR/SMS/Part/B, NR/SMS/Test/004
6. Network Rail – NSC-IAD(2016) – High Performance Switch System

9 Appendix A – HPLL FPL Inspection

NR/L3/SIG/10663 Signal Maintenance Specifications		
NR/SMS/Test/004		
Facing Point Lock Test (HPSS)		
Issue No: 06	Issue Date: 06/09/2014	Compliance Date: 07/03/2015

General

Ask the signaller to operate the points to ensure the correct points are being tested and thus eliminate confusion or doubt.
You shall come to an understanding with the signaller to apply a safe system whilst undertaking the FPL test.
This FPL test is carried out with the machine under power, controlled by the signaller. To avoid injury whilst placing and removing gauges, it is recommended that you use the Hands-Free gauges (ask your SM(S) or hold the gauges with a pair of pliers or mole-grips. A safe method of communicating with the signaller shall be arranged.

Important
Detection is confirmed by referring to the meter connected to the KR circuit at the location/disconnection box. The HPSA Handset is not used to confirm detection as it is powered from a port on the ECU separate to the outgoing detection circuitry. It is **essential** to confirm that detection is made and broken by referring to the meter only.

The secondary (supplementary) detection tests confirm the Rail Position Sensors shall not give detection when an obstruction is placed between the stock and switch rail, even though the rail bends around the obstruction.

This test requires a

- Voltmeter, HPSA Handset (and passwords for old variants of Psion Handset)
- Two 3.5mm point checking gauges. (Hands-free FPL Gauge recommended)
- Two 8 mm (CEN 54) or two 10mm (NR60 / RT60)

Before carrying out the test, connect the HPSA Handset and Check that each closed switch position is showing 0mm. If the value is outside the limits -0.1mm to +0.5mm (primary / toe sensors) and/or –1mm to +2mm (secondary / supplementary sensors), this could indicate that the system is not securely fixed and it could impact performance. Before and after values shall be recorded onto the NR/SMS FPL record card so that any movement between maintenance visits will be recorded. If any excess movement is recorded, it shall be investigated and be reported as corrective maintenance.

1. TEST

1.1 Connect the meter to the outgoing KR circuit at the location/disconnection box.

1.2 Perform a Datum Reset as detailed in NR/SMS/PC51 Appendix A.

1.3 Check that the correct voltage is present on the outgoing KR circuit for the points being tested.

1.4 Place the 3.5mm gauge between the open switch and stock rails at a point in line with the centre-line of the switch rail drive bracket.
Hands-Free FPL Gauge recommended.
The gauge shall be adequately inserted to prevent the switch rail from bending under the gauge and making detection.

1.5 Ask the signaller to operate the points and ask what detection, if any, is given.

1.6 Check that no voltage is present on the outgoing KR circuit, by referring to the meter.

1.7 Place another 3.5mm gauge between the open switch and stock rails at a point in line with the centre-line of the switch rail drive bracket.
Hands-Free FPL Gauge recommended.

1.8 Ask the signaller to operate the points and ask what detection, if any, is given.

1.9 *Check* that no voltage is present on the outgoing KR circuit, by referring to the meter.

1.10 Remove both gauges (operation of points is required).

1.11 Operate points under power and using the HPSA Handset, *Check* that each supplementary position shows 0+/- 0.5mm at the closed position, *Check* that any residual switch opening at the closed side is less than 2mm at the supplementary detection positions.

1.12 At the rear most pair of supplementary detection sensors place an 8 mm (CEN 54) or 10mm (NR60 / RT60) gauge between the open switch and stock rail at a point in line with the centre line of the switch rail drive bracket, power operate the points to close the open switch rail. It is strongly recommended that the Hands Free Detection Gauge is used (placed on the stock rail), to avoid injury.

The purpose of this test is to confirm that the correct number of supplementary sensors have been selected during the datum reset procedure. Therefore the testing of the supplementary detection sensor is only required to be completed with the points in either the normal or reverse position.

1.13 Check that no voltage is present on the outgoing KR circuit, by referring to the meter.
If voltage is present on the outgoing KR circuit:
Check that any residual switch opening at the closed side is less than 2mm at the supplementary detection positions.
Check on the HPSA Handset that the correct number of supplementary sensors have been commissioned during the datum reset procedure.

1.14 Remove all gauges (requires operation of Points)

1.15 Observe correct operation of the points to the normal and reverse position.
The time taken should be nominally 4 seconds.
If the time taken is greater than 5 seconds, make arrangements to carry out further investigation.

1.16 Record all sensor readings (open and closed positions) from the HPSA Handset, and any adjustments that have been carried out, on the NR/SMS FPL record card.

End