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Deliverable D2.1

Development of Novel S&C Motion/Locking Mechanisms: Design Concept Report [TRL3]

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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
Option selection criteria are needed to demonstrate the link between the State of the Art (SoA) and the proposed solutions, including the assessment of root of causes of current faults (not clearly examined in Ch.5).	<p>Section 5 – Discusses POE failures broken down to component level</p> <p>Section 5.3 – Consideration of other known root causes of POE failure for use during solution concept development</p> <p>Section 6 – Switch flexure study demonstrating other root causes of failure linked to whole system performance</p> <p>Section 10 – Option selection criteria and process for how novel concepts will be assessed against existing state-of-the-art POE systems.</p> <p>Section 11 – Study of other industry technologies and proposed solutions under consideration for further detailed design (D2.2)</p>
The SoA in S&C actuators is very focused on UK data (Ch.3); need to consider the wider European systems and context, while focusing on the common aspects among the different systems.	<p>Section 3.3 – Whole new section added to identify a comprehensive database of all European POE systems.</p> <p>Appendix B – Contains the key parameters of 86 additional POE systems from around Europe.</p>
The report conclusions include only two final solutions, one of which appears to contradict the principle of independency between the locking system and the actuator (also listed in Appendix C req.0013). Additional alternative solutions should be explored / presented.	<p>Section 12.2 – Identifies that the concepts presented within D2.1 are only an initial set of ideas. Further concepts are being developed and will be reported and ranked within D2.2 for recommendations to Shift2Rail</p> <p>Section 12.2.2 – Discussed in more details the comparison of the screwlock concept with the requirements set out within Appendix C.</p>
Existing knowledge (Ch.4) also includes two ongoing studies (Repoint and Autochoc), which should not be taken as existing knowledge as they are still at feasibility stage and involve a much more significant and revolutionary design concept than only the actuators.	Section 4.2 – Section restructured to indicate that the inclusion of Repoint and Autochoc is purely for background information. It has been recognised that these are technologies are still at feasibility stage and that learning from these should be considered as 'technology development' and not state of the art.

Executive Summary

The aim of this deliverable is to explore the possibility for improving existing Switch and Crossing (S&C) Points Operating Equipment (POE) reliability and availability.

Chapter 2 discussed the 'V'-model approach taken within Task 2.1, which uses a systems engineering methodology for technology development. Task 2.1 within Work Package 2 (WP2) of In2Rail uses only the early stages of the 'V'-model to take the technology up to a Technology Readiness Level of 5. This deliverable has taken the project up to an estimated TRL of 3.

Examples of the type of S&C point operating equipment (POE) used in a number of countries across Europe are described in Chapter 3. The details of each systems method for actuation, locking and detection are discussed, indicating the different approaches taken by POE manufacturers in designing these subsystems.

Existing source of knowledge related to Task 2.1 have been identified within Chapter 4 and were considered during the development of subsequent chapters.

S&C failure data within Chapter 5 has identified that the switch system is vulnerable to single component and sub-system failures due to a lack of redundancy. Increasing switch lengths and complexity have also been seen to reduce the Mean Time Between Service Affecting Failures for all POE types, and hence contribute significantly to a reduction in asset reliability and availability.

Multiple POE failures are attributed to 'Out of Adjustment' faults, indicating that the POE system may also be suffering from degraded whole-system conditions. Any new designs of POE equipment emanating from In2Rail must therefore take careful consideration of operating under degraded track conditions.

Chapter 5 concludes with a financial assessment of annual POE failures to give an indication of the opportunity available within Task 2.1. Elimination of POE service affecting failures has the potential of saving of 37,007,553.77 € per year in delay costs and 3,666,880.80 € per year in maintenance costs within the UK alone. This analysis will be expanded to include other EU Infrastructure Manager failure and associated cost data.

Following the analysis of existing POE knowledge and common failure mechanisms, Chapter 7 provides a summary of how the scope of work to be undertaken within Task 2.1 has been refined. A review of existing tolerance and limits was also completed to help support the development of future design concepts and subsequent detailed design assessments. EN 13232 for railway switch applications was reviewed and tabulated within Review of EN 13232.

An industrial review of switch kinematic principles was undertaken within Chapter 8 and highlighted the importance of maintaining continuous contact between the closed switch rail and the stock rail to reduce switch rail dynamic movement and lateral forces experienced by the switch. Accurate assembly of stretcher bars is also required to avoid any unnecessary residual loads being stored within the switch system and possible incorrect positioning of the switch rails. The review also discussed that in-service damage, such as lipping, to the switch and stock rails needs to be considered within the tolerances for new POE designs and associated maintenance requirements. Correctly locating the switch rail to ensure adequate minimum flangeways and avoid excessive flange back contact was also stressed and must be considered within any new concept emanating from In2Rail Task 2.1. Finally, the industrial review discussed the importance of obstruction detectability within the switch detection system to enable the POE system to communicate potentially unsafe conditions to the signalling system. Recommendations for pursuing the concept of redundancy within the POE system were made.

A further academic assessment of wheelset kinematic through railway switches has concluded that the residual switch opening should be a maximum of 3 mm if interference contact between wheel and switch rail is to be avoided. If this requirement is to be challenged, the wear tolerance limits for wheel profiles, and hence the requirements on the wheel profiles that are allowed to pass, must be questioned.

Chapter 9 took the concept of redundantly designed engineering systems and presented a range of possible solutions that could be applied and adopted within and / or alongside existing switch POE systems. Multiple options exist for improving the fault tolerance and redundancy of existing POE systems, which will all be considered for implementation as more conceptual designs come to fruition.

Chapter 10 took everything learnt from the previous chapters and combined them into a condensed set of system requirements for informing the both the idea generation and conceptual design stages of the project. Functional and non-functional requirements have been set and will be used for comparing the suitability of a range of concepts for further work.

The OptiKrea process for ideas generation was used and is summarised within Chapter 11 along with a categorised list containing the outcome of the ideas workshop. Some preliminary conceptual designs, including a concept for a 'Model Based Estimator' and a 'ScrewLock' design, have made early developments and are presented within Chapter 12.

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Abbreviations and acronyms

Abbreviation / Acronyms	Description
POE	Points Operating Equipment
S&C	Switch and Crossing
RPCL	Rail Point Clamp Lock
IBCL	In-Bearer Clamp Lock
BoD	Break out Device
SO	Switch Operator
UIC	International union of Railways
FBC	Flange-Back Contact
FMEA	Failure Mode and Effects Analysis
MGT	Million Gross Tonnes
UIC60	European Rail Section
AC	Alternating Current
DC	Direct Current
HPSS	High Performance Switch System
CEN54B	UK Rail Section
HPSA	High Performance Switch Actuator
GENSIS	Vehicle Dynamics Software
ECU	Electrical Control Unit
LVDT	Linear Variable Differential Transformer
HW	Brand of Points Machine
R&D	Research & Development
RSSB	Rail Safety and Standards Board
EPSRC	Engineering and Physical Sciences Research Council
GCR	Great Central Railway
MTBSAF	Mean Time Between Service Affecting Failure
SIMPACK	Vehicle Dynamics Software
EBHA	Electric Backup Hydraulic Actuator
RBD	Reliability Block Diagram
TRL	Technology Rediness Level

1. Background

The present document constitutes the second issue of Deliverable D2.1 “Development of novel S&C motion mechanisms: design concept report” in the framework of the Project titled “Innovative Intelligent Rail” (Project Acronym: In2Rail; Grant Agreement No 635900).

It is commonly agreed across European Railway Infrastructure Managers that Points Operating Equipment (POE), used for Actuating, Locking and Detecting the movement and final position of the switch rail, suffer from poor reliability due to their evolution from mechanical hand points. Existing POE systems have not been designed with sufficient redundancy (if any) to enable the switch system to continue operating should part of the POE system fail. A large proportion of service affecting failures are attributed to the common ‘Points Failure’, which in turn account for a significant number of delay minutes and associated costs to the industry.

In2Rail WP2 Task 2.1 focussing on investigating this issue through the development of novel switch locking mechanisms in order to achieve a step change in POE reliability and availability.

Deliverable D2.1 provides a detailed review of the issue surrounding POE reliability and explores possible solutions to be progressed within the In2Rail project and for further recommendation for detailed design within Shift2Rail.

2. Objectives / Approach

The overall objective of In2Rail Work Package 2 is to explore solutions that will enable a step change in performance of railways switches and crossings. Task 2.1 focusses on solutions for enhancing the existing switch system whilst embracing ‘state of the art’ technologies. This chapter will describe the general approach adopted (Section 2.1) and the overall objectives related to Deliverable D2.1 (Section 2.2).

2.1. Approach

Within In2Rail WP2, Task 2.1, a systems engineering approach has been adopted for systematically tackling the problem statement from ‘Planning’ right through to ‘Operation & Maintenance’. The ‘V’ Systems Engineering Model has been implemented, which is illustrated within Figure 2.1:

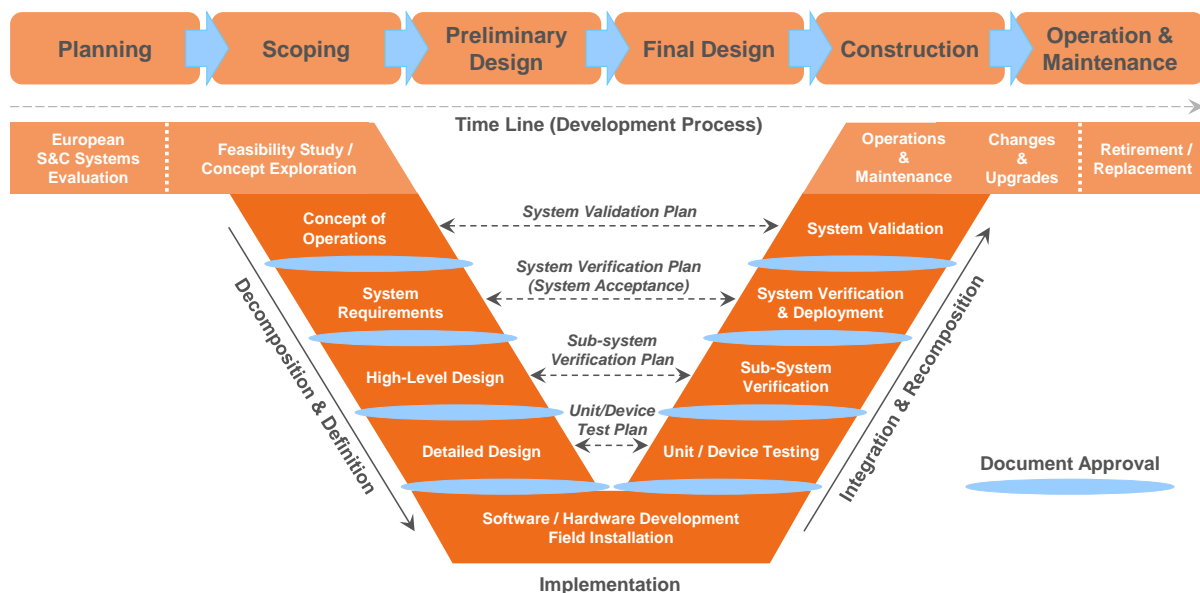


Figure 2.1: Systems Engineering Approach (V-model)

The overall aspiration for Task 2.1 within In2Rail is to achieve a Technology Readiness Level of 5 (TRL5), which requires the developing technology to be validated within a relevant environment. This early stage deliverable takes the process up to the ‘Feasibility Study / Concept Exploration’ phase of the ‘V’-Model.

Chapters 3 to 7 constitute the first phase of the ‘V’-Model by providing a summary of existing points operating equipment in use within Europe, investigating failure statistics to assess POE reliability and the size of the opportunity and finally refining the scope of work to focus effort within Task 2.1.

Chapter 8 moves on to evaluate the kinematic principles of railway switches from both an academic (opportunities) and industrial (existing situation) perspectives.

The 'Feasibility Study' aspect of the 'V'-Model begins to take shape within Chapter 9 by evaluating the opportunity of bringing redundancy to existing POE sub-systems (actuation, lock and detection) for enhancing whole-system reliability and availability.

Chapter 10 expands upon the background research from previous chapters to establish a key set of high-level requirements for the novel switch locking mechanism. These requirements are then used within Chapter 11, which describes the process steps taken during the initial idea generation process.

Deliverable D2.1 concludes at the onset of the 'Concept Exploration' stage of the 'V'-model by using both the high-level system requirements and the description of the ideas generated to begin drawing up preliminary conceptual designs, which are presented within Chapter 12.

2.2. Deliverable Objectives

It is commonly agreed between each European Infrastructure Manager that the existing Points Operating Equipment (POE) suffers from a lack of redundancy within each of its major functions. A single failure occurring within the actuation, locking or detection systems will often result in whole system failure and, consequently, severe impact upon network and train performance.

The high-level objective for WP2, Task 2.1 is to investigate the benefits and feasibility of implementing a novel switch locking and detection mechanism onto existing switches with the aspiration of improving reliability, availability and resilience of existing EU switch designs.

A further objective of this report is to quantify the issue in terms of current POE failure modes and associated costs.

The specific objectives of this deliverable include:

1. Identify the main types of POE used across European rail networks;
2. Analyse up-to-date failure data to better understand the causes of failure;
3. Introduce the concept of redundancy to existing switch / POE systems for improved reliability and availability;
4. Establish fundamental S&C principles (both industrial and academic) to aid specification development;
5. Establish a high-level specification to allow innovation and creativity during conceptualisation of ideas;
6. Introduce the ideas generation process and summarise the outcome;
7. Present initial conceptual development.

3. European Points Operating Equipment (POE)

Rail switches, points or turnouts are a crucial element of any track network, being incorporated for use on the railways and trams across the world. Generally used to direct a carriage from one track to another, the mechanical aspect of the railroad switch has remained virtually unchanged since being patented in 1832. However operation and control of switches through the use of different types of point operating equipment (POE) has developed throughout the years.

Points Operating Equipment (POE) comprises the system that connects to and operates (moves) the switch rails to provide route setting for oncoming vehicles. In general, POE systems operate with three primary functions:

- Actuation;
- Locking;
- Detection.

Actuation provides the mechanical drive to move the switch rail from one position to another, the locking mechanism ensures that the switch rail is maintained in its final position upon successful actuation and the detection system provides confirmation, to the signalling system, that the switch position is safe for the passage of rail vehicles.

The main categories of POE are external or in-bearer, coupled or uncoupled, and multiple or single machine (with optional supplementary drive).

External point equipment consists of a box containing actuator, plus optionally locking and detection, mounted on extended bearers or a trackside frame fixed to the bearers and delivering movement via rods which occupy the space between bearers.

Often the rods occupy the space required for ballast, and this can lead to degraded and unmaintainable track support. This has prompted the development of in-bearer point equipment. While some external machines have been adapted for bearer mounting to protect the rods, others have been specially developed for the purpose.

Coupled switches have stretcher bars connecting the switch rail pair so they move simultaneously. Uncoupled switches instead move the rails in a sequence whereby the open switch rail partially closes, both rails then move together until the switch fully closes and finally the opposite switch fully opens. These machines can lock with the capability for unlocking in the event of run-through.

A single machine is adequate for shorter switches if it enables sufficient switch opening for free wheel passage. If not, then either multiple actuators or a supplementary subsystem is needed.

Supplementary subsystems may be via mechanical linkages and cranks connected directly to the point machine (delivering full available stroke and thrust) or indirectly via switch rail attachment (as used presently in the UK). There are variations, for example single-acting linkages (which behave significantly differently in normal and reverse, ie tension versus compression), double-acting linkages (in which force and stroke delivery is always operate in tension), and torsion linkages (which behave identically in both directions but there is a limit on switch length).

3.1. Network Rail (UK) Points Operating Equipment

There are approximately 20 different types of POE systems in use on the UK rail network. The methods of operating the points vary and can be categorised as:

- Mechanical – Using levers, cranks and rods;
- Electro-Pneumatic – Use of an electrically controlled pneumatic actuator;
- Electric Machines – Incorporates an electric motor, gear trains, cams and cranks;
- Electro-Hydraulic Machines - Electric pump generates pressure to hydraulic actuators;
- In-Bearer Electric Machines – Electric mechanisms within the bearer/sleeper;
- In-Bearer Hydraulic Machines – Hydraulic mechanisms within the bearer/sleeper.

3.1.1 Rail Point Clamp Lock (Electro-Hydraulic Machine)

The clamp lock system is designed to lock and detect a pair of coupled point switch rails using hydraulic actuators to move the switch rail. The 'clamp lock' mechanism is made up of two parts, a lock and detector assembly attached to the stock rail and a switch rail bracket assembly attached to the switch rail. The lock & detector assembly incorporates a driving lock slide and electrical detection components. The switch bracket assembly carries a lock arm, detector blades and packing used for adjustment of the lock.

3.1.1.1 Actuation, Locking & Detection

Two hydraulic actuators, mounted back to back in the centre of the 4 foot between two adjacent bearers, are used to move the switches (see Figure 3.1). The extending and retracting hydraulic actuators are used push a drive lock slide across, these moves the points into position. Hydraulic fluid is pumped into the retracted actuator, which drives motion towards the neighbouring switch rail causing the adjacent extended actuator to retract. From one end as the drive lock assembly slides, the lock arm drops into its respective slot, disengaging the switch rail from the stock rail. At the other end, the lock arm raises and engages the other lock arm piece to the stock rail, ensuring that the switch rail is securely locked (Facing Point Lock (FPL)).



Figure 3.1: Rail Point Clamp Lock photograph

The clamp lock allows the switch rails to move independently of each other; therefore a stretcher bar is used to ensure that the correct gauge is maintained between the two switches. A single motor power pack is used to power the system. Figure 3.2, below, illustrates the left switch rail fixed against the stock rail with the lock arm raised and locked into position and the right lock arm disengaged. The sequence is repeated when setting the switches to the opposite direction.

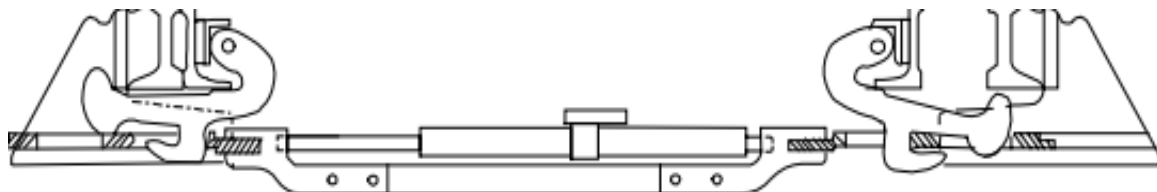


Figure 3.2: Rail Point Clamp Lock diagram showing locking mechanism

The electrical detection system used with the clamp lock detects the position of both the closed and open switch rails, as well as the condition of the lock slide. The system only recognises a complete circuit once both switch rails are correctly positioned with the lock arm securely engaged. Each clamp lock contains two plunger type limit switches, two spring loaded cam followers used to follow the cam profile, one adjustable linear cam fixed to the detector blade and a fixed linear cam attached to the drive lock slide.

3.1.1.2 Key Attributes - RPCL

There are various types of lock and detector mechanisms fitted within the clamp lock, known as Mk I & Mk II:

- Rail Point Clamp Lock Mk I: Body assembly is fabricated from steel plates;
- Rail Point Clamp Lock Mk II: Uses a cast steel body and provides a force-down mechanism if the lock arm fails to release during movement, along with several other subtle modifications to improve the locking and fixture to the rail;
- In-Bearer Clamp Lock (IBCL): The clamp lock system is mounted within a hollow steel bearer. Modern installations utilise the in-bearer clamp lock, as it offers added protection, minimising exposure to trackside contaminants. This layout is designed to be fully tamped;
- Both open and closed switches are held independently without the need for a stretcher bar.

3.1.2 Hy-Drive (Electro-Hydraulic Machine)

This type of POE utilises the Mk II clamp locks mounted within hollow bearers (IBCL) and an Alstom Switch Operator (SO) hydraulic supplementary drive system. A Hi-Flow Power pack is used to power the hydraulics. The complete system with all the above componentry is referred to as 'Hy-Drive'. Each Hy-Drive system contains a Hi-Flow power pack, SO unit(s), Break-out Devices (BoD's). The Hy-drive system is most commonly used for long switches on NR60 layouts. There are two variations of the Hy-Drive system using different actuator stroke plates (Mk1 & Mk2).

3.1.2.1 Actuation, Locking & Detection

The Hy-Drive operates with the Mk II lock and detector mechanisms used in clamp lock. The system employs SO Units which are used to drive the switch further down the rail by the use of hydraulic back-drives. The SO's contain hydraulic actuators for the switch's movement. The SO units also hold and detect the positions of the rail with the use of an internal slide, gear system and a rotary electrical switch within its assembly. The number of SO units depends on the type of switch, the drive positions and length of switch. A twin motor variant of the RPCL power pack is used as it has greater power flow rate for longer switches this is known as the Hy-Flow pack.

The Break-Out-Device (BoD) is the part of the switch bracket assembly for the SO Units and acts as the switch rail connection in order to uncouple the SO unit from the switches in the event of a run-through. It is designed to lock in the operated position (either in or out), such that detection shall fail on the next operation of the switch, then cannot be obtained until the BoD has been replaced. The operation of the BoD is shown in Figure 3.3.



Figure 3.3: Operation of the Break-Out-Device (BoD)

3.1.2.2 Key Attributes – Hy-Drive

- Hy-Drive Mk I: Design does not have roller base plates fitted;
- Hy-Drive Mk II: Design uses roller base plates installed on the bearer next to the actuation. Different combinations of actuator strokes are implemented for longer switches;
- Twin motor variant of RCPL Power Pack with removable handles;
- Alstom SO Units;
- Utilises IBCL design with hollow bearers and Mk II lock body castings.



Figure 3.4: Hy-Drive Mk I & Mk II

3.1.3 High Performance Switch System (HPSS)

The HPSS point machine is designed to accommodate different in-bearer depths, for CEN54B and CEN60 rail section types. Since bearers have been supplied from several different manufacturers, the HPSS system can cope with the ranges of dimension variation. It uses a High Performance Switch Actuator (HPSA) to operate the toe of the points. The back drive uses a torsional tube situated in the 4 foot, allowing easy tamping for the entire system panel. The HPSS is shown in Figure 3.5.



Figure 3.5: High Performance Switch System (HPSS)

3.1.3.1 Actuation, Locking & Detection

The HPSA, situated in hollow steel bearers, is powered and operated through an Electrical control unit (ECU) and interface cables. This commands, drives and monitors the HPSA. The ECU energises a duplex brake which releases the HPSA; it then energises a brushless 3 phase motor to drive the switch rails. A reduction gearbox and acme lead screw is used to transfer the rotary motion to linear. Once the switch rail has moved to the stock rail the motor stalls out; the ECU detects the stall out and reapplies the brakes; the motor is then turned off. The ECU monitors the position of the rail sections, controls safety relays and detects the connection feeds provided on the 10 core input cable.

Linear Variable Differential Transformer (LVDT) position sensors are used in the HPSS. They detect the position of the switch rail relative to the stock rail. Installed in pairs, sensors are positioned on the toe (toe sensors) and various other positions along the rail (supplementary sensors). This varies according to the length of the switch. Feedback from the LVDT is monitored by the ECU.

Most recent designs of back drive from 2004 onwards are called 'Power Link'. The high efficiency back drive is optimised to cater for different switch lengths. The drive uses high efficiency bearings and swinging links. This helps eliminate losses caused from backlash and gain maximum drive when the switch actuates.

3.1.3.2 Key Attributes - HPSS

- HPSA: Robust electro-mechanical in-sleeper point machine with built in condition monitoring;
- Torsional Back Drive: Supplementary drive system mounted in the four foot with in-sleeper stretcher bars and supplementary detectors;
- PowerLink Backdrive: Making it the most efficient in-bearer design in use. The PowerLink Backdrive is compulsory in all new designs;

- Can be found on CEN54 (113A)/CEN54 (UIC54), RT60 and NR60 types of S&C;
- Both open and closed switches are held independently without the need for a stretcher bar.

3.1.4 HW Point Machines

The HW point machines uses a throw bar & crank mechanism to actuate and drive the points. Consisting of an electric motor, reduction gear train set, clutch assembly, electric actuator, a snubbing device and locking & detection features to provide full compliant movement of the switches.



Figure 3.6: HW Points Machine photograph

3.1.4.1 Actuation, Lock and Detection

An electric motor is used to turn a cluster of reduction gears that drive an escapement crank. The motion from the crank is used to drive a throw bar which pushes/pulls the switch rails across. As seen in Figure 3.6 the motion from the motor drives a geared shaft to rotate a disk attached to the crank arm and initiate the point throw.

A characteristic that sets the HW series point machine apart from other types of POE system is its use of a mechanical clutch. If the points are obstructed the clutch is used to 'slip' to a predetermined load setting to avoid causing damage to the motor. Early systems such as HW 1000 series use a spring loaded dry plate clutch, but more recent systems like the HW 2000 use an electro-mechanical clutch.

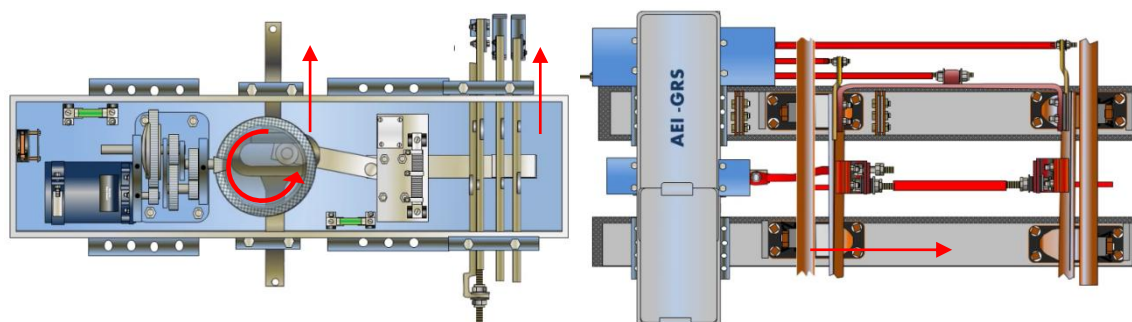


Figure 3.7: Schematic of a HW Points Machine

A snubbing device is used to bring the motor to a controlled stop at the end of the cranks throw movement. The device has an encapsulated diode unit fitted with plug couplers. A mechanical 'lock dog' ensures points are locked when points have completed their movement. Motor contacts are used to allow the direction of movement to be controlled and set. Detection contacts points are used to indicate the positions of the points. The entire system is mounted on two sleepers/bearers.

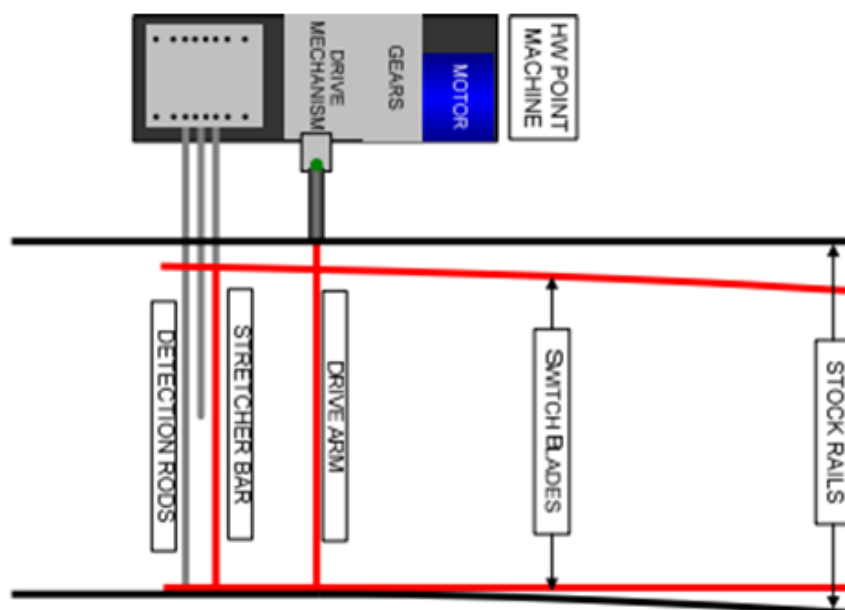


Figure 3.8: HW Points Machine System View

3.1.4.2 Key Attributes / Drawbacks

- HW 1000 machine fitted with a spring loaded dry plate clutch;
- HW 2000 machine fitted with an electric clutch;
- Reliant on a stretcher bar to maintain the position of the open and closed switch rail.

3.1.5 Style 63 Points Machine

The style 63 point machine is an improvement of style M3 point machine developed by British Rail in the 1960s. The style 63 began its service in 1968. This system includes a drive,

locking mechanisms and circuit controller compartments for electrical detection; it is all integrated into one complete system.



Figure 3.9: Style 63 Points Machine photograph

3.1.5.1 Actuation Locking & Detection

The mechanics of the system is based on an escapement device, more commonly used in mechanical watches and clocks used to transfer energy using a throw impulse action. The style 63 point machine incorporates this concept to transfer rotary motion to linear motion and transmit fast initial point movement.

To create the linear motion of the switch, a motor drives a ball-screw via a glass fibre reinforced toothed belt, this engages an escapement crank which then actuates a throw bar, moving the drive bar across. The motor incorporates an overload clutch. This helps to guard against any stalling conditions caused by the layout switch. A high thrust, gained from the cranks throw, is used to press the switch rail against the stock rail. This helps withstand repulsive loads caused by heavy traffic and turbulent stresses. The system also uses a snubbing device and circuit to help overcome 'kick-back' on the electric motor.

The detection circuit control assembly consists of a cam shaft, drive slide bar, contact blocks and gears. As the drive bar moves, the switch rail moves across, the lock blade engages with its corresponding lock dog by means of interlocking notches similar to the HW point machine. Locking is detected by contact pairs in the modular switch blocks. Each point blade is detected independently with the use of separate detector blades. Figure 3.10 shows the typical layout schematic of a type 63 point machine.

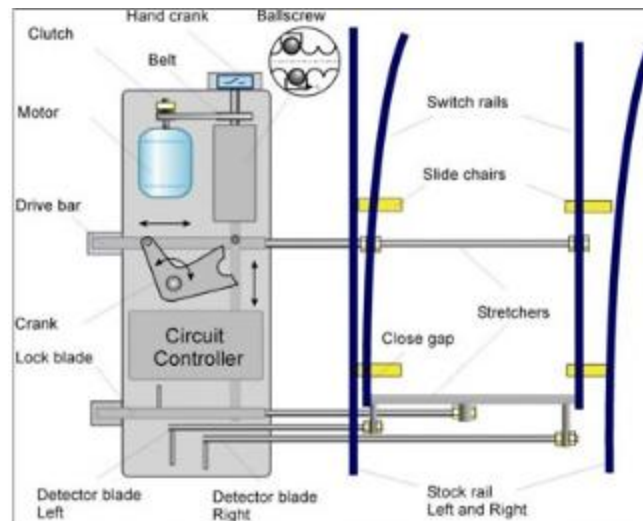


Figure 3.10: Style 63 Point Machine Layout

3.1.5.2 Key Attributes / Drawbacks

- Uses a belt drive to link the motor to the actuator drive;
- Uses an 'escapement crank';
- Reliant on a stretcher bar to maintain the position of the open and closed switch rail.

3.2. Trafikverket (Swedish) Points Operating Equipment

Trafikverket have several types of switch point machines, but two of them are the most important in main track switches. The electro-mechanical system JEA was introduced for more than 70 years ago. An electro-hydraulic system, EasySwitch, was introduced in 2014 and is still in an evaluation phase.

3.2.1 Switch Point Machine JEA 73

The electro-mechanical switch point machine consists of a motor, gear box and relays (see Figure 3.11). This switch point machine has internal locking. For most sizes of S&C (radius 300m – 1200m) there are two point machines in the switch panel and for moveable frogs (swing nose crossings) two more point machines (see Figure 3.12).

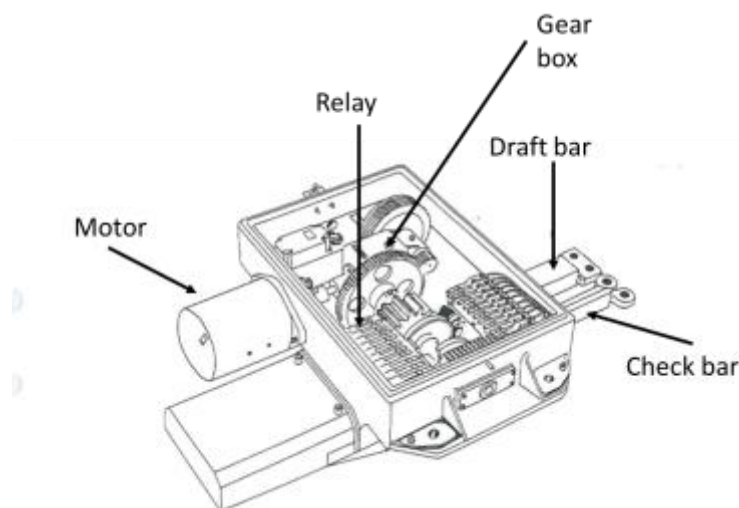


Figure 3.11: Sketch of JEA 73, point machine at Trafikverket



Figure 3.12: Switch with 2 point machine in switch panel and two point machines in crossing panel

The point machines are connected to the interlocking system both electrically (230 V AC or DC) and by signalling cables to ensure the position of the switch blade. The force to the switch blade is transferred by draft bars (one to each side) and the position is checked by check bars. In normal cases there are no mechanical problems with these bars as they are 35 mm diameter rods. The bars are adjustable and might need to be adjusted several times per year due to dimensional changes caused by temperature. The normal force is 6,000 N per point machine. There are in total six position detectors on both sides, which are connected in series. Four of these detectors are inside the point machine and two of the detectors are checking the switch blade positions between the point machine and behind the second point machine (see Figure 3.13). Two additional relay contactors are used to cut the power of switch motor, so in total there are 8 detectors that must work on each side.

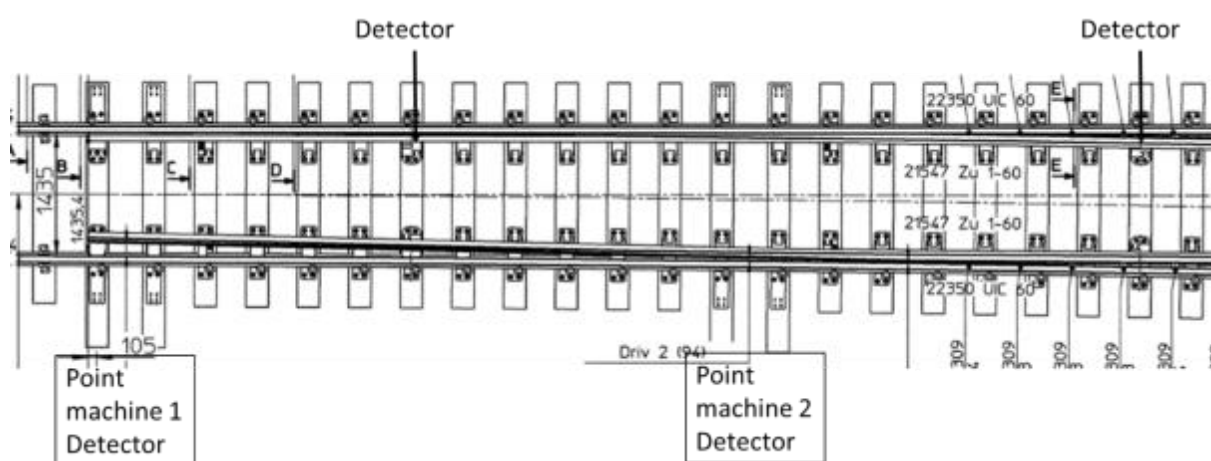


Figure 3.13: Detectors in switch panel for a UIC60-760-1:15 switch

3.2.2. Switch Point Machine EasySwitch

A sleeper integrated point machine was introduced in 2014 (see Figure 3.14). This point machine is intended to be used in all new S&C and was needed to be able to run 250 km/h as it has an external locking mechanism. The point machine is electric-hydraulic and modular to enable easy replacement of the different modules. The most important modules are:

- Hydraulic Unit;
- Unit for manual movement;
- Locking device for switch blade;
- Mechanical unit;
- Switch point detectors.

Movement of the rails uses a central rod and hydraulic actuation. The end position is checked by two different detectors in the mechanical unit and two detectors at switch blade per point motor that is in total four detectors per side. The external detectors are checking

both the closed and the open position separately. As for the JEA point motor there are two more detectors between the point motors and behind the second point machine. In comparison to the JEA motor EasySwitch has two more detectors per side and that EasySwitch have six of the detectors outside the point machine and JEA only two.



Figure 3.14: Switch with 2 hydraulic-electric point machine in switch panel

3.3. Other European Points Operating Equipment

To ensure that other types of Points Operating Equipment (POE) in use across Europe are considered throughout Task 2.1, a comprehensive database of existing systems has been developed. A range of parameters have been collected for each type of POE in order to help identify strengths and weaknesses and to ‘guide’ future novel concepts and designs within In2Rail. Not all parameters were / are currently available for every POE system identified. The following parameters have been collected:

Category	Parameter
Product	<ul style="list-style-type: none"> Manufacturer, Model, Version, Application Type, Price range, Manufacturer Country(s), Reference countries
Technology	<ul style="list-style-type: none"> PM Technology, Integration, Crossing solution, Actuation, Auto-tamping, Changing side possibility, Height, Track gauge, Vignole AND Tram
Power / Electrical Characteristics	<ul style="list-style-type: none"> Power output, source, IP level, Power Supply, Interlocking, Nr of cables
POE Stroke	<ul style="list-style-type: none"> Stroke Min, Stroke Max, Stroke settable on site, Operating Force (kN)
Trailability Features	<ul style="list-style-type: none"> Maximum Speed of Trailing, Trailable Reversible, Trailable Force, Trailing Detection
Lock Characteristics	<ul style="list-style-type: none"> Lock Trailable, Lock depends on Rail profile, Direct Locking, Maintained Force (kN), Detection, Axle Load, Expected solution for thermal expansion, Locking system supplier, Locking Type
Performance	<ul style="list-style-type: none"> SIL, MTBF, Design standards, UIC/AREMA, MTTR full PM, MTTR sub-asm, Maintenance intervals, Delivery time, Lifetime in years
Switching Times	<ul style="list-style-type: none"> Switch Time Min, Switch Time Max, Operations counter
Physical Properties	<ul style="list-style-type: none"> Point machine mass, Operating temperature min, Operating temperature max, Heating, Salty environment, Solar radiation, Humidity level, Oil type
Backdrive	<ul style="list-style-type: none"> Backdrive type, Maximum attacks number, In-track backdrive

Table 3.1: European POE Parameters

86 different European POE types have been catalogued, details of which can be found within Appendix B. These will be referred to throughout the duration of Task 2.1 to influence novel concepts and designs to help integrate additional redundancy in parallel to existing switch systems. It should be noted here that Appendix B contains a reduced version of the overall POE database. This is due to the large quantity of data obtained and to ensure that the key parameters are legible to the reader.

4. Existing Knowledge

This chapter describes existing knowledge related to railway switch points operating equipment (POE) research and development (R&D) projects.

Section 4.1 provides an overview of transferrable results from previous EU funded R&D activities related to In2Rail Work Package 2 (WP2), Task 2.1. Section 4.2 then describes some existing and ongoing development projects specifically aimed at improving the reliability and availability of railway switch POE.

4.1. Previous EU Funded Projects – Knowledge Review

TRANSFERABLE RESULTS FROM PREVIOUS AND ON GOING PROJECTS			
Project	In2Rail Task Description	Project Interest for WP2 of In2Rail	
INNOTRACK Deliverables are available from www.innotrack.net	Task 2.1 (2) Identification of key requirements, limits and tolerances	Yes	<ul style="list-style-type: none"> • D3.2.5 Technical and RAMS requirements/recommendations for the actuation system, the locking and the detection device for UIC 60- 300/1200 switches • D6.5.4 Guideline for LCC and RAMS analysis: it includes social cost benefit analysis, root cause analysis and failure mode, effects and criticality analysis also <ul style="list-style-type: none"> • D3.2.1 Definition of acceptable RAMS and LCC for DLD's • D3.3.3 Requirements for Switch and Cross monitoring • D3.3.5 Requirement specification for the DLD and monitoring demonstrator
SUSTRAIL	Task 2.1 (2) Identification of key requirements, limits and tolerances	Yes	Task 4.4: Switches and Crossings: novel S&C component design building on the outputs from INNOTRACK. Conclusions converge towards the INNOTRACK recommendation (above) that the current state-of-the-art physical arrangement for Switch and Crossing (S&C) drive and locking device is to have combined drive, locking and detection devices integrated into hollow bearers at the main drive locations.

TRANSFERABLE RESULTS FROM PREVIOUS AND ON GOING PROJECTS			
Project	In2Rail Task Description	Project Interest for WP2 of In2Rail	
INNOTRACK	Task 2.1 (3) Interface and system integration	Yes	D3.2.3 Functional Requirements for the open standard interface for electronic interlocking
CAPACITY4RAIL	Task 2.1 (2) Identification of key requirements, limits and tolerances	Yes	SP1: <ul style="list-style-type: none"> • New concepts for switches and crossings design based on failure modes analysis, revisiting curving physics and incorporating sensors for condition monitoring. • New optimised designs for switches that are more resilient to extreme weather
Shift2Rail	Task 2.1 Development of novel S&C locking mechanisms	Yes	S2R open call and call for members projects will coordinate with In2Rail WP2: S2R-OC-IP3-01-2016 – Research into new radical ways of changing trains between tracks. S2R-CFM-IP3-01-2016 – Research into enhanced track and S&C systems.

Table 4.1: Overview of previous and ongoing projects related to In2Rail Task 2.1

4.2. Ongoing Projects Technology Review

This section identifies some existing, non-European funded projects, which have the potential to provide useful insight for future conceptual designs within WP2 Task 2.1. These projects only at feasibility stage and are not formally part of In2Rail (i.e. these will not be taken forward by the project) but have been included as part of a review of existing and related technology development.

4.2.1 Repoint

The Repoint project at Loughborough University has been under development for over 5 years, beginning with concepts looking to increase rail capacity without building new railways, analysis of UK rail performance data showed that the rail network is negatively affected by switch failures to a greater degree than failures of any other asset [1]. A cross industry focus group was established to generate candidate track switching solutions to reduce switch failure, ranging from improvements to existing equipment through to new concepts for track geometry and wheel-rail interface. These were then evaluated against a set of essential functional requirements developed for track switches as a part of this research, and against a set of non-functional requirements forming a set of trade-offs [2].

The solutions identified retain the flanged wheel on rail used for almost 200 years, but introduce novel designs for the point actuation and locking mechanism. There are currently two versions; the full Repoint is a hopping stub switch, Repoint “Light” retains the rail geometry of a conventional switch while introducing the hopping mechanism and passive locking elements of the full Repoint solution.

4.2.1.1 Repoint hopping stub switch

The stub switch reverses the elements in a traditional switch, and replaces the long, planed down switch rails shown in with short, stub-ends formed of full section rail which are able to move between 2 (or more) positions. Actuation is provided by a multi-channel actuation bank, with the actuation elements contained within bearers near the movable rail ends.

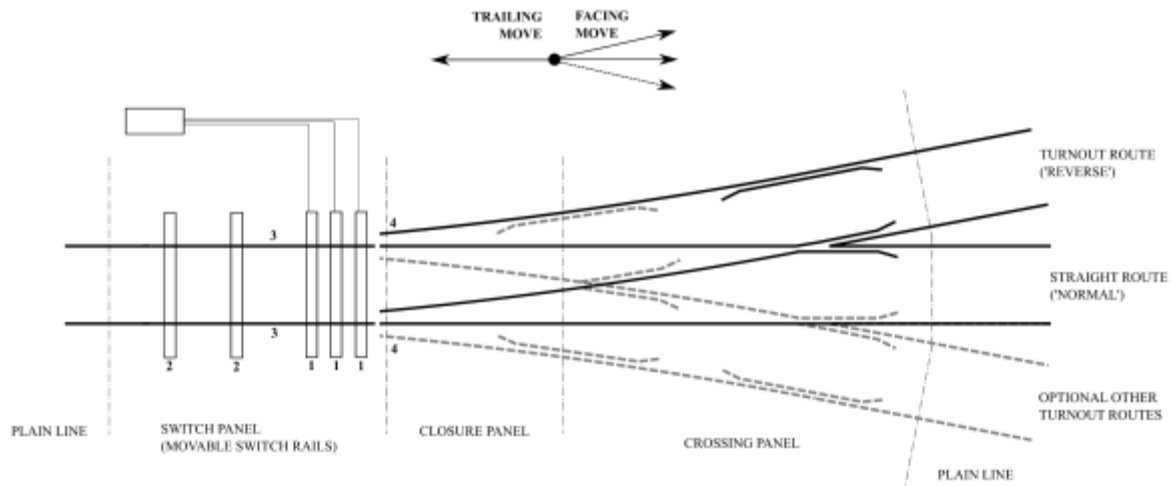


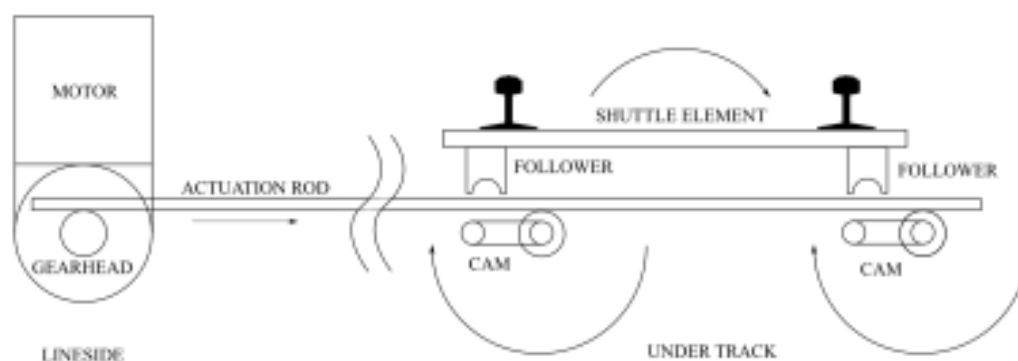
Figure 4.1: Repoint hopping stub switch arrangement

Figure 4.1 shows the general arrangement of a 'Repoint' stub switch, with an optional second turnout route shown dotted. Numbered elements as follows; (1) In-bearer type electromechanical actuators featuring integral passive locking elements with detection system; (2) Bearer featuring integral passive locking elements; (3) Bendable, full-section switch rails; (4) Interlocking rail ends.

Triplex redundancy is shown, with each actuator/bearer being capable of moving the switch alone. Multi-channel actuation is provided through an arrangement which has been termed 'passive locking'.

The theory of passive locking is that when the rail is in one of its stationary, lowered positions, it is unable to move in any direction apart from directly upwards. It is a requirement to lift the interlocking rail ends to disengage them. When the track is lifted, it is free to move laterally, but not longitudinally. Thus the rail hops between adjacent positions. If an actuator is isolated for whatever reason, the adjacent unit(s) can still actuate the switch, as the lifting action will unlock the isolated unit. It is this feature which enables redundant actuation to be provided as part of the 'Repoint' concept, something not possible with the conventional switch. The general arrangement of the components within each actuator bearer is shown in Figure 4.2.

(A) Actuation Elements - Cross section through each actuator-bearer



(B) Locking Elements - Cross section through each actuator-bearer

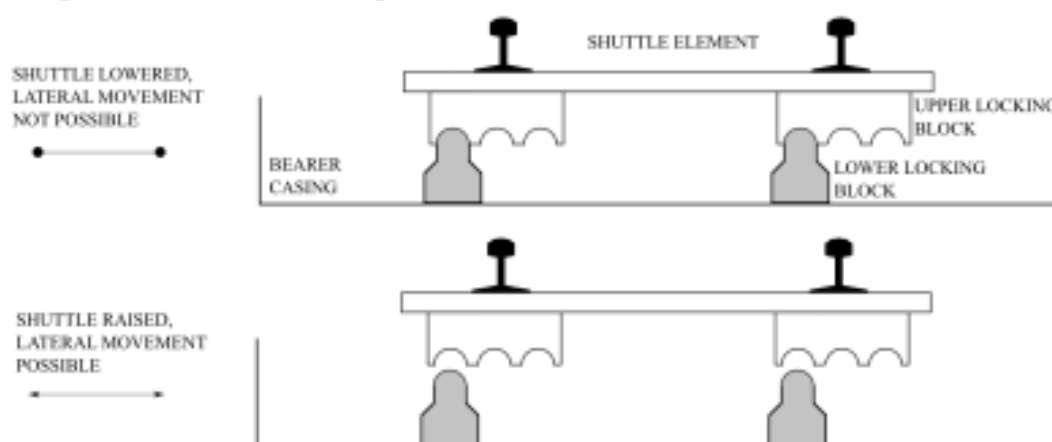


Figure 4.2: Repoint actuator/bearer

Cross sections of each actuator-bearer; (A) showing internal elements related to the actuation system and (B) showing the associated locking elements, which would be present inside each bearer alongside (A).

4.2.1.2 Repoint light

Repoint light retains the rail geometry of a conventional switch; however the movement of the switch blades follows the lift-move-drop actuation method and passive locking of the full repoint solution. This allows the Repoint benefits of actuation redundancy and passive locking to be achieved, whilst retaining the well-understood geometry of a conventional switch.

4.2.1.3 Further development

The Repoint intellectual property is the subject of 3 published patents [3], [4] and [5]. A scale demonstrator of the concepts has been constructed in a laboratory at Loughborough University at 384mm gauge.

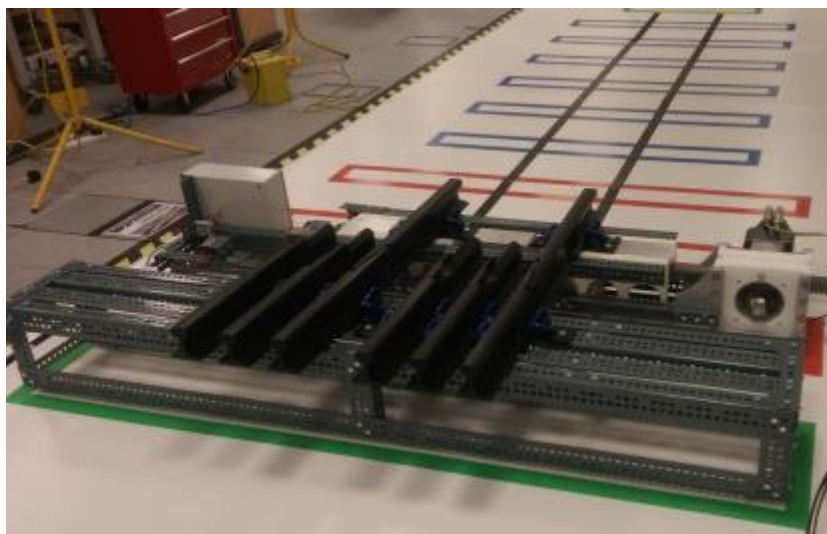


Figure 4.3: Repoint Demonstrator

The demonstration actuator/bearer features all components which would be required in a full-size design - controller, motor, gearbox, drive arrangement, roller-cams, and passive locking elements. Work at Loughborough University is moving forward, funded by the RSSB, to identify an industrial partner to undertake the design of a prototype switch to be installed on London Underground Infrastructure for a test period.

4.2.1.4 Acknowledgements

Loughborough University acknowledge the financial support provided by the United Kingdom EPSRC (Engineering and Physical Sciences Research Council) and the United Kingdom RSSB (Railway Safety and Standards Board) in grant number EP/I010823/1, for the project REPOINT: Redundantly engineered points for enhanced reliability and capacity of railway track switching. The authors also acknowledge the support of the UKs Future Railway, for providing funding towards concept demonstrator design and construction (<http://www.futurerailway.org/>).

4.2.2 Autochock

‘Autochock’ is the development name for a proposed retrofit supplementary points lock to restrain the open switch rail. This section of Deliverable D2.1 provides background information to the Autochock system and why it is believed that it provides an enhanced level of safety beyond either ‘well maintained’ traditional stretcher bars, or more modern, revised stretcher designs.

4.2.2.1 Autochock Description

The Autochock concept replicates passively and automatically the function of the scotch block during normal operation. It provides positive lock for the open switch rail.

The Autochock body clips on to the stock rail at near the point toes, in the same bay as the POE drive rod. The prototype unit is held in place with a spring clip and magnets, though other attachment methods are under consideration. The actuating lever then attaches to the end of the points drive rod. Adjustment is made via a nut pair on the actuating lever which sets its length correctly. A spring pack in the actuating lever applies a small preload and also acts to take up any drift in the mechanism over time. When the points are moved, the actuating lever raises and lowers a block between the open switch rail and corresponding stock rail. The block contacts the stock rail, but is clear of the switch rail. In normal operation, the mechanism presents minimal additional load to the point motor, and the block does not contact any element apart from the stock rail. In the event of a catastrophic stretcher failure, the block prevents the open switch rail springing back against the stock rail, keeping the flangeway open and preventing derailment.

It has several other important features of note:

- It is a clip-on addition which does not require interference with any safety critical aspects of the switch apparatus (e.g. Stretcher bars or POE);
- After setup, it is self-adjusting through the use of a double-acting spring pack;
- It can be fitted alongside traditional or revised stretcher bar designs;
- It is designed to be fitted by a single worker with a single spanner in less than 5 minutes;
- Two Autochock mechanisms are required per point end to protect both routes. Alternatively, it can be fitted singularly to protect a single 'higher risk' route;
- It is single-man portable;
- It consists of only four moving elements, which are encased to prevent ballast ingress;
- It uses motion already provided by the point motor for actuation;
- It requires no ongoing maintenance beyond a visual check at each points overhaul;
- Using minimal specialist engineering and machining, minimal parts count, and COTS components allows a low unit cost;
- It can be removed quickly and easily for maintenance operations.

The concept is a fundamentally different solution to revising the stretcher bar. Rather than trying to make the stretcher bar more resilient to failures, we accept that some stretcher failures may always occur, whatever the design, and instead act to prevent the consequences of such a failure being a facing move derailment.

Autochock also serves to close the feedback/safety loop by providing a further level of assurance that, once the open switch blade is detected in position, it will not be able to close again without a command to do so from the interlocking, and actuation of the POE.

It is envisioned there are many scenarios where Autochock could be fitted, and it is not believed that its fitment is mutually exclusive with the new stretcher bar; Autochock provides a fundamentally different solution.

4.2.2.2 General Arrangement

General arrangement cutaways of the prototype unit are included below, alongside photographs of the trial installation.

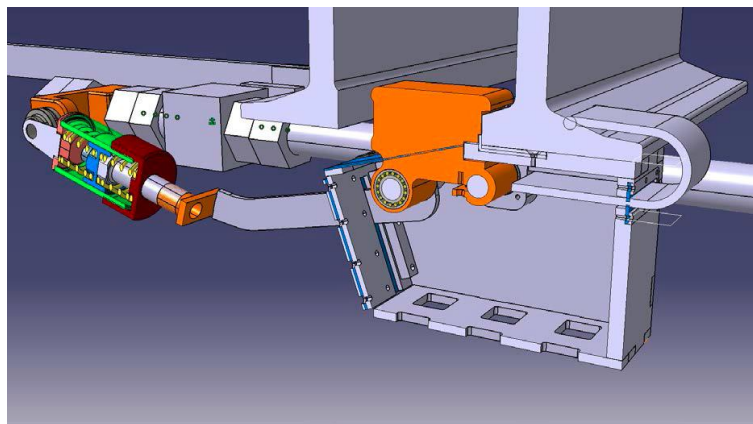


Figure 4.4: Autochock CAD Model (Section View)



Figure 4.5: Autochock Prototype



Figure 4.6: Autochock Installation

4.2.2.3 Project Status

The operational concept has been developed into a prototype design, and a prototype has been manufactured. The prototype has been fitted to a set of points upon the GCR (Great Central Railway), just south of Loughborough Central Station in the UK, since October 2015.

4.2.3 Ongoing Projects Summary

Description of the Repoint system has been included to demonstrate existing technological developments within the area of novel locking mechanisms for railway switches. Much can be learnt from such existing projects to enable efficient developments to be made within In2Rail WP2 Task 2.1.

Optimum solutions seldom come from a single conceptual design but rather are generally a combination of multiple ideas. Inclusion of existing project is therefore an important part of filtering through to an optimum solution that fulfils the requirements of Task 2.1.

5. POE Failure Analysis

This chapter aims to describe common failure modes, delays and associated costs related to points operating equipment.

5.1. Failure analysis for S&C at Network Rail

To demonstrate the business case for Task 2.1, Network Rail has completed an analysis of Points Operating Equipment (POE) service affecting failures. The following sections describe the whole-system impact and then drills down to POE component level before demonstrating potential savings through optimisation of POE for reliability and availability.

5.1.1 National Service Affecting Failures

To demonstrate the size of the opportunity for improvement within Task 2.1, asset failure data has been assessed to provide a business case for points operating equipment initiatives. Section 5.1.1 looks at all service affecting failures occurring within a 12 month period from April 2015 and begins with a whole-system (all railway network assets) assessment.

Figure 5.1 illustrates the number of incidents occurring across each asset category and then relates this to the total number of delays attributed to those failures. Over the 12 month period analysed, Infrastructure assets accounted for only 7% of all incidents but totalled 29% of all delays and associated costs. Breaking down the Infrastructure category down to a further system level, it can be seen that, outside of broken rails, Points Failures have a significant influence on the network service (12% of all delay minutes) despite only 8% of failures being attributed. This indicates that a single point failure can have a significant impact on network availability.

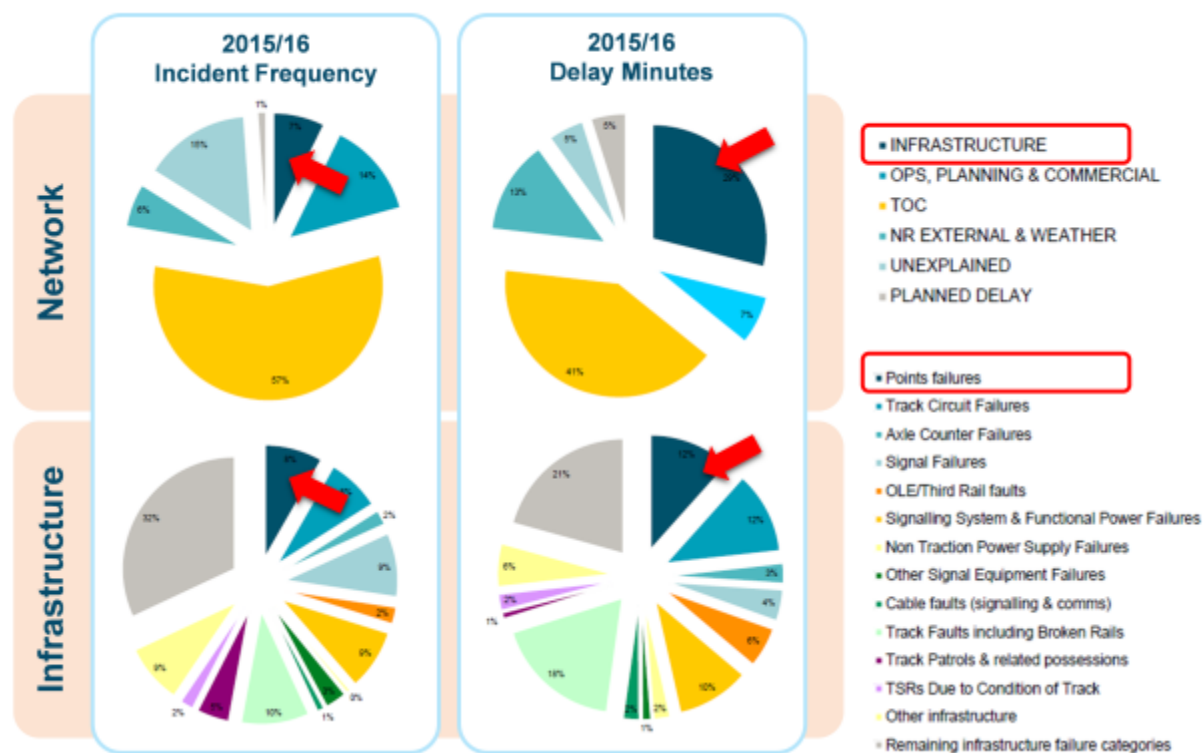


Figure 5.1: Network Rail (UK) Service Affecting Failures

Table 5.1 compares the Mean Time Between Service Affecting Failure (MTBSAF) values for each of the major infrastructure sub-systems. It is evident that POE is currently underperforming, from a reliability perspective, with only 4.0 years being achieved (against an expected MTBSAF of 6.0 years) between service affecting incidents.

Asset Category	MTBSAF (Years)
Track Circuits	17.5
AC Traction Supplies	17.5
Axle Counters	12.0
Signals	10.0
DC Traction Supplies	10.0
Track & Other Infrastructure	6.0
Points Operating Equipment (POE)	4.0

Table 5.1: Infrastructure Asset MTBSAF League Table (UK)

5.1.2 Points Operating Equipment Failures

Figure 5.2, below, illustrates the population of different POE types currently in use on the UK rail network. The total population of operating mechanisms is 20130. The dominant systems in use are the Clamplock and HW Points Machine systems.

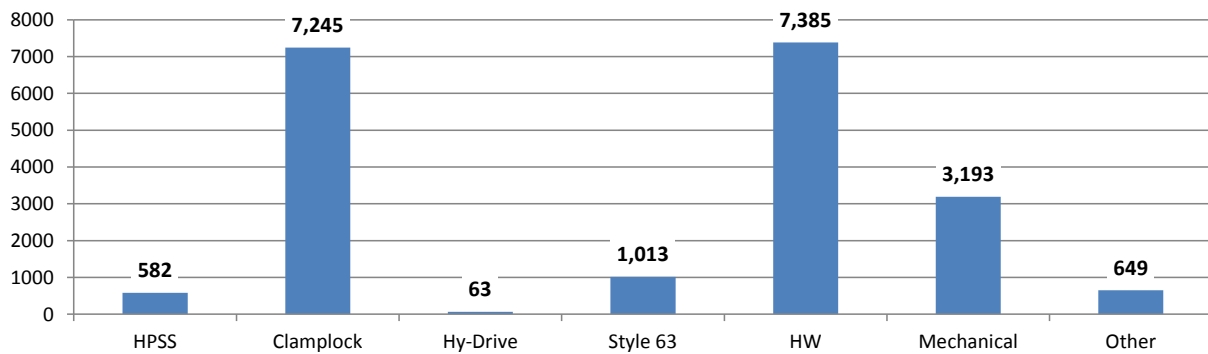


Figure 5.2: UK national POE types and populations

Figure 5.3 indicates that, although not often used on the UK network, the Hy-Drive system currently proves to be the most reliable system. This may be a result of such few systems in use (hence limited failure data for a range of operating conditions) and also the duration that have been in operational service. Further work is therefore required to fully understand whether this is a true reflection on the systems performance. One very important observation though is that, of all the systems, Hy-Drive is the only system that provides independent switch rail actuation at multiple points along the length of the switch. All other systems rely upon a single actuation unit that use to provide load to both the primary and supplementary drive positions. This does not necessarily relate to system redundancy, although the load required from the primary actuation device is reduced and suitably distributed along the length of the switch.

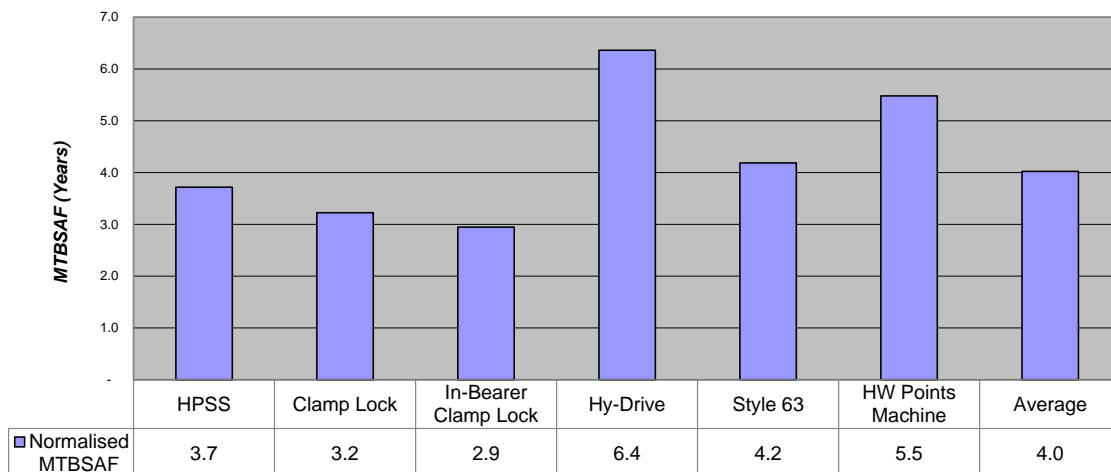


Figure 5.3: Normalised POE MTBSAF Chart for Major UK POE Types

The observation made above is also reflected within Figure 5.4, below. POE system reliability drops off significantly as the length of the switch panel increases. For longer switches (D to F), the Hy-Drive system provides an improved reliability when compared to other systems, although its own MTBSAF still drops significantly. This also raises the question of whether older POE designs, such as the Westinghouse Type 63 and HW Points Machine, are suitable for longer switch applications. Assessment of the quantity of these systems installed on each

length of switch will be required to understand this fully. As the switch panel increases in length, additional detection is required at positions away from the switch toe. A range of additional supplementary drives and detectors are required as switch lengths increase from C through to anything greater than F (refer to Figure 5.7 on page 41). Figure 5.4 shows that the MTBSAF drops consistently for all POE types at these switch lengths. This places further emphasis on the need for redundantly engineered systems for improved reliability performance.

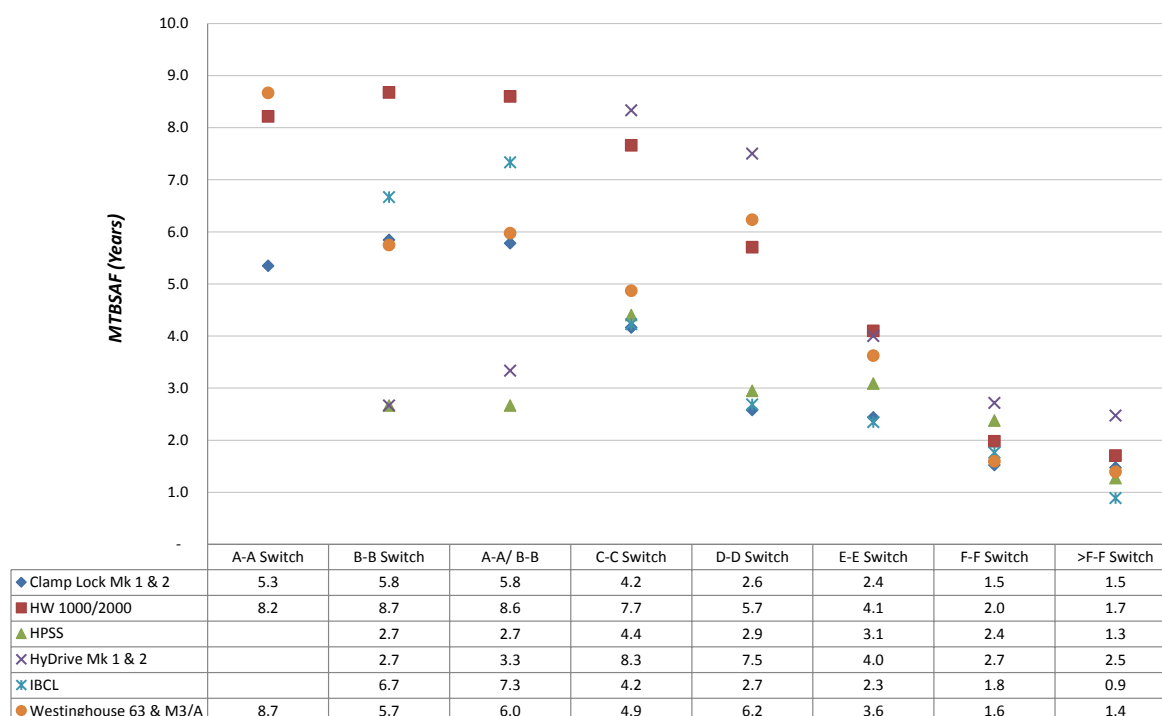


Figure 5.4: MTBSAF of POE for Different UK Switch Lengths

The MTBSAF values used within the above analysis do not yet include an assessment when, during the life of the asset, failure occurred. Further reliability assessment work, completed by Loughborough University, strongly indicates that POE suffers significantly from 'Infant Mortality' (i.e. early life failures after initial installation). Further details of this analysis will be made available within Deliverable D2.2 and will form part of the future reliability analysis as introduced within Section 7.4 of this report.

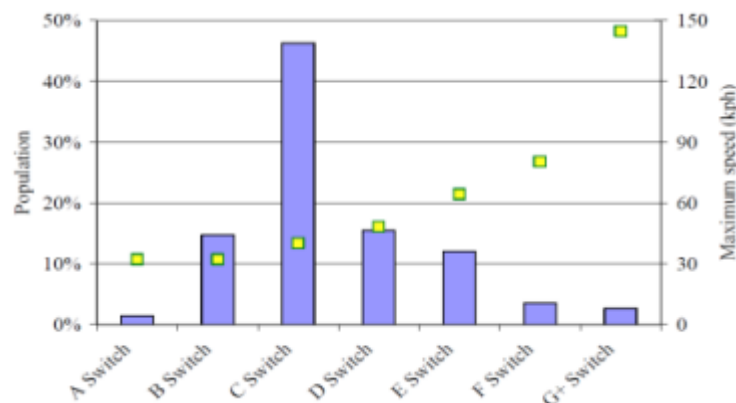


Figure 5.5: Population percentage of switch lengths and their associated design maximum speeds (on secondary axis) as published by Cornish [6]

Figure 5.6, below, breaks all of the POE failures into their causes (and sub-systems). Faults have been attributed to five causes:

1. Actuation;
2. Detection;
3. Locking;
4. External;
5. No Fault Found.

At this stage in the analysis, all of the different UK POE systems have been combined to provide a national picture. It can be seen that over 50% of all POE failures have been attributed to Actuation and Detection faults whilst the smallest proportion aligns with the locking mechanism. A separate category for 'External Factors' has been included to remove all incidences of reported POE 'failures' that were due to the POE system alerting the signalling system that an unsafe 'condition of track' exists (i.e. switch blade obstruction) and corrective action is required. Analysis data attributed to 'No Fault Found' will most likely have been due to one of the other four causes above but not identified at the time of the maintenance visit.

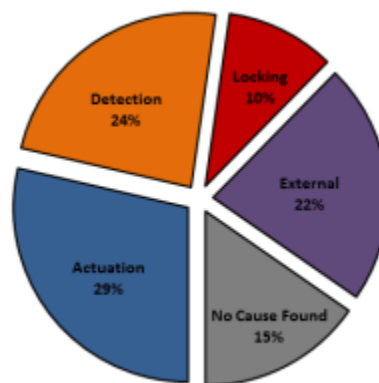


Figure 5.6: Percentage of Failures attributed to POE Sub-systems

Figure 5.8 further breaks down the data into different component levels for each of the five failure categories. Simply assessing the details that are recorded, a large proportion of service affecting incidents are due to single component failures, which have the overall consequence of whole switch system failure. Another key observation is that there are a large number of 'Out of Adjustment' / 'Incorrect Setup' type faults. Failures attributed to the mechanical backdrive and drive rods, for example, both feature within the top ten failures within Figure 5.8 and would also generally require some kind of manual adjustment. This may indicate that the actuation system is sensitive to whole system degradation and that any new designs must be more tolerant to operating under degraded conditions. Ranking of all failures within Figure 5.8 by total percentage of failure, locking faults do not appear at all within the top ten failures. The largest total percentage of failures associated with the locking system is 2.15% for 'Out of Adjustment Locking Blades'. This again indicates the POE systems vulnerability to whole system degradation.

The largest contribution to total failures comes from the 'Backdrive Mechanism', which accounts for 7.54% of all POE system failures. This might be expected when comparison is made with Figure 5.4, above, and Figure 5.7, below. A significant decrease in MTBSAF is observed from the length of C-switch and continues to drop as the switch length increased. This observation goes hand-in-hand with the increase in systems required for driving and detecting the position of the switch rails as the switch length increases. Combining this additional complexity with the distinct lack of redundancy proves to have a significant effect on the POE system reliability and hence availability.

TRACK LAYOUT INFORMATION RELATING TO MECHANICAL												
	TYPE OF RAIL SECTION											
	FLAT BOTTOM INCLINED			BULLHEAD INCLINED			FLAT BOTTOM VERTICAL			UIC 54B SWITCH 113A FBV STOCK		
Switch Type	Number of Stretcher Bars	Supp Drives on Stretcher	Supp Detector on Stretcher	Number of Stretcher Bars	Supp Drives on Stretcher	Supp Detector on Stretcher	Number of Stretcher Bars	Supp Drives on Stretcher	Supp Detector on Stretcher	Number of Stretcher Bars	Supp Drives on Stretcher	Supp Detector on Stretcher
A	2	-	-	2	-	-	2	-	-	2	-	-
B	2	-	-	2	-	-	2	-	-	2	-	-
C	3	-	-	3	-	-	3	3	-	2	2	-
D	3	3	-	4	4	-	4	4	-	2	2	-
E	4	4	-	4	4	-	4	4	-	3	3	2
F	4	4	-				5	3 & 5	3	3	2 & 3	2
SG	6	4 & 6	4				6	4 & 6	4	5	3 & 5	2 & 4
G	6	4 & 6	4				6	4 & 6	4	5	3 & 5	2 & 4

Figure 5.7: Switch requirements for stretcher bars, supplementary drives and supplementary detectors from UK Standard RT/E/C/11772 – Supplementary Point Drives and Detection

Whilst it may not be possible to redesign existing actuation and detection systems to eliminate all single sources of failure, introducing complimentary systems to work alongside existing may enable the switch to operate under degraded condition whilst the original fault is rectified.

Development of Novel S&C Motion/Locking Mechanisms: Design Concept Report [TRL3]

POE SUB-SYSTEM	Failure %	Component Level 1	Failure %	Component Level 2	Failure %	Component Level 3	Failure %	Total %		
ACTUATION	29%	Backdrive Mechanism		7.54%				7.54%		
		Drive	5.80%	Drive Rod / Shaft		3.13%		3.13%		
				Drive Mechanism		1.45%		1.45%		
				Clutch		0.70%		0.70%		
				Gearing		0.29%		0.29%		
				Snubbing Device		0.23%		0.23%		
		Motor / Actuator	6.38%	Motor		2.55%		2.55%		
				Actuator / Hoses		2.04%		2.04%		
				Hydraulics	1.79%	Hydraulic Accumulator Unit		0.50%		0.50%
						Hydraulic Pump Unit		0.43%		0.43%
						Hydraulics		0.50%		0.50%
		Loss of Hydraulic Oil		0.36%		0.36%				
		Clamplock Mechanism		3.48%				3.48%		
		Incomplete Points	3.48%	Points Difficult to Operate		2.09%		2.09%		
				Points Fail to Complete Movement		1.29%		1.29%		
Points Lock Unable to Detect				0.07%		0.07%				
Points Stuck on Manual				0.03%		0.03%				
Other		2.32%				2.32%				
DETECTION	24%	Detection Components	12.24%	Detection Assembly		3.79%		3.79%		
				Detection Rods		3.18%		3.18%		
				Incorrect Setup / Foreign Body		2.69%		2.69%		
				Detection / Drive Contacts / Cams		1.35%		1.35%		
				Detection Units		1.22%		1.22%		
		Fails to Detect	4.32%	Points Fail to Detect		1.81%		1.81%		
				Tappets Out of Adjustment		1.81%		1.81%		
				Bush Siezed		0.56%		0.56%		
				Other		0.13%		0.13%		
		Supplimentary Detection	2.88%	Detection Slides		1.21%		1.21%		
				Detection Rods		0.86%		0.86%		
				Microswitch Failed		0.40%		0.40%		
				Other		0.23%		0.23%		
		Termination Fixings		0.17%		0.17%				
		Clamplock Mechanism		1.92%				1.92%		
		Rail Position Sensors (LVDT)		1.20%				1.20%		
		ECU / Wiring	0.96%	Electrical Control Unit (ECU)		0.53%		0.53%		
				Disconnection Box		0.16%		0.16%		
				Circuit Controller		0.13%		0.13%		
				Wiring		0.10%		0.10%		
				Tail Cable Fault		0.04%		0.04%		
		Other		0.48%				0.48%		
		LOCKING	10%	Clamplock Mechanism	4.50%	Locking Piece		2.03%		2.03%
Lock Slide						1.31%		1.31%		
Lock Arm						0.90%		0.90%		
Other						0.27%		0.27%		
Locking Mechanism	3.90%			Locking Blades		2.34%		2.15%		
				FPL Out of Adjustment		0.86%		0.86%		
				Poor Lubrication		0.39%		0.39%		
				Locking Piece		0.12%		0.12%		
				Machine Locking Bar		0.12%		0.12%		
				Other		0.08%		0.08%		
				Incorrect Setup		0.80%		0.80%		
Other				0.50%		0.50%				
Brake Assembly				0.30%		0.30%				
EXTERNAL	22%	Baseplates / Chairs	6.16%	Contamination		3.94%		3.94%		
				Roller Inserts Out of Adjustment / Worn		1.05%		1.05%		
				Loose		0.43%		0.43%		
				Broken / Defective		0.37%		0.37%		
				Inspected Fit for Purpose		0.18%		0.18%		
				Slide Table Needs Lubrication		0.18%		0.18%		
		Signalling Relay	5.72%	Relay Failed		2.92%		2.92%		
				Relay Contacts HR		2.52%		2.52%		
				Base / Plugboard		0.29%		0.29%		
		Stretchers Bar		3.08%				3.08%		
		Staff Error		2.20%				2.20%		
		Obstruction	1.98%	Detection Rod		0.91%		0.91%		
				Drive Rod		0.57%		0.57%		
				Locking Mechanism		0.34%		0.34%		
				Switch		0.16%		0.16%		
		Damage		1.32%				1.32%		
		Other		0.66%				0.66%		
Incorrect Setup		0.44%				0.44%				
Terminations / Fixings		0.44%				0.44%				
NO CAUSE FOUND	15%	Right when Tested		10.6500%				10.65%		
		Inspected / Fit for Purpose		2.700%				2.70%		
		Not a Fault		1.0500%				1.05%		
		Non-failure Working as Designed		0.4500%				0.45%		
		Non-failure - Out of Sequence		0.1500%				0.15%		

Figure 5.8: POE Sub-System and Component Failure Percentages

5.1.3 Financial Implications

Using the Network Rail framework for cost attribution, Table 5.2 shows the annual cost POE failures to the UK rail network.

POE System	Delay Minutes	Cost	POE Population	Normalised Cost
HPSS	35978	£3,306,089.85	582	£5,680.57
Clamplock	224217	£18,593,856.96	7,245	£2,566.44
Hy-Drive	6431	£494,914.49	63	£7,855.79
Style 63	26109	£1,849,278.50	1,013	£1,825.55
HW	237074	£20,615,238.59	7,385	£2,791.50
Mechanical	15782.5	£845,451.48	3,193	£264.78
Other	9,554	£731,651.43	649	£1,127.35
Total	555145.5	£46,436,481.29	20,130	£2,284.34

Table 5.2: Annual Cost of POE System Failures

Assessing delay minutes alone for the three major POE sub-systems, there is a potential saving of 37 million € / year to be made if the POE system was designed with redundancy and hence the ability to continue operation in a degraded state.

Sub-System	Failure %	Potential Annual Savings (£/yr)	Potential Annual Savings (€/yr) *
Actuation	29%	£13,466,579.58	17,035,223.16 €
Lock	10%	£4,643,648.13	5,874,214.88 €
Detection	24%	£11,144,755.51	14,098,115.72 €
Total	63%	£29,254,983.22	37,007,553.77 €

* **Note:** Exchange rate of 1 GBP = 1.265 EUR used as of 22/06/2016 from Thomas Cook.

Table 5.3: Potential Delay Minute Savings associated with 100% elimination of POE Failures

It has been assumed that the introduction of redundancy, and hence enabling the POE system to operate in a degraded mode, will enable a more proactive maintenance approach to be taken. This will result in a reduction of reactive and frequency based maintenance activities.

It is estimated that:

- Each switch requires 4-5 maintenance visits per year;
- 2 maintenance visits will be saved per year due to degraded operation;
- 2 Signalling Technicians are required per maintenance visit;
- Average rate of a Signalling Technician is £48/hour;
- Each maintenance visit averages 0.75 hours in duration.

Based on the above assumptions and focussing on the total population of switches on the UK rail network (20,130), a total maintenance saving of £2,898,720.00 (3,666,880.80 €) per year is estimated.

5.2. Failure analysis for S&C at Trafikverket

The analysis is made on S&Cs with 60 kg/rail (UIC60), which are in main track with traffic varying from 1-32 MGT/year. This is the 2 000 most important S&C out of total 12 000. There are about 1,500 other S&C in main track with 50 kg/rail that has traffic 1-12 MGT/year that has not been analysed. Failure data is taken from 2013 until May 2016. Trafikverket has divided the S&C in six subsystems. 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/S&C/year. In winter the number of failure increases so for S&C with 8-12 MGT/year over 40 % of the failures are winter related. The term winter related is used for failures that are registered to be caused by snow and ice or needed the maintenance action snow clearance. All failures on heating system and snow protection are also defined as winter related. The other sub system has a relative low number of failures directly connected to the term winter related, as the normal cause is a failure in the heating system, see Figure 5.9. Over the year there is also an increase of failures during summer.

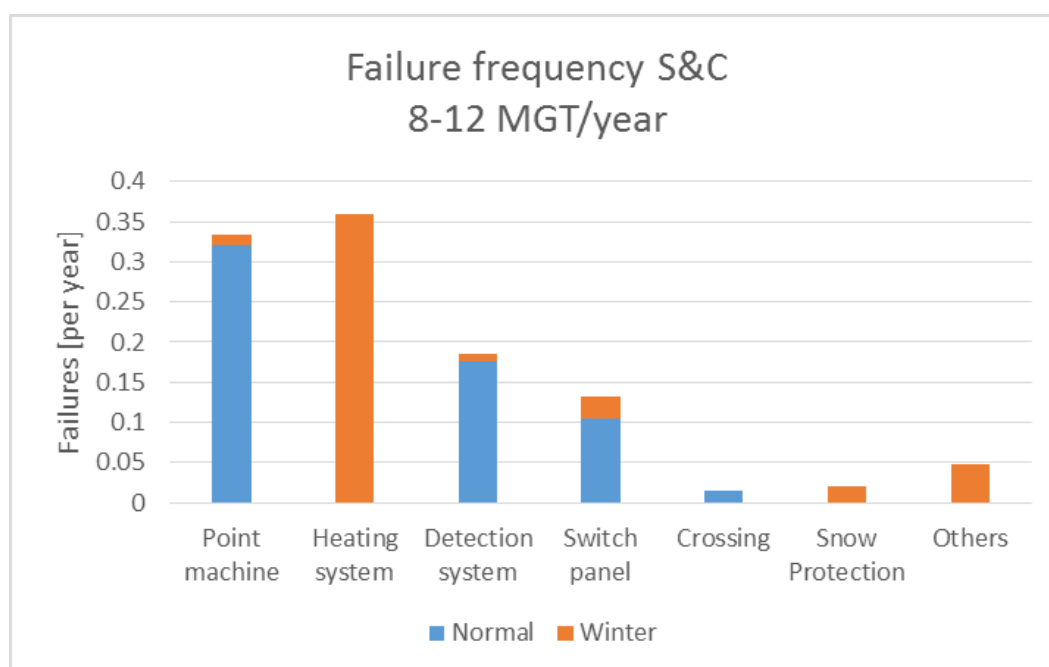


Figure 5.9: Failure for UIC60 S&C with traffic of 8-12 MGT/year and total traffic load of 50 – 350 MGT. The failures are divided into normal condition and winter related

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 5.10. In this study the

number of switch blade movements has not been included. This factor is also important to understand the failure rate, but there is a lack of data at Trafikverket which makes difficult to include in a study over the whole country.

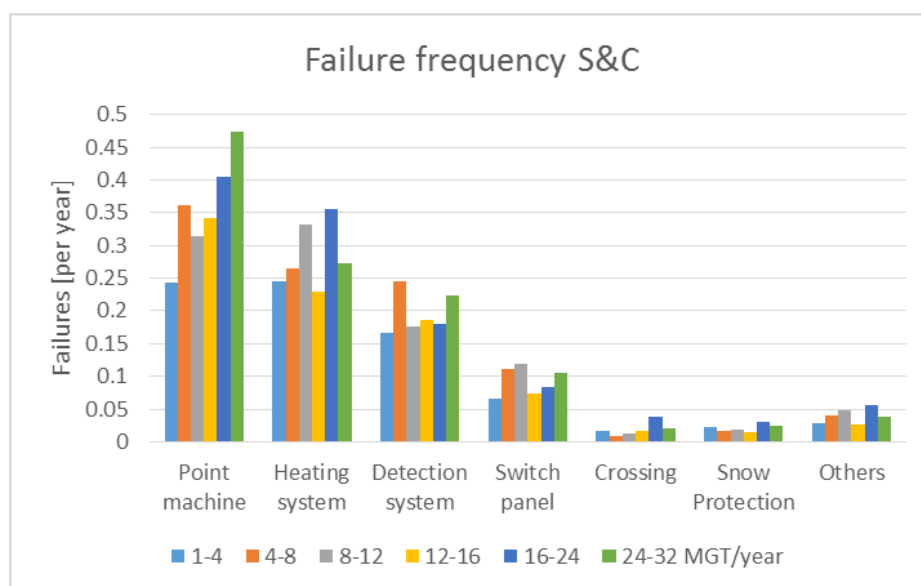


Figure 5.10: Failure for UIC60 S&C with traffic of 1-32 MGT/year

Regarding problems with moving the switch blade it has been observed by Trafikverket that the type of interlocking system also influence the failure rate. The more modern computerized interlocking system has fewer failures than the old relay-based interlocking system. The motors were changed from DC-motors to AC-motors when going from the relay interlocking system to the modern ones. There is no direct evidence that the motor itself should have more or less failures. The main reason for the difference is that the old interlocking system has longer cables between the physical S&C and where the interlocking system connects to the power line. More than 2 000 m long cables exist. These cables are also not always dimensioned in a proper way which gives power drop if the point machine needs high current.

It is difficult to compare the S&C with AC or DC-motors due to the fact that they normally are on different track sections. In order to get a fairly good representation it track sections with less winter related problems has been chosen (with number higher than 409). In Figure 5.11 the relation is shown for non-winter related problems and in Figure 5.12 for winter related problems. The DC motors has 38 % more failures without winter related and 21 % more failures that is winter-related. The conclusions so far are that the interlock system contributes with about 20 % of the failures. Further investigation is needed to clarify this.

Taking the best figures would be to take the data from new interlocking system on the selected track sections with traffic varying from 1-32 MG/year the failure rate is 0.89 failures/S&C and year, this is shown in Table 5.3 and Figure 5.13.

Sub-system	Failure rate/year
Point machine	0.34
Heating system	0.24
Switch blade point detector	0.15
Switch panel	0.08
Crossing	0.01
Others	0.07
TOTAL	0.89

Table 5.3: Failure rate for selected track sections with AC-motors in the point machines

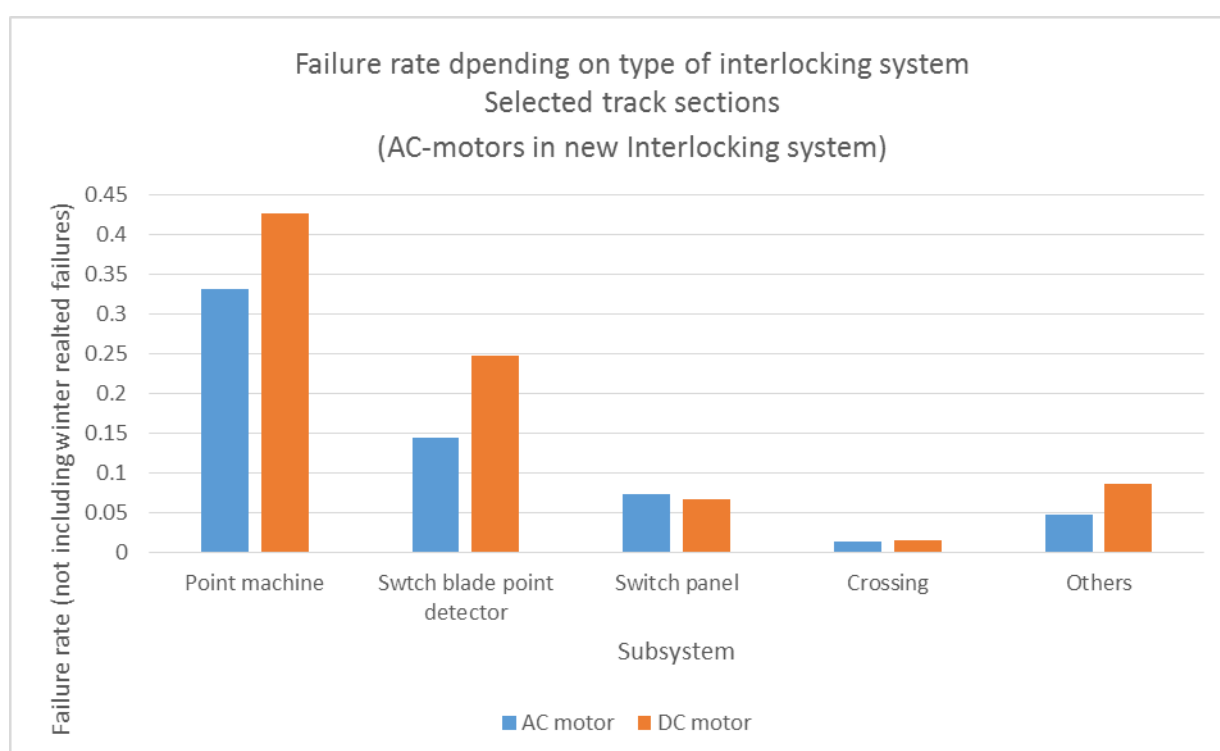


Figure 5.11: Failure rate depending on type of interlocking system, not related to winter

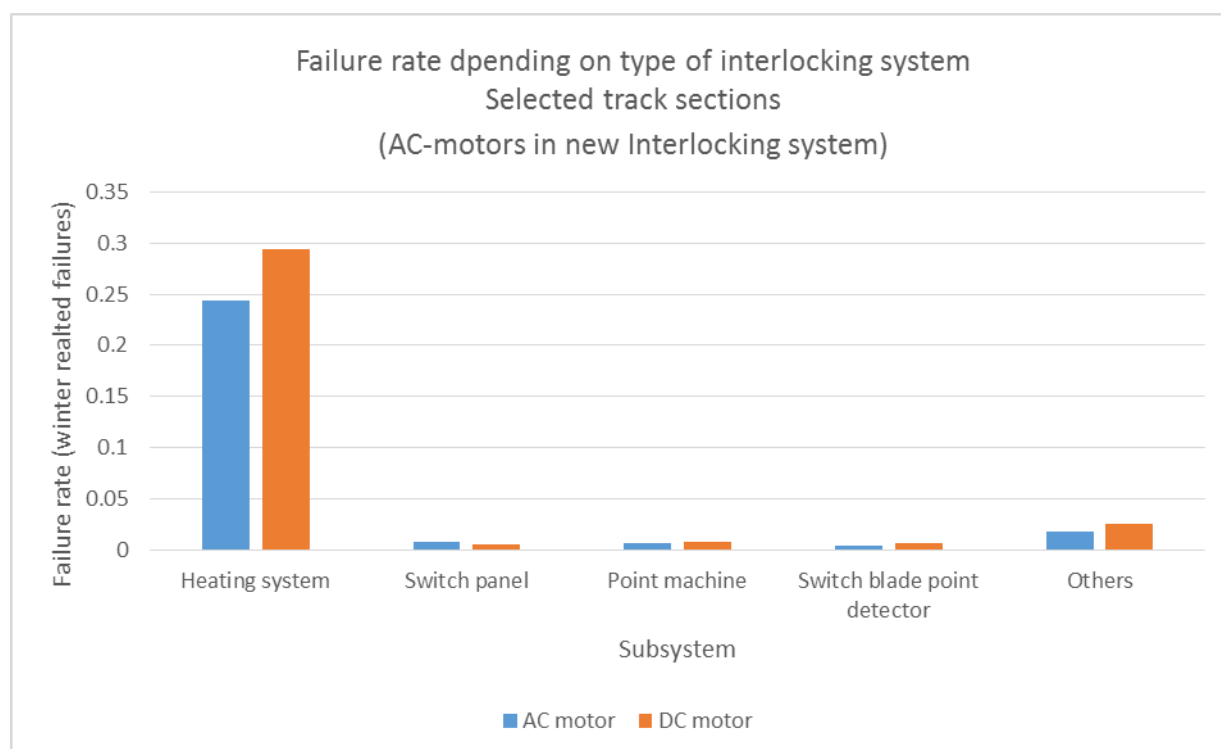


Figure 5.12: Failure rate depending on type of interlocking system, related to winter

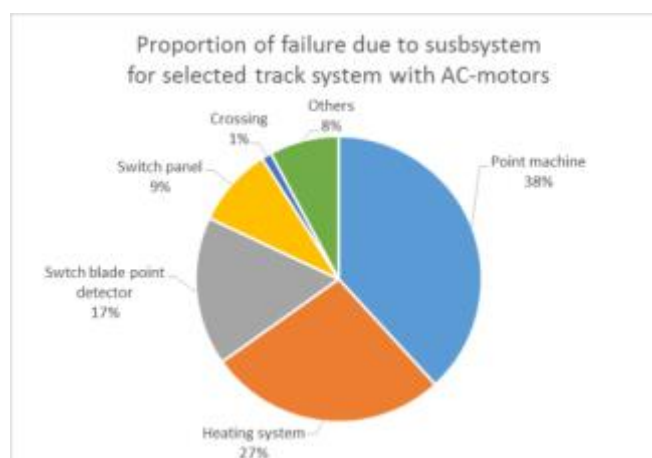


Figure 5.13: Proportion of failures due to subsystem for selected track system with AC-motor point machines. Traffic varying from 1-32 MGT/year

Trafikverket system for failure record does not really give to opportunity to go deeper than the subsystem level. There is a small possibility to use the field of action to understand a little more, shown in Figure 5.14.

Lubrication, adjustment, control and cleaning are the main headings showing that there is no change in the point machines. Only 19% of the failures actually are treated by repair or replacement. That should give an opportunity to improve the design to minimize the actions that are more adjustments than repair.

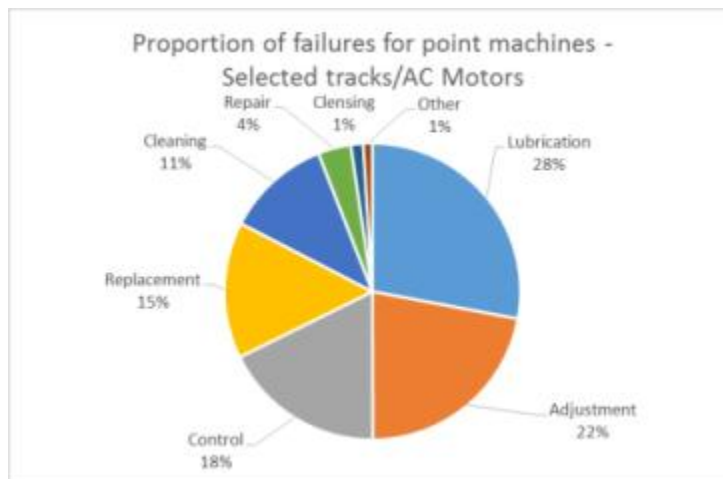


Figure 5.14: Proportion of failures due to maintenance for point machines at selected track system with AC-motor point machines. Traffic varying from 1-32 MGT/year

5.3. Other Considerations

Ref [7] deliverable describes in section 2.5.1 a number of failure modes and reports that over a third of failures are unexplained or due to the backdrive, but the report does not include incorrect design as a category for attribution of failures. This may have the consequence that design is not being used enough to reduce complexity or to suit modern requirements such as higher speeds, reduced track access times, etc. Making significant improvements probably requires more fundamental assessment than just considering the failures arising from existing equipment, and the attribution of failure modes in existing Failure Modes and Effects Analysis (FMEA) studies need to include design.

Current development work in the UK is using predictive modelling (using the software F-Melba, see ref [8]) with practical testing to eliminate failure modes by optimising switch flexure, and tuning the distribution of forces according to the size of switch and the type of drive equipment. Switch flexure modelling is being used to optimise switch setup, achieve the right stretcher bar settings, balance and reduce switch machine load, demonstrate obstruction detectability, and compute the headroom between normal operation and failure to operate.

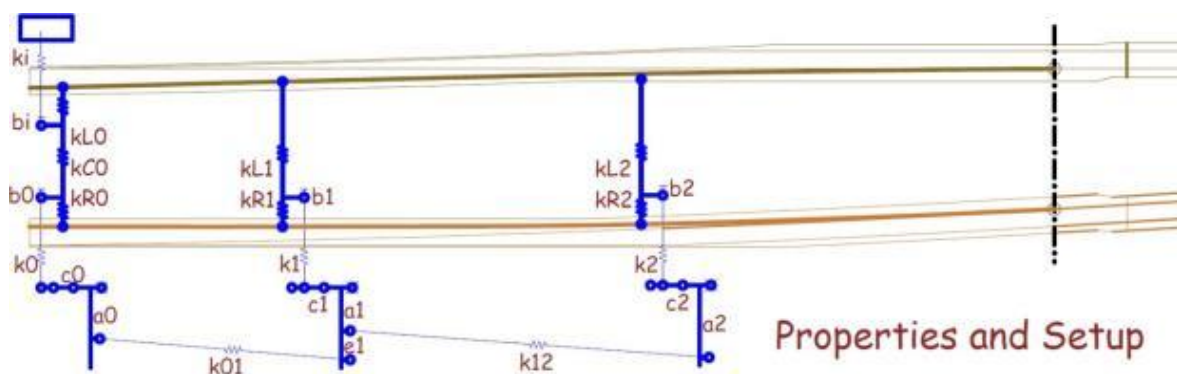
Ref [9] draws conclusions from an analysis of switch failures and identifies which switch types cause the most failures.

Other known root causes of failure for consideration include:

1. Thermal distortion leading to failures (especially in switch diamonds);
2. Installation/fitment of new equipment, which may have a profound effect on the performance of switches due to poor installation techniques). There is a need to design switches that have sufficient robustness to cope with stresses applied on components during installation (e.g. lifting operation of switches);
3. Seasonal effects of winter (ice and snow) by ensuring switch and POE designs take account of switch heating capabilities to maintain reliability and operation during periods of ice and snow build up.

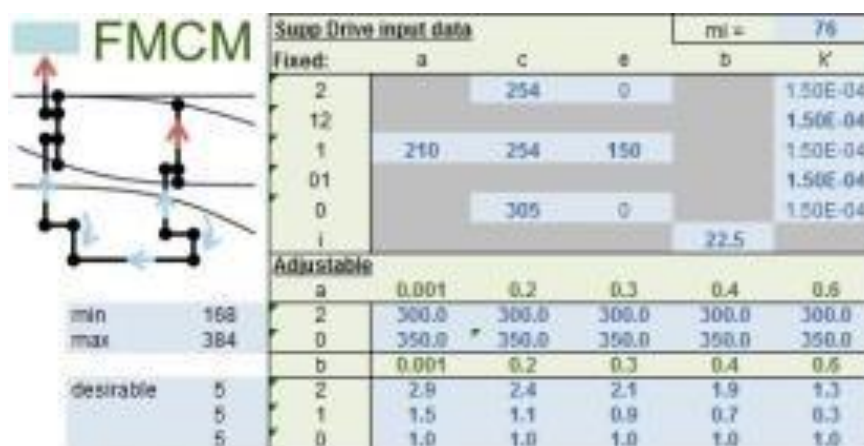
6. Flexure analysis related to failure data

Flexure analyses using F-Melba and FMCM have shown that some switches, particularly longer ones, fail due to deficiencies in available stroke and not just lack of thrust. The behaviour of a supplementary drive is complex with high redundancy in its setup and adjustments. The tools illustrate the effect of setup, tolerances, slideplate resistance and ranges of adjustment.



Where they have been used, the tools predicted solutions to problems and been found to be correct, and where they have been used to warn of potential problems the problems have been averted. Despite this the values of many of the variables aren't known in practice but are considered reasonable; also the assumptions made in the analyses are plausible but haven't been validated by practical tests. A possible consequence is that the results may be conservative. Research is welcomed in the general area of validation.

In one example in which a perfectly stiff supplementary drive behaved well with plenty of lost motion and adjustment, introducing flexibility into the mechanical linkages predicts that much of the stroke available from the switch toe is used up. This is a particular issue where the channel rod goes into compression and suffers buckling instability. Torsional supplementary drives are also flexible but much more predictable and should behave the same in both normal and reverse moves.



F-Melba Context Matrix

FVs with Point Machine		Stroke	coefficient of friction					
			0.001	0.2	0.3	0.4	0.6	
Run 1		backdrive thrust	26	1477.5	2081.6	2385.2	2688.8	3296.0
		mid drive thrust	41	0.0	0.0	53.1	263.8	685.2
		front drive thrust	53.5	124.9	259.4	327.0	394.5	529.7
detectability	1							
obstruction size	15	aggregated thrust usage		16%	43%	57%	70%	97%
stall friction coeff	0.000	residual opening		2.8	2.8	2.9	2.9	3.0
heel reaction	2035	rear slide stroke		1.0	0.9	0.9	0.8	0.8

We observe from many studies that a high proportion of switch failures is unexplained. The observed and recorded failure modes are all to do with maintenance. One possibility is that the switch subsystem design is the problem. The mechanical supplementary drive is particularly vulnerable to its setup and condition. Previous work on vertical switches highlighted the difficulties, in particular longer switches.

The tools and thorough testing are being applied to new designs of switches and the mechanical supplementary drive is being designed out of longer switches, but these solutions have relatively high first cost and there is reluctance to apply them to legacy switches. We need to provide guidance and increase confidence through evaluating more solutions to see if there are more affordable ones which meet the requirements.

7. Scope Refinement

Section 7 outlines the scope of work for WP2 Task 2.1 by considering knowledge gained through work completed within section 3 alongside the resources, timeframe and anticipated Technology Readiness Level (TRL3) to be achieved within In2Rail.

7.1. Scope of Work

Table 7.1 provides a summary of what has been deemed to be both in and out of the scope for WP2 Task 2.1.

In scope	Out of scope
Switch actuation system(s) if existing actuation is not compatible with novel switch locking mechanism	Power supply <i>This will be in scope at the detailed design stage (i.e. within Shift2Rail)</i>
Switch locking mechanism(s)	Uncommon, low population and low failure rate switch designs
Switch POE detection system(s)	Designing to withstand the loads associated with run-throughs
All major European rail profiles, switch designs and constructions	
Interface with existing signalling systems	
Consideration of degraded substructure	
Interaction with other systems (i.e. points heating)	
Weather resilience	
Compliance with existing European and individual infrastructure manager standards	
Understanding of the impact of and designing to ensure controlled failure during run-through conditions	

Table 7.1: Task 2.1 – Specific Extent of Scope

7.1.1 Railway Switch Standards

This section is aimed at describing the current standards that are applicable for Points Operating Equipment to help provide a set of universal requirements that should be met by the novel European locking and detection system.

7.1.1.1 EN13232 – Railway Applications – Track – Switches and Crossings

EN13232 covers the design and quality of switches and crossings in flat bottomed rail. The list of Parts is as follows:

- Part 1 : Definitions;
- Part 2 : Requirements for Geometric Design;
- Part 3 : Requirements for Wheel/Rail Interaction;
- Part 4 : Requirements for Actuation, Locking and Detection;
- Part 5 : Switches;
- Part 6 : Fixed common and obtuse crossings;
- Part 7 : Crossings with moveable parts;
- Part 8 : Expansion devices;
- Part 9 : Layouts.

Section 0 provided a summary of the key sections related to Task 2.1.

Part 3 deals with wheel/rail interaction through switches and crossings. For the anticipated wheel profiles for a given infrastructure the critical wheel/rail parameters can be calculated by individual IMs or their designers/suppliers using this standard. These include the minimum flangeway in switches, which in conventional switches can depend on the effectiveness and state of maintenance of the switches and of the point operating equipment.

Part 4 covers the design of switches from an operation viewpoint. The relationship between lateral movement of the switches and the lateral beam stiffness and distribution of actuation is discussed, with a view to defining the minimum flangeway and ensuring that the required value is achieved.

Part 5 tables manufacturing tolerances for switches and Part 7 for moveable crossings which have similar requirements including those for minimum flangeway.

UIC 716R describes how to assess whether the contact between a wheel flange and a switch is safe. If part of a wheel flange a wheel makes contact with a switch rail with range of contact angles around the flange tip (the contact danger zone) then there is a significant risk of wheel climb and consequent derailment.

It is a requirement of the design of switches to consider what would happen if an obstruction were to become lodged between a switch and a stock rail such that a switch would be held partially open yet be reported as closed by the detection system. In this circumstance the effective track gauge is reduced and/or the wheel encounters the switch

rail within the contact danger zone. Obstructions could be litter, ballast, broken rail fastenings or ice.

EN13231 Acceptance of works for in-service tolerances. Part 1 applies in general then part 2 applies for S&C (ref. Tables 1 and 2 of EN 13231).

7.1.1.2 Key points relevant for Task 2.1

There is a wide range of options for driving switches and some of these are covered in [7].

Key differences are the use of multiple individual actuators versus a single machine with a mechanical supplementary mechanism, machines which incorporate actuation, locking and detection versus those which do not and which work with separate locks and/or detectors, and switches wherein the individual switch rails are coupled (move simultaneously) versus those which are uncoupled.

7.1.1.3. Basis for developing new designs of POE equipment on existing S&C

Many failure modes arise out of this complex system and its many interfaces. Some results of failure analyses are discussed in 3.3.4. The justification for development of novel approaches is to eliminate significant failure modes as these failures often have a disproportionate effect on the cost of running the railway. See ref [9]. Improvements to reliability and maintainability are also justifications for development. See ref [10] for one suggested list of parameters to be considered.

The most critical area for making sure that the track is maintained well is near the switch toes, where reliable operation depends on having well supported switches. However it is this area where track support is often least well maintained, owing to operating rods and stretcher bars occupying the space needed to enable mechanised tamping. Tampability is therefore a critical attribute.

Ref [9] in section 2.6 describes the state-of-the-art as hollow bearer mounted drives which aim to achieve their superiority by enabling tamping. It should also be considered to what extent and where eliminating ballast from switches is beneficial. If full employment of non-ballasted track isn't viable, then non-ballasted switches should be considered on its own merits.

Ref [9] section 2.4 describes condition monitoring of S&C and will be referred to during conceptualisation of any novel detection systems within Task 2.1.

8. Fundamental Principles

This chapter aims to take a wider view of S&C fundamental principles related to the switch panel kinematics. An industrial overview of S&C kinematic principles provides information on some of the key principles and opportunities based on practitioner experience. An academic review of vehicle kinematics in S&C is then provided.

8.1. Industrial review of S&C Kinematic Principles

Continuous contact between the closed switch rail and the stock rail along the whole tapered part of the switch rail is considered to be an important quality requirement because gaps will tend to close under the lateral forces pertaining during traffic passage. Good contact between the closed switch rail and the distance blocks in the full-section flexing part of the switch rail is also a quality requirement for similar reasons. Both are normally checked at the conclusion of the manufacturing phase. Consistent gauge through the S&C unit will also help to reduce lateral forces.

When stretcher bars are assembled and the switches are coupled together, incorrect setting up may upset the zones of contact. There may also be gaps or 'residual switch opening' (RSO) when the switch is closed in one direction or the other. The effects of RSO are investigated further within section 8.3.

During service, lipping may occur to the stock rail running edges to the open switch side which then inhibits proper switch rail/stock rail contact. It is a requirement of maintenance to remove this lipping and restore the stock rail running edge periodically. Any system designed within Task 2.1 should consider such degradation of contact conditions between switch and stock rail. This is a very important factor in the material degradation of the switch. Periodic removal of the lip on the stock rail may still not be sufficient as the bending of the top part of the switch blade, under lateral loading, is sufficient to break it after only a short number of wheel passages. Consideration needs to be given to the use of a higher yield strength material for the stock rail. It is suggested that the design of the system within Task 2.1 should include consideration of materials.

The open switch should normally provide a minimum flangeway so that the backs of passing wheel flanges do not cause damage arising from repeated lateral impact (flange back contact (FBC)). Such impacts impart loading to stretcher bars, rods and POE components which may not be designed to withstand them. This had led to failures and derailments (e.g. Potters Bar, Grayrigg, and Hilversum).

Some switches incorporate provision for withstanding these loads and 'fully guarded switches' use the open switch rail as a guide. Others use a 'snipe cut' which removes material from the inside headcut at the rear to increase the minimum flangeway above what is achievable from the actuation system alone. Consideration of the loads generate during

FBC should be made during any detailed design of new systems interfacing with the switch rail and existing POE. The switch toe opening and resulting switch flexure should also be considered to optimise the overall switch position, particularly in relation to the minimum flangeway at the rear of the switch. Although the avoidance of FBC is highly desirable, it is also desirable to consider fatigue resistant design (including material selection and manufacturing technique).

Obstruction detection in many switch systems is provided for by using detectors in the point operating equipment. If there is an obstruction it can cause the switch rail not to close properly at its actuation points and this will be apparent to the detector. However if there is too much compliance in the drive train (e.g. if the rods are too flexible or loose or the drives are too far apart) then the point equipment will readily close the switch around the obstruction and the consequent reduction in gauge may lead to wheel climb and derailment. If the thrusts are distributed to several points along the switch and this distribution is uneven or unbalanced, then it will be easier for the machine to close around the obstruction and fail to detect it. More drive positions, stiffer load paths or additional detectors may help mitigate the problems. These are all possible opportunities to pursue within Task 2.1.

8.2. Vehicle Kinematics in Railway Switches – Academic Review

This section will give an overview of the kinematic principles for wheel-rail interaction in railway switches and their implications in terms of damage and opportunities for improvements in design and maintenance. Most parts of this section have already been published in (Pålsson 2014) which in turn is based on previously published work in (Pålsson & Nielsen 2012a), (Pålsson 2013) and (Pålsson 2015).

8.2.1 Wheel–rail guidance mechanisms

To better understand the geometrical conditions encountered when a wheel passes through an S&C, a short introduction to wheel–rail guidance mechanisms will be given inspired by the presentation in (Andersson et al 2007). Figure 8.1 illustrates the contact conditions for a wheelset with S1002 wheel profiles at two different lateral displacements on nominal 60E1 rails. The dashed wheel profiles illustrate the situation where the wheels are positioned on the rails with zero lateral wheelset displacement, $\Delta y = 0$, whereas the wheel profiles drawn with full lines correspond to a situation where the wheelset is displaced outwards, $\Delta y > 0$. Due to the conical shape of the wheels, the lateral and vertical locations of the wheel–rail contact points will change when the wheelset is displaced laterally, in particular for the right wheel which in this case is displaced towards the rail gauge corner and where the contact point is located on the wheel flange.

Also due to the conical shape of the wheels, the effective rolling radius for each wheel will change as the contact point location changes. This phenomenon can be illustrated using a

rolling radius difference diagram as shown in Figure 8.2. Here the difference in rolling radius between the left and right wheels is illustrated as a function of lateral wheelset displacement. As the wheels in a standard wheelset are rigidly connected via an axle, the rolling radius difference provides a counteracting steering effect as the wheel with the larger rolling radius will travel faster for a given rotational speed of the wheelset. A non-dimensional measure of the influence of lateral wheelset displacement on the difference in rolling radius, and thus steering, is obtained by the concept of equivalent conicity as shown in Equation (1).

$$\lambda_{eq} = \frac{r_r - r_l}{2\Delta y} = \frac{\Delta r_r - \Delta r_l}{2\Delta y} \quad (1)$$

Here $r_{r/l}$ are the rolling radii of the left and right wheels and Δ indicates a change. Note that the rolling radius difference is typically a non-linear function of the lateral displacement, as exemplified in Figure 8.2, which makes λ_{eq} a linearized measure that is only valid for a given lateral displacement amplitude.

If the equivalent conicity is low over a range of lateral rail and wheelset displacements, these displacements will have a small impact on the steering and the resulting lateral displacements of the wheelset, while a higher equivalent conicity will induce more steering. Further discussions on equivalent conicity and its connection to steering and running stability can be found in e.g. (Andersson et al 2007, Iwnicki 2006).

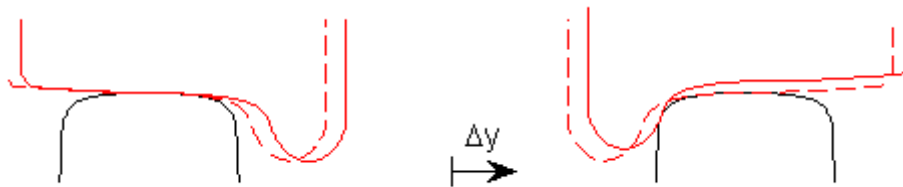


Figure 8.1: Illustration of vertical wheel movement and change of rolling radius with lateral wheelset displacement Δy . The lateral rail and wheel spacing is not to scale

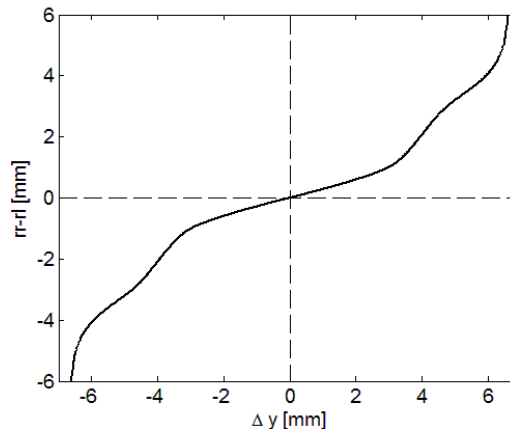


Figure 8.2: Rolling radius difference as a function of lateral wheelset displacement. Results for a nominal S1002 wheel on nominal 60E1 rails without inclination

8.2.2 Switch panel kinematics

A set of nominal composite rail profiles representing the switch and stock rails in the switch panel is shown in Figure 8.3. Due to the discontinuity at the separation between the deviating stock rail and the straight switch rail as seen in the figure, the rolling radius difference (r - r difference) curve is non-smooth in some areas. This can be observed in Figure 8.4, which shows the rolling radius difference in a contour plot as a function of wheelset position from the front of the turnout and lateral wheelset displacement Δy . The figure is based on the rail geometry in Figure 8.3 with an added nominal rail profile on the opposite side. The configuration is thus the same as in Figure 8.1 but with one nominal rail replaced by the switch rail cross-sections from Figure 8.3. Before the calculation of rolling radius difference, all cross-sections were positioned to achieve nominal track gauge (lateral rail spacing) for the switch panel. The wheel profile used is a nominal S1002 wheel profile and the rolling radius difference characteristics were calculated using GENSYS (Persson 2015). Note that only lateral wheelset movement towards the switch rail is considered here, but that Figure 8.4 is applicable for traffic in both the through and diverging routes.

Compared to the rolling radius difference characteristics obtained for a pair of standard 60E1 rails, which is visible in the diagram beyond 10 m, the composite profile combinations cause kinematic problems along most of the tapered switch rail that affect traffic in both the through and diverging routes.

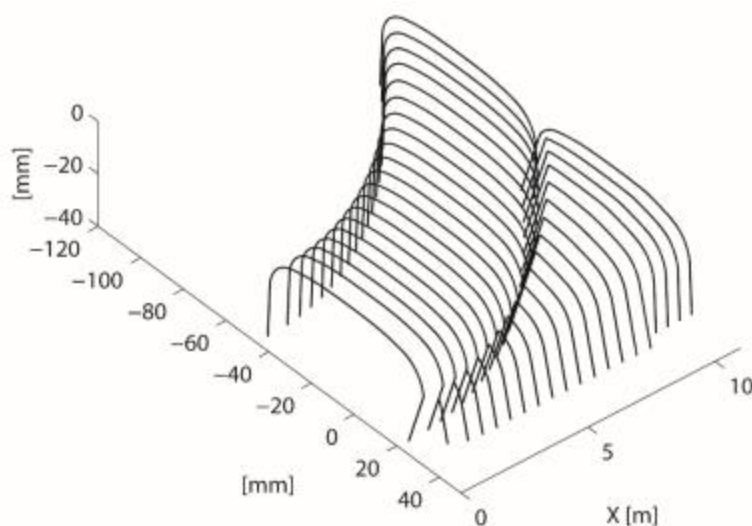


Figure 8.3: Nominal switch rail sections where X is the distance from the front of the turnout

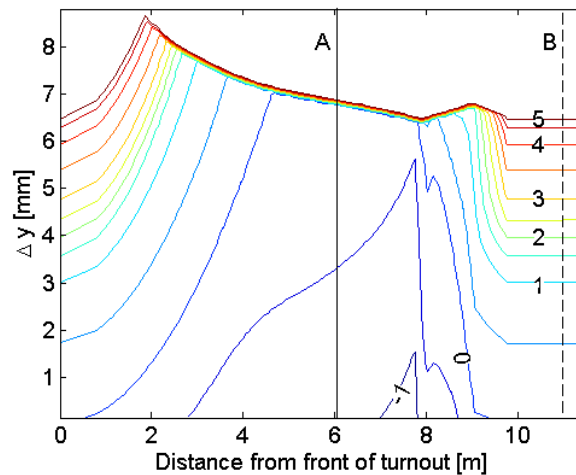


Figure 8.4: Contour plot of rolling radius difference [mm] as a function of lateral wheelset displacement towards the switch rail and position from the front of the turnout. The plot is based on the rail geometry in Figure 8.3 and a nominal S1002 wheel profile

The difference in rolling radius difference characteristics between sections can be studied in more detail in Figure 8.5. Here the rolling radius difference for the two cross-sections A and B in Figure 8.4 are plotted. It can be noted that the rolling radius difference characteristics at cross-section B, where there is a nominal 60E1 profile, is smooth and progressive and goes to zero for zero wheelset lateral displacement. This indicates that the rolling radius difference characteristics are symmetrical as can be expected when the rail profiles are the same on both sides as in Figure 8.2. At cross-section A, however, there is a rolling radius difference at $\Delta y = 0$ indicating an asymmetrical rail configuration. Then there is a small linear increase until the wheel flange makes contact with the switch rail leading to an abrupt increase in rolling radius difference. As this situation corresponds to flange climbing, it will typically not appear during normal negotiation of a switch. Instead the wheel will be subjected to a two-point contact situation with one contact point on the switch rail and one on top of the stock rail. The asymmetric rolling radius difference characteristics in the switch panel also make the wheelset steer towards the switch rail even if the track is straight as in the through route, as there is a negative rolling radius difference towards that side due to the deviating curved stock rail.

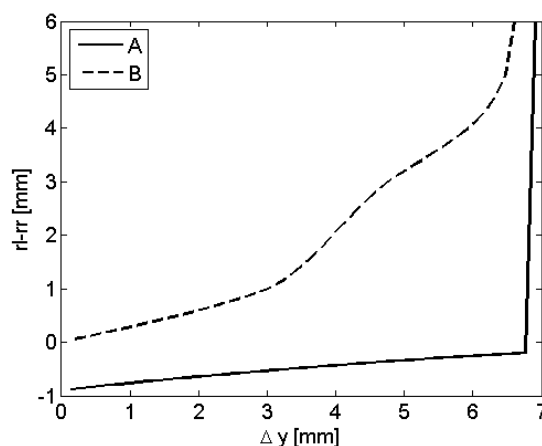


Figure 8.5: Rolling radius difference characteristics for sections A and B of Figure 8.4

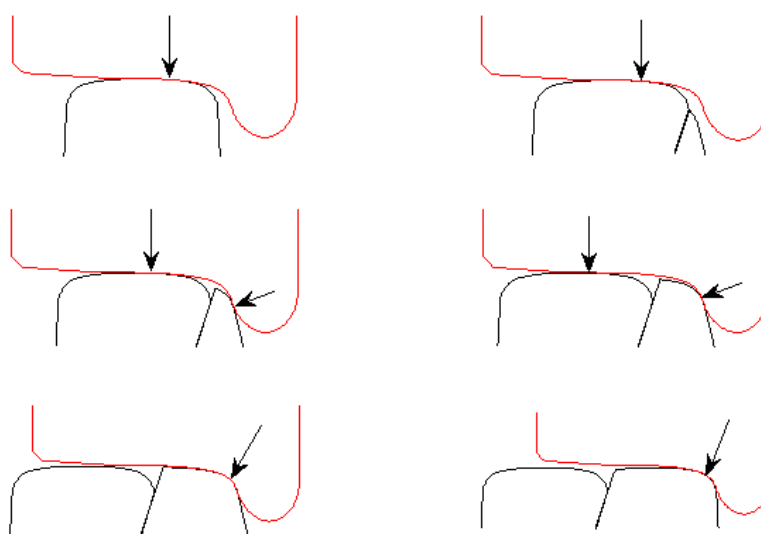


Figure 8.6: Schematic contact conditions and normal wheel–rail contact forces during a switch transition in the diverging route

A schematic presentation of the contact conditions when a wheel passes through the switch in the diverging route is presented in Figure 8.6. As the wheel is travelling on the outside rail of the turn it has to generate a lateral wheel–rail contact force. Due to the poor conicity properties related to the composite switch rail cross-sections, the wheel ends up in the above described two-point contact situation which causes poor steering, high lateral force on the switch rail and significant amounts of wear as the difference in rolling radius between the contact points induces relative motion between wheel and rail in the contact points.

8.2.2.1 Implications

In order to reduce forces and wear due to the unfavourable contact conditions and rolling radius deficiency in a switch, design changes that reduce the distance travelled with a two-point contact situation are desirable. Example strategies to achieve this are to increase the height and thickness of the switch rail to allow for an earlier wheel transition to the switch rail. Such changes can also be combined with gauge widening solutions that allow more space for a thicker switch rail.

8.3. Switch Rail Tolerances and Derailment Risk

The objective of this study is to assess the risk of derailment for traffic in the facing move of a switch as a function of residual switch rail opening and switch rail height. In addition, the associated risk of interference contact between wheel and the tip of the switch rail is considered. The residual switch rail opening is the gap between stock rail and switch rail that remain when the switch is closed. The switch rail height in this study is simply a vertical offset of the switch rail (positive downwards) used to mimic a lowering of the switch rail profile due to wear. The residual switch rail opening δ and the switch rail height offset Δ are illustrated in Figure 8.7.

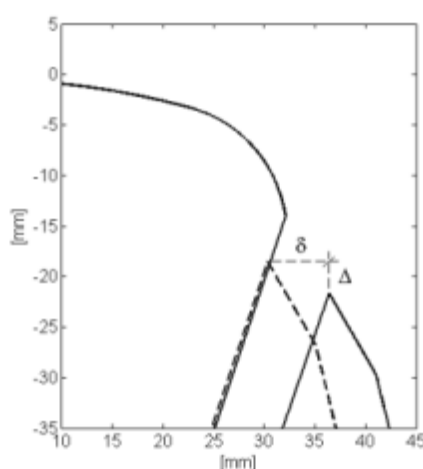


Figure 8.7 - Illustration of residual switch rail opening δ and switch rail height offset Δ

8.3.1 Assessment methods

To investigate the risk of derailment, dynamic simulations of train-track interaction are carried out using the commercial Multi Body Simulation package SIMPACK (Simpack 2016). To investigate the risk of interference contact between the tip of the switch rail and passing wheels, both the dynamic and a kinematic assessment is performed.

8.3.2 Wheel profiles

According to the UIC standard 716 R Maximum permissible wear profiles for switches (UIC 2004), both new and worn wheel profiles should be considered if both the risk of derailment in switches and the risk of interference contact between wheel and switch rail tip is to be assessed. The new profile and its comparably low flange height and low contact angles makes it the most likely wheel profile to climb the switch rail and derail. The wheel profile with the worn flange is in the greatest risk of interference contact with the tip of the switch rail as its flange height is typically higher and the flange angle larger (steeper) than for a nominal wheel.

The worn flange profile used in this study was created using the dimensions given in Figure 3 of UIC 716 R. This profile has the minimum allowed qR of 6.5 mm and a flange height Sh of 34 mm. In the standard the worn flange is used as a worst case scenario in the creation of a gauging template to measure the risk of interference contact between switch rail and wheel. As only the flange is specified by the standard, the reminder of the profile is in the shape of a nominal S1002 wheel profile. Both profiles are illustrated in Figure 8.8.

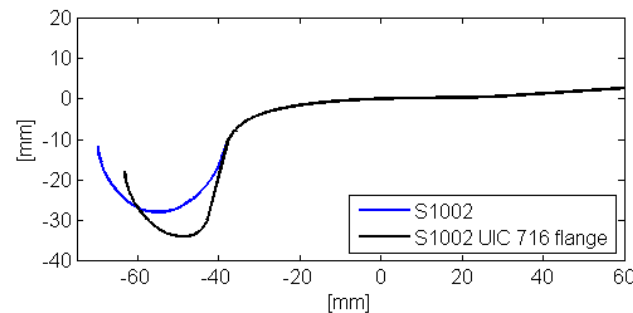


Figure 8.8 - Nominal S1002 wheel profile and S1002 wheel profile with worn flange from UIC 716

In order to get an impression of feasible values for the residual switch opening during normal operational conditions, a sample of 120 measured wheel profiles from freight trains (Pålsson & Nielsen 2012b) have also been considered in the kinematic study.

8.3.3 Switch geometry description

The switch rail geometry for this study comes from drawing 9-511401 of the Swedish railway administration (Trafikverket) which describes the geometry of a switch rail for a UIC60-R760-1:14/1:15 turnout. The numeric profile data needed for simulations has been created from the drawing data using the in-house script MakeSwitch (Pålsson 2013). For I2R the script has been updated to create individual rail cross-section of stock rail and switch rail which makes it easy to investigate the influence of relative displacement between switch rail and stock rail such as residual switch opening. For I2R the script has also been updated to account for the 60° profile chamfer stretching from the tip of the switch rail to a point about 5 m from the tip along the switch rail. With this chamfer included the profile data created with MakeSwitch is in full agreement with the drawing. The drawing considers rails with zero inclination. Assuming that the same switch rail milling depths apply also for rails with inclination, switch rail geometries based on rails with 1:30 inclination have been created using a switch rail profiling tool with zero inclination. In order to obtain switch rail geometry data for turnouts of other radii the same rail cross sections have been used, but their longitudinal spacing has been adjusted to fit the smaller switch radius. The two first rail cross-sections specified by the drawing, the tip and a section 200 mm from the tip, are presented in Figure 8.9.

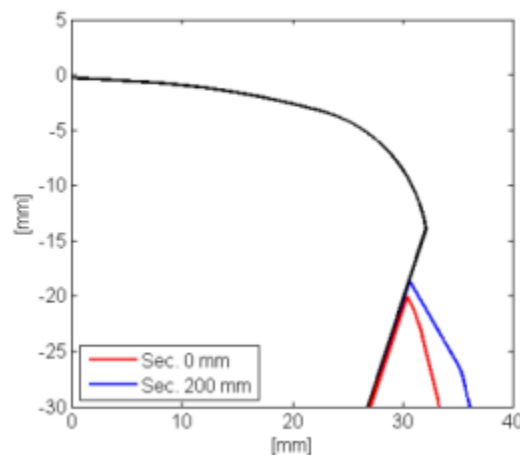


Figure 8.9: Switch rail cross-sections for switch tip and 200 mm from the tip

8.3.4 Dynamics assessment

In this study the commercial simulation code SIMPACK was used to simulate train-track interaction in a small radius switch.

8.3.4.1 Simulation Set-Up

The following simulation set-up was chosen to achieve a critical case with respect to derailment and interference contact:

- The vehicle model was the two axle freight vehicle from the Manchester simulation Benchmarks (Iwnicki 1998). This vehicle was chosen as two axle vehicles typically exhibits worse curving performance, and hence larger risk of derailment, compared to bogie vehicles;
- Traffic in the facing move of the diverging route in a switch with radius $R=190$ m. This is because a smaller curve will generate larger lateral forces and a larger risk of derailment, everything else being equal;
- The vehicle enters the switch coming from a curve of 190 m radius in the same curving direction as the diverging route of the switch. In this way the leading wheelset is already at its largest lateral displacement towards the outside of the turn at switch entry. This running condition thus maximises the risk of the oncoming wheel to climb the switch rail;
- The wheel-rail friction was set to $\mu=0.5$;
- The speed was 40km/h which is a standard limit for a freight train in a 190 m curve;
- The leading wheelset is assessed as it runs with the hardest flange contact through the curve and switch and is thus the most critical case;
- Changes in both δ and Δ are applied to the full length of the switch rail as this is considered to be the most conservative implementation;

- The sampling frequency corresponds to one data point per 5 mm;
- The wheel profiles of Figure 8.8 were used to investigate derailment risk and interference contact respectively;
- Switch rails with 1:30 inclination were considered.

A numerical grid of δ and Δ values was evaluated by running the above simulation set-up for all combinations of δ and Δ with both values varying from 0 to 15 mm in 1 mm discretization steps. The assessment criteria were derailment and interference contact between the tip of the switch rail and the wheel flange. Derailment was assessed using wheel lift. If the vertical wheel displacement was larger than 6mm at any time while travelling along the tapered part of the switch rail, a derailment was assumed. The reason for a wheel to reach more than 6mm lift was flange climb on the switch rail. The risk for interference contact was estimated by measuring the distance from the tip of the switch rail and the longitudinal position of the first wheel contact on the switch rail.

8.3.4.1.1. Modelling limitations

SIMPACK only considers 2D rail cross-sections in its contact point search. It does account for a change in wheel profile contour and longitudinal movement of the contact point due to wheelset yaw. Due to this limitation it is not possible to evaluate how the oncoming flange would interact with the tip of the switch rail as the full 3D body isn't accounted for. It is however possible to study the case of flange climb derailment under tangential contact conditions and whether there is an interference contact between wheel and the tip of the switch rail based on output data for contact positions and whether there is a rapid lateral wheelset displacement at the switch rail tip in order for the wheel to pass it.

8.3.4.2 Results and Discussion on Derailment Risk

The wheel lift results from the evaluation of the δ - Δ grid are presented in Figure 8.10. Red squares indicate derailment while blue circles mean no derailment. It can be observed that only Δ has a significant influence on the derailment risk and that a vertical offset of more than 9 mm is required to provoke a flange-climb derailment for this simulation case.

As the nominal distance from Top of Rail (ToR) to the highest point on the tip cross-section is 20 mm, this distance is above 29 mm for the simulated derailments. According to Swedish measurement templates (Trafikverket 2010) the highest point on the tip of the switch rail is not allowed to be more than 25 mm below ToR.

The nominal vertical distance from ToR to the 200 mm Section is 18.5 mm. According to Swedish maintenance limits (Trafikverket 2010) the switch rail is not allowed to be lower than 22 mm from ToR for a distance of 200 mm or more. This requirement only concerns the switch rail from 200 mm from the tip and beyond. With a lowered switch rail of at least 9

mm at derailment the vertical distance from ToR to the 200 mm Section is 27.5 mm (18.5+9 mm).

According to these simulation results there should thus be a significant margin to derailment if these two maintenance limits are utilized.

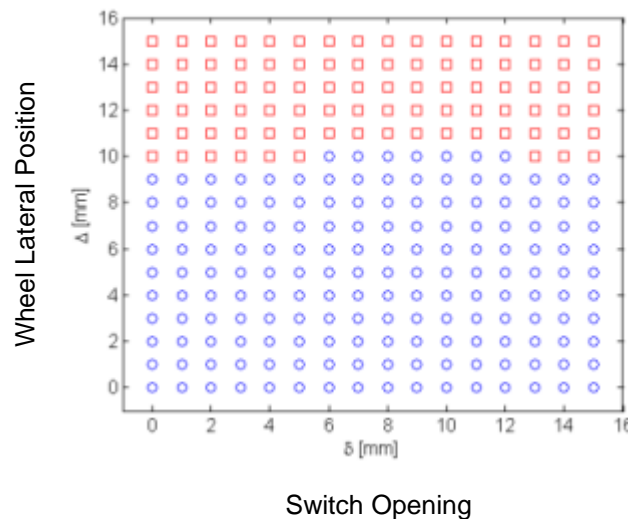


Figure 8.10: Derailment (red squares) or no derailment (blue circles) as a function of δ and Δ . S1002 wheel profile

8.3.4.3 Results and Discussion on Interference Contact

The risk of interference contact between wheel flange and the tip of the switch rail is estimated using the measure Θ defined as the longitudinal distance between the tip of the switch rail and the location of the first contact point between wheel and switch rail.

Contour plots of Θ as a function of the evaluated δ - Δ grid are presented in Figure 8.11 for the S1002 wheel profile and in Figure 8.12 for the UIC716 R worn flange profile. Due to the discretization of the output data and what appears to be a slight smoothing of the discrete jump in profile geometry on behalf of SIMPACK, all Θ values below 25 mm can be assumed to correspond to interference contacts. Comparing Figure 8.11 and Figure 8.12 it can be observed that the worn flange has a larger risk of interference contact with the switch rail tip as the 25 mm iso-line covers a larger portion of δ and Δ values. This was also the expected result according to UIC716 R. It can also be observed that a lower switch rail tip reduces the risk of interference contact for both wheel profiles as expected.

In the simulations, interference contact or overlap between the oncoming wheel and the tip of the switch rail resulted in a rapid lateral displacement of the wheelset proportional to the overlap. The magnitude of this displacement also corresponds to a large impulse with high peak loads. It should be noted that for large δ -values and large overlap between flange and switch rail tip the more likely outcome in reality would probably be that the wheel flange climbs on top of the switch rail rather than being pushed sideways. These simulations should

thus only be indicative of interference contact, not the following events. In the UIC 716 R code there is a geometric method to determine whether there is a risk of flange climb derailment in the case of interference depending on how the highest point of the switch rail is positioned relative to the oncoming wheel contour.

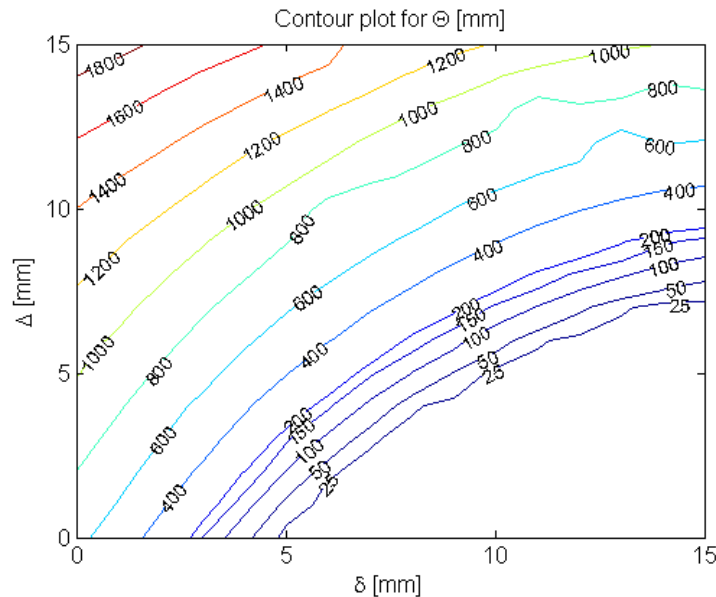


Figure 8.11: Contour plot for Θ as a function of δ and Δ . S1002 wheel profile

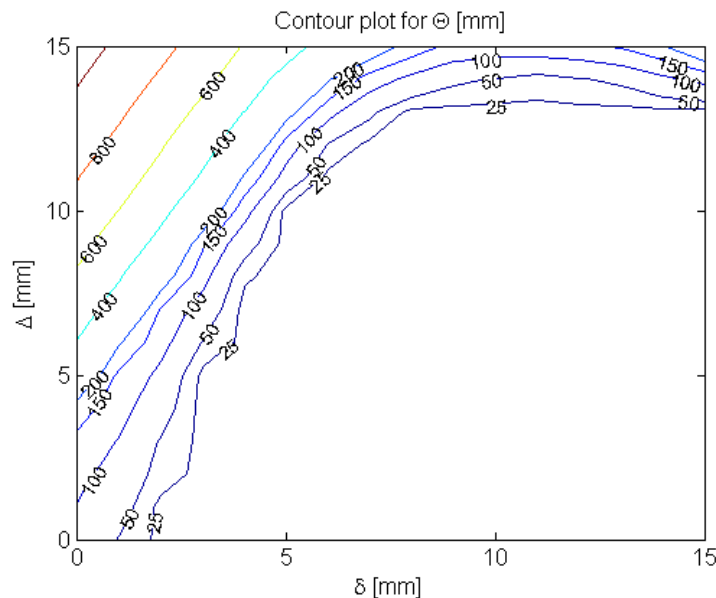


Figure 8.12: Contour plot for Θ as a function of δ and Δ . UIC 716 R worn flange profile

8.3.5 Kinematics assessment

In this section it is investigated how large residual switch openings that can be allowed while still avoiding interference contact between switch rail and passing wheels. Thus, in this study only δ is considered as $\Delta=0$ is the most critical case for interference contact. This study is performed on the two rail cross-sections of Figure 8.9 with zero and 1:30 inclination.

8.3.5.1 Method

The GENSYS (Persson 2015) module kpf was used to evaluate the possible contact conditions between a given wheel and rail profile. This module create tabularised data of wheel-rail interaction quantities intended for multi body simulations, and one of the outputs is the contact point locations on wheel and rail as a function of lateral wheelset displacement. From these data it was found whether any switch rail contact was present for all wheelset displacements corresponding to less than 5 mm wheel lift for a given combination of wheel profile, rail profile and residual switch opening δ .

8.3.5.2 Results

Results for a nominal S1002 wheel profile on the different rail sections and inclinations are presented in Table 8.1 and results for the UIC 716 R worn flange in Table 8.2. By studying the difference in residual switch opening δ at the first wheel to switch rail contact, it can be observed that the contacts appear for smaller δ for the worn flange as expected. The general trend is also that contact is obtained for smaller δ for the rails with 1:30 inclination. As the section of the tip of the switch rail (Section 1) receives better protection by the stock rail than the section at 200 mm (Section 2), a larger residual switch opening can be tolerated before contact is obtained at this section.

Wheel profile	Rail	Section	δ at first contact
S1002	60E1, inc. 1:30	1	6
S1002	60E1, inc. 1:30	2	4
S1002	60E1, inc. 0	1	6
S1002	60E1, inc. 0	2	5

Table 8.1: Feasible residual switch openings for Nominal S1002 wheel profile and various rail cross-sections

Wheel profile	Rail	Section	δ at first contact
UIC 716 R	60E1, inc. 1:30	1	3
UIC 716 R	60E1, inc. 1:30	2	0
UIC 716 R	60E1, inc. 0	1	4
UIC 716 R	60E1, inc. 0	2	1

Table 8.2: Feasible residual switch openings for S1002 wheel profile with UIC 716 R flange and various rail cross-sections

Comparing the δ -values for Section 1 and 1:30 rail inclination in Table 8.1 and Table 8.2 with the results of the dynamic study in Figure 8.11 and Figure 8.12 which were obtained for rails with 1:30 inclination, it can be observed that the results are in good agreement.

Example contact conditions from this kinematic study can be found in Figure 8.13 and Figure 8.14.

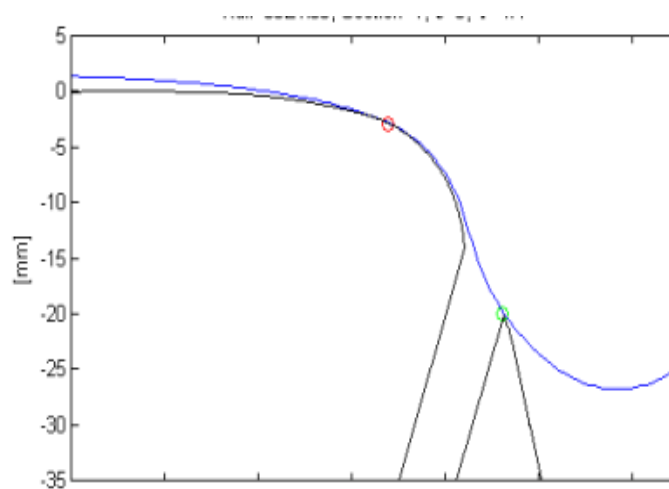


Figure 8.13: S1002 to switch rail contact for $\delta = 6$ at Section 1 with zero inclination rails

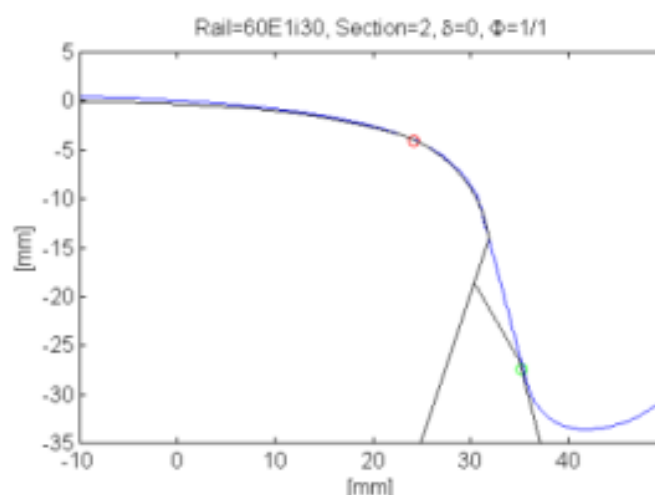


Figure 8.14: UIC 716 worn flange profile to switch rail contact for $\delta = 0$ at Section 2 with 1:30 inclination rails

The kinematic study was also performed for a set of 120 measured freight train profiles. As a fraction of the number of wheel profiles in contact for different levels of the residual switch opening. The δ -values for obtained contact are in the range between the nominal S1002 profile and the worst case flange from UIC 716 R of Table 8.1 and Table 8.2. Example contact conditions are illustrated in Figure 8.15 and Figure 8.16.

δ [mm]	1	2	3	4	5	6	7
Inc. 0, Sect 1,	0	0	0	0	82/120	119/120	120/120
Inc. 30, Sect 1,	0	0	0	27/120	107/120	120/120	120/120
Inc. 0, Sect 2	0	0	24/120	104/120	120/120	120/120	120/120
Inc. 30, Sect 2,	0	0	69/120	119/120	120/120	120/120	120/120

Table 8.3: Fraction of wheel profiles from measured sample of 120 wheel profiles in possible contact with the switch rail as a function of residual switch opening. Various rail cross-sections. 60E1 rails

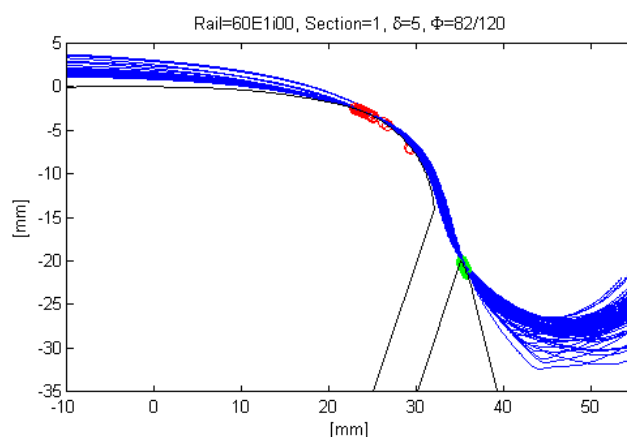


Figure 8.15: Wheel to switch rail contact for $\delta = 5$ at Section 1 with zero inclination rails for 82 out of 120 measured wheel profiles

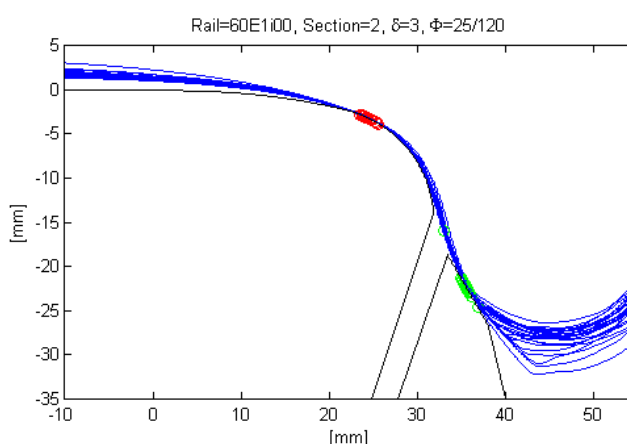


Figure 8.16: Wheel to switch rail contact for $\delta = 3$ at Section 2 with zero inclination rails for 25 out of 120 measured wheel profiles

8.3.6 Conclusions

The presented studies support the requirement for the residual switch opening to be max 3 mm if interference contact between wheel and switch rail is to be avoided. If this requirement is to be challenged the wear tolerance limits for wheel profiles, and hence the requirements on the wheel profiles that are allowed to pass, must be questioned.

Whenever dimensions of components that degrade through wear are the subject of discussion, it is also necessary to consider the impact of material selection as any changes to limits of dimensions will influence LCC.

This Section has investigated the risk of flange climb derailment for freight traffic in the diverging route of a small radius switch using multi body simulations and the risk of interference contact between the tip of the switch rail and passing wheels using multi body and kinematic simulations. The studied switch geometry was based on 60E1 rails.

According to the presented simulation case a rather large lowering of the nominal switch rail, at least 9 mm, is required to provoke a flange climb derailment for a two axle freight train with nominal S1002 wheel profiles. For reference the largest lowering that can be tolerated

by Swedish maintenance standards for the studied geometry is 5mm. The nominal profile poses the greatest risk of derailment due to its low flange height and shallow flange angle compared to a worn wheel profile. The result therefore suggests that there is plenty of margin against derailment in these standards. It should be noted though that in this study a worn switch rail is mimicked via the lowering of a nominal switch rail which can mean that the rail profile geometry might not be the worst case scenario for a given profile height.

The presented dynamic and kinematic studies have shown that the maximum gap that can be allowed between switch rail and stock rail is in the order of 2-3 mm if interference contact between the switch rail tip and passing wheel flanges is to be avoided. The study was performed for the worst case worn wheel flange as referenced by UIC 716 R.

The results are in agreement with the regulations of e.g. The Swedish Railway Administration which state that the maximum allowed gap between stock rail and switch rail tip is maximum 2 mm at inspection [13]. A similar requirement is posed by Network Rail where the switch rail locking detection allows for a deviation of 2.5-3.5 mm depending on asset. This agreement is not surprising as the worn flange in these simulations is the very same wheel profile used by UIC716 R to define inspection templates which in turn are used by many infrastructure managers for reference when tolerances are defined. Given the current limits on wheel profile dimensions, it is therefore difficult to relax requirements for the residual switch opening which would in turn relax the requirements for switch detection and locking to any large extent. It should be noted that the UIC 716 R doesn't use the worn wheel flange directly to construct the inspection templates and does allow for some interference contact between flange and switch rail tip. The assessment in this study should therefore be a few mm more conservative than a direct application of the UIC716 R templates would specify.

8.4. Switch Flexure Handbook

A study has been carried out to consider how the behaviour of lateral switch flexure can influence the relationship between this and the actuation, locking and detection systems of point operating equipment (POE).

The paper discusses possible modelling options that could be investigated further that would increase the understanding and conclusively prove the theory behind this paper [8].

The ability of a point machine to adequately operate and lock a switch, with sufficient headroom (simple fault tolerance) between available force and required force and range of movement, is investigated in the UK by means of the mathematical model F-Melba [8] either to investigate causes of failure or at the design stage prior to physical testing. This technique can identify first where switch systems are most likely to fail and second how point equipment can be configured more appropriately to give reliable service.

9. Fault Tolerance and Redundancy

Chapter 9 explores the concept of introducing additional fault tolerance and redundancy, through novel design, into existing EU POE systems.

There are two methods an engineer can take to improve the reliability of a system:

- make it perfect (improve the mechanical/electrical design or the metallurgy/manufacturing process);
- make it fault tolerant (it can keep operating after a component fails or can new materials/designs eliminate existing failure modes).

Fault-tolerance is the property that enables a system to continue operating properly in the event of faults within some of its components. Fault-tolerance is particularly important in high-availability or safety-critical systems. This should include fault tolerant:

- Sensors;
- Actuators;
- Process/System parts;
- Processors;
- Communications;
- Control Algorithms.

Examples of fault tolerant designs with multiple redundancy are relatively commonplace in aerospace and nuclear applications, driven by certification requirements (and/or legislation). Equivalent systems in lower cost and non-safety-critical applications still need to be developed, and there is some progress in e.g. manufacturing plant and automotive applications (for safety and cost reasons).

With regard to Novel S&C locking mechanisms, in making such a mechanism fault tolerant, we might consider redundant sensors for detection purposes and redundant actuators for locking purposes.

9.1. Sensor redundancy

A sensor (or sensor system) can be thought of as being fault tolerant if it remains operational with one sensor fault present. There are two basic approaches to redundancy; static and dynamic:

The first of these is considered to be hardware or functional redundancy in that we have multiple sensors, functionally identical in any given position, and by relatively simple means judge which sensor to ignore should it fail and rely upon the remaining measurements.

Secondly, analytical redundancy (soft sensors) uses data available to the control system from other sources to provide an estimate of a data that may become unavailable due to a failed sensor.

In simple systems, where determination of only one parameter is required, analytical redundancy may be an unnecessary complexity. Installing sensors measuring several parameters and using some form of analysis to estimate the one parameter of interest may be an excessive step. Providing three identical sensors, all directly measuring the required parameter would be sufficient. However, if data from several different sensors is already available, then redundancy can be achieved analytically without the need to add multiple sensors in each functional location. The decision for which is very much based upon the application's criticality and the relative financial and time cost to the overall system.

Care should be taken when considering the physical installation of multiple sensors for the purpose of redundancy. Multiple sensors in the same location may not provide adequate redundancy as all sensors will be subject to the same environmental effects and may all fail together (or within a short time of each other).

9.1.1 Static Redundancy

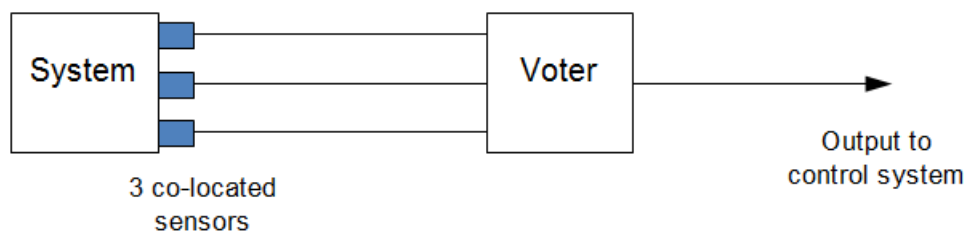


Figure 9.1 : Static Redundancy Schematic

Static Redundancy requires 3 or more sensors, see the schematic in Figure 9.1. Should the state of any one disagree with the other two, the voter disregards the sensor(s) in the minority. Three sensors allow 1 fault to be tolerated. In general, a voting system with n sensors can tolerate m faults, where $m = n - 2$.

9.1.2 Dynamic redundancy

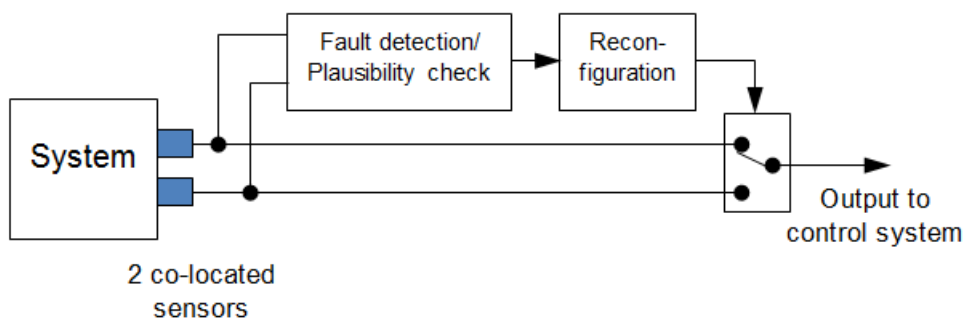


Figure 9.2: Dynamic Redundancy Schematic

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 9.2. Dynamic redundancy using 2 sensors allows 1 fault to be tolerated. In general a dynamic system with n sensors can tolerate m faults, where $m = n - 1$.

9.1.3 Analytical redundancy

Analytical redundancy removes the need for two or more functionally identical sensors in a given location; however it requires data from alternative sources/sensors. Non-identical sensors and process models are used. Each sensor and model is providing estimates of the outputs of other sensors in the system/module. 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. [12] at Loughborough University has been published in this field.

In the example in Figure 9.3, we can measure steering angle directly, but we can also make an estimate of the steering angle from other information available from alternative sensors.

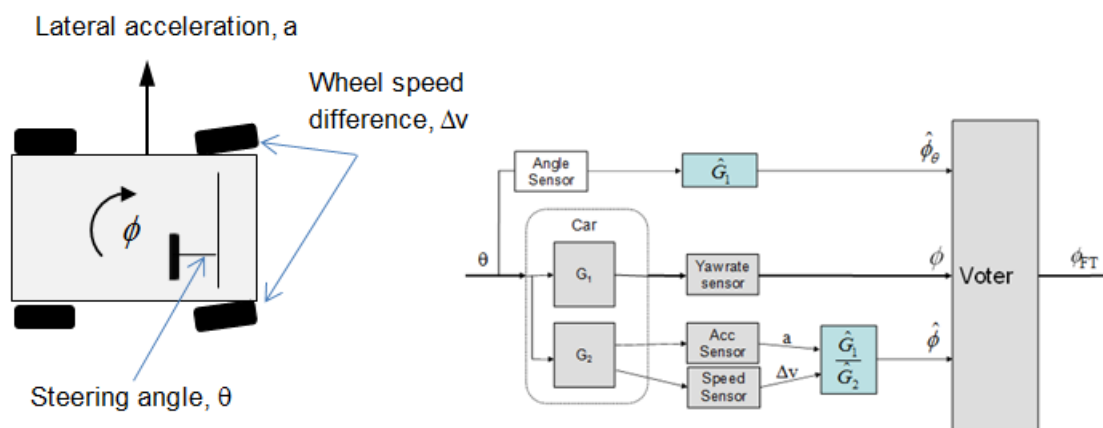


Figure 9.3: Analytical Redundancy Schematic

Combinations of vehicle speed, yaw rate, lateral acceleration and wheel speed difference allow an estimate of the steering angle to be made. We can use this estimate to understand whether the single steering angle sensor is giving a reliable value. Should that value be deemed unreliable, we may be able to vote out the direct measurement and use the estimates.

9.2. Actuator redundancy

Fault tolerance is generally harder for actuators than for sensors as they often transform large quantities of energy and tend to be physically large. The basic function of an actuator is to transform a signal into an effect in the real world. Hence they tend to comprise some generic elements. The model shown in Figure 9.4 below is typical of many actuators, although the number of the basic elements may change. A signal from the controlling

system is converted into the real world effect of opening a valve. Sensors within the actuator may provide feedback to the controlling system.

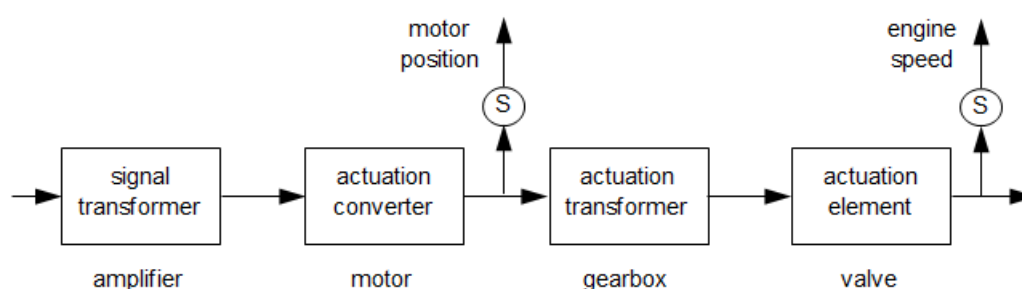


Figure 9.4: Typical Actuator Schematic

The basic approaches to fault tolerance and fault detection are very similar to those for sensors. Concepts of static redundancy, dynamic redundancy can still be applied:

- Static – no detection and reconfiguration (switching) is required;
- Dynamic – detection of a fault and reconfiguration.

9.2.1 Static redundancy

The simplest method of providing redundant actuations is to provide one or more additional actuators in parallel. When providing two actuators, in order to be able to complete the actuation function with one failed actuator, each actuator must be able to perform its function alone and must be specified accordingly. If three or more actuators are provided, it is possible to reduce the actuator capability as we may be able to assume that any one actuator will not have to drive the system alone.

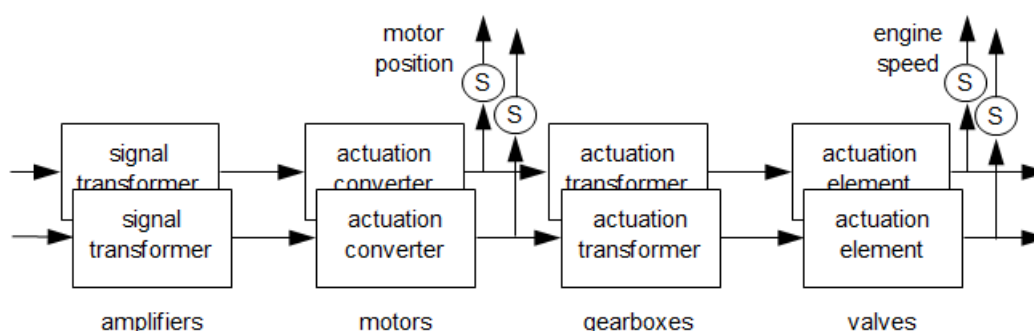


Figure 9.5: Static Actuator Redundancy

In aerospace flight control applications it is usual to provide two or three independent actuators per function. Each with an independent hydraulic power source, independent and separately routed wiring, and each able to provide the full control force necessary, should the others fail. In a weight critical environment such as aerospace, the emphasis given to fault tolerance and fail safe design is evident.

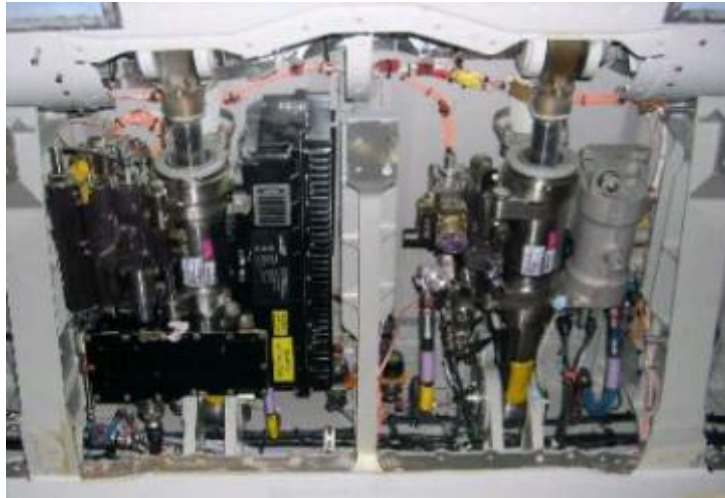


Figure 9.6: Aileron actuators on an Airbus A380

Figure 9.6 shows the aileron actuators on an Airbus A380. The aircraft has two hydraulic systems; each of the two actuators shown is powered using a different system. On the right is a hydraulic actuator; on the left is an electric backup hydraulic actuator (EBHA). The EBHA has a built in electric pump to provide hydraulic power in case of hydraulic system failure.

Rather than duplicating the complete actuator, it is possible to enhance the fault tolerance of an actuation system by limiting redundancy to the lowest reliability parts of the actuator, for example:

- Dual servo-valves on a single hydraulic actuator;
- Dual or Triplex windings (and power electronics) in an electrical motor;
- In drive-by-wire automotive throttle the wiper on the potentiometer is doubled up to make this part of the actuation system statically redundant.

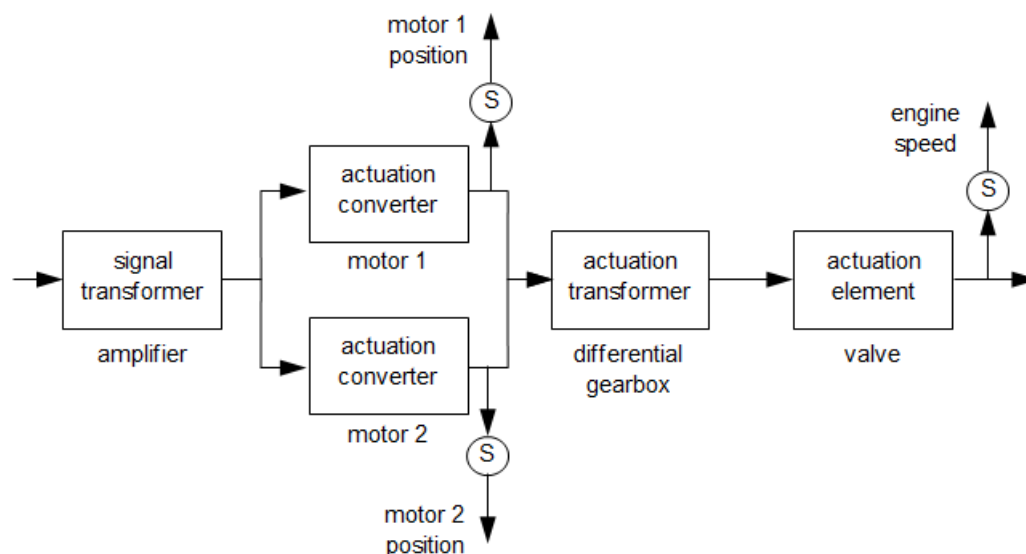


Figure 9.7: Limited redundancy, duplicating the least reliable part of the actuator

This approach as illustrated in Figure 9.7, is also shown in Figure 9.8 where the valve actuator has an additional motor.



Figure 9.8: Fuel valve twin-motor actuator

Figure 9.8 shows a typical aerospace fuel valve twin-motor actuator. The valve body and pipework are hidden from view in the fuel tank beyond the bulkhead. Top left and top right are the connectors for the independent wiring for the two motors that are bottom left and bottom right. In the centre is the reduction and differential gearbox that allow either motor to drive the output shaft to the valve. The gearbox had a manual drive/lock function.

The redundant parts of the actuator system can be at any level:

- Electrical:
 - at the signal level,
 - dual control processors, one amplifier,
 - at the electrical power level,
 - dual processors, dual amplifiers and windings, single rotor (electric motor);
- Hydraulic/Pneumatic:
 - at the working fluid level,
 - dual pump, single actuator (or motor),
 - tandem actuator (two hydraulic supplies);
- Mechanical:
 - planetary gearbox, clutch (rotary),
 - parallel attachment to moving actuation surface (linear),
 - triplex flight surface actuator.

9.2.2 Dynamic redundancy

On-going Research at in the Control System Group at Loughborough University aims to develop intrinsically fault tolerant actuation through high redundancy. This uses a large number of actuator elements, each contributing only a small part of the force necessary. Single element faults have little effect on the overall performance of the actuator.

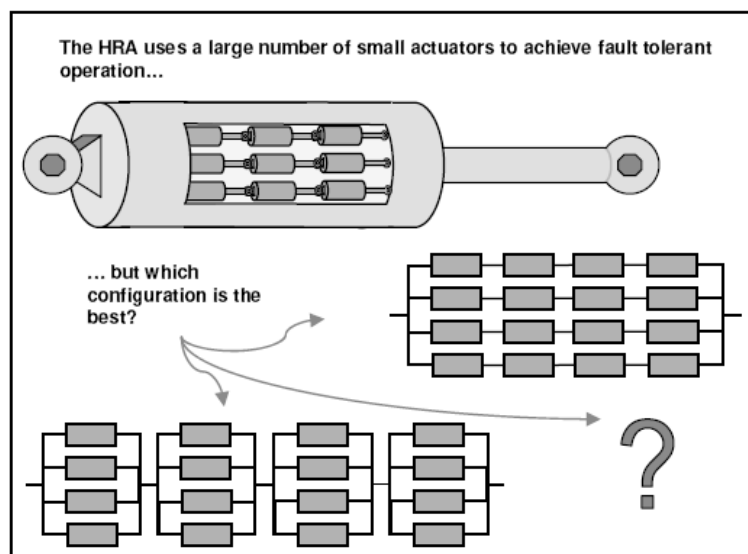


Figure 9.9: Schematic of fault tolerant actuation concept at Loughborough University

Future research intends to:

- consider possible configurations;
- analyse the fault tolerance;
- investigate control strategies;
- compare active (reconfiguration) and passive (robust) methods of control;
- build a demonstration rig.

Work on High Redundancy Actuation that may be applicable to this application has been undertaken at Loughborough University by Steffen et al. [13].

9.3. Redundancy concepts for Common UK Point Operating Equipment

The designs of the POE in use on the UK rail network today incorporate features that rule out some of the redundancy concepts outlined above. At the complete switch level, adding fault tolerance through redundancy would require a new actuation and locking concept. This is considered to fit better within the scope of Task 2.3 – Radical Mechatronic S&C Concept. However, some features of the existing designs lend themselves well to improving fault tolerance by incorporating redundancy.

9.3.1 HW and style 63

The detection and locking is heavily integrated into the point machine. If a point machine fails in the locked position, having a second adjacent point machine for redundancy would be of no benefit, as the points would remain locked in position by the failed machine.

As a direct replacement for either HW series or style 63 point machines, an electromechanical point machine could be devised where individual elements within the machine are duplicated. However without fundamental changes to the drive/locking mechanism, it must remain a single point failure system.

Position detection is by contacts within the point machine driven by detection rods. There is potential to apply fault tolerant sensor design to this mechanism.

9.3.2 Clamplock

Potential exists for redundancy in actuation, locking and detection. Redundancy could be achieved throughout the hydraulic drive system, although the space available for duplicate actuators could be restrictive. Careful design of any redundant locking mechanism would be needed to ensure that a failed locking mechanism is able to be released, but that the locks cannot be overcome by back-driving the mechanism.

Detection is by switch contacts driven by cams/levers at rail level. There is potential to apply fault tolerant design to this mechanism.

9.3.3 HPSS

The HPSS design incorporates redundancy to some extent, e.g. 2 LVDTs, 2 brakes on the gearbox. A redesigned gearbox with differential gearing could accommodate 2 motors. Should one motor fail, the remaining motor would be able to drive the points at half speed.

Locking is achieved using a screwjack, which by design cannot be back driven, so redundant elements cannot be introduced.

Detection uses LVDTs (Linear Variable Displacement Transformers), one at the toe end and of the points and, optionally, a second at the supplementary drive location. As a non-contact, limited moving part device, the LVDT is likely a more reliable device than traditional contacts; however use of LVDTs requires controlling electronics, adding another possible source of failure. Duplication of the LVDT at each location would add redundancy. It may be possible to use the different values from the toe end and supplementary LVDTs for analytical-type redundancy.

9.4. Reliability Analysis

Track switches are safety critical assets which provide flexibility to rail networks, but, as demonstrated within chapter 5, also present single points of failure. Switch failures upon dense-traffic passenger rail systems cause a disproportionate level of delay. Subsystem redundancy is one of a number of approaches that can be used to ensure appropriate safety integrity and / or operational reliability level, successfully adopted by, for example, the aeronautical and nuclear industries.

Loughborough University are completing a reliability analysis of POE systems through use of 2P-Weibull failure distributions for each functional POE subsystem (based upon 40,000 sampled failure events over 74,800 years continuous operation), the reliability block diagram (RBD) approach to model the static reliability effects of engineering fault tolerance, through subsystem redundancy, into existing switching systems and, finally, using the RBD's with a Monte-Carlo simulation approach in order to model the availability of redundantly engineered track switches over expected asset lifetimes.

Although the detailed analysis is not yet available for inclusion within this deliverable, initial results indicate that switch designs utilising a multi-channel redundancy approach can significantly improve switch reliability and availability and are therefore worth further investigation. Significant increases in whole-system reliability have been demonstrated in a range of possible implementations.

A further interesting and very noteworthy conclusion from this analysis is that, in a redundantly engineered system, the dominant contributor to system unreliability comes from human interaction [14].

10. System High-Level Requirements

In order to allow innovation and creativity during the conceptual design phase of Task 2.1, a high-level set of fundamental system requirements have been established. These have been divided into both functional and non-functional requirements.

10.1. Functional Requirements

Any system developed within Task 2.1 must be capable of being retrofit to a range of European switch designs. To establish a set of universal, European functional requirements, a study of the European Standard EN 13232 – Railway Applications – Track – Switches and crossings was completed. The detailed assessment of the requirements from this standard can be found within Review of EN 13232.

Following the review of EN 13232 and consultation with Infrastructure Managers within WP2, a detailed set of system requirements were established (see Appendix C). At this point, it became immediately apparent that enforcing such a prescriptive set of requirements would stifle innovation and creativity within the project. For the development of conceptual design from the ideas generated within Chapter 11, the following key functional requirements were set:

1. The mechanism shall adequately lock the switch rail in the correct position

- a) It shall be strong enough to withstand existing POE drive forces.
- b) It shall apply a locking force sufficient to maintain the position of the switch rail under dynamic loading from rail vehicles.

2. The mechanism shall operate alongside existing POE sub-systems (Actuation, Lock & Detection (ALD)) and provide additional detection of the switch rail position

- a) It shall not affect the performance of any existing POE sub-systems that remain as part of the overall ALD system.
- b) It shall provide additional redundancy to the any existing lock and detection systems.
- c) It shall enable the switch system to operate in a degraded mode upon failure of part of the ALD system and it is still confirmed safe to pass trains.
- d) It shall not increase unreliability or faults.

3. The mechanism shall confirm to the interlocking the route vehicles will be directed along and that all active elements are safe for the passage of trains

- a) It shall provide feedback to the interlocking that a requested route is set.
- b) It shall provide feedback to the interlocking if the requested route is unable to be set.
- c) It shall provide feedback to the interlocking on (3a) and (3b) within a given timeframe.
- d) It shall not affect the operation of the existing signalling system (i.e. identical signals (as per existing ALD systems) shall be sent to the interlocking).

4. The mechanism shall provide maintenance information regarding ALD system degradation

- It shall monitor the ALD system performance and inform the maintainer if any part of the lock and / or detection system fails (i.e. enabling pro-active maintenance).
- It shall achieve a given level of reliability commensurate with the operations at the switch system.
- It shall minimise the amount of time the switch system is unavailable due to maintenance activity and the amount of time maintainers must spend trackside.

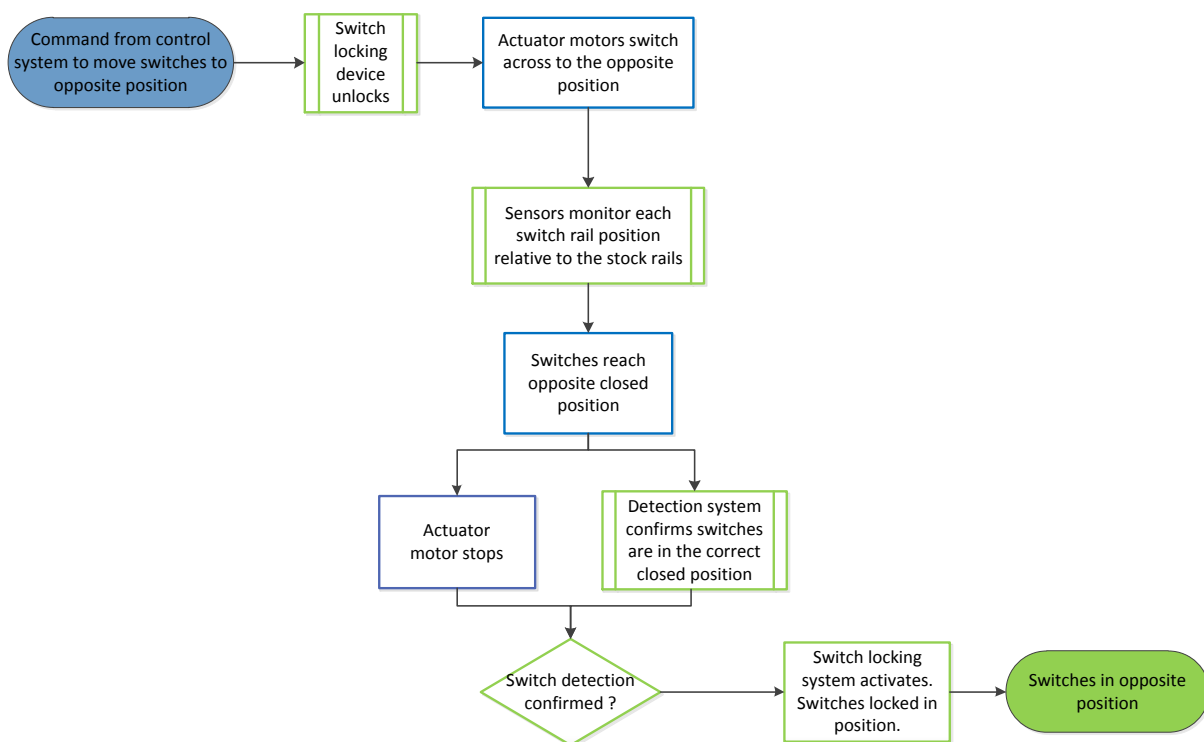


Figure 10.1: Switch actuation, locking and detection process flow chart

10.2. Non-Functional Requirements

Non-functional requirements are those that cover additional business, spatial and safety requirements. Unlike the functional requirements, which must all be satisfied by the final system design, the non-functional requirements can be traded off against each other depending on how relevant they are to specific applications of the technology. For instance, in some locations / asset types, space may be a premium (i.e. installing a new piece of equipment onto a switch diamond or slip switch layout will present difficulties with regards to physical space available for installation). In these situations, compromises on the non-functional aspects of the ideal specification may be necessary.

The non-functional requirements adopted for the novel switch locking mechanism mirror those identified the existing Repoint project [2] and include:

- **Degree of Fault Tolerance:** Major benefits have been discussed around introducing sub-system redundancy into existing railway switch systems. Any new technology applied to the existing system must have the net effect of reducing the whole-system failure modes and enable the switch to operate in a degraded mode (i.e. enhanced fault tolerance).
- **Design Adaptability:** Switches must handle many types of traffic at many speeds. Whilst it could be argued many different designs could fulfil these different purposes, a single, adaptable design is preferable.
- **Whole-Life Cost:** Whole-life cost of the system related to initial purchase and installation through to additional maintenance and decommissioning costs, estimated using engineering judgement.
- **Space Utilisation:** Any new concept must be capable of being installed within the existing footprint of EU railway switch systems without compromising other remaining systems (i.e. if existing actuation is maintained, this must not be negatively affected by the proximity of any new equipment).
- **Energy Requirements:** Any energy requirements must be within the reasonable capabilities of existing power supplies.
- **Ease of Manufacture:** Able to be mass-manufactured using existing techniques and processes.
- **Likelihood of Acceptance:** The rail industry has strict process and standards regarding the design of products for use upon the network.
- **Switching Speed:** If the concept involves modifications to or replacement of the POE actuation system, faster switching speeds are deemed to be better.
- **Maintainability / Modularity:** There are pressures to reduce the amount of time personnel spend performing maintenance tasks trackside. Does the design help to achieve these ambitions? Any new system should be designed with modularity in mind. Is it easy to replace the system in cases of damage or failure?
- **Standardisation:** Can the design maximise the use of COTS components, or minimise custom components?
- **Human Factors:** Maintenance teams and trespassers may be exposed to movable elements of the switch. How big the risk is posed compared to that currently present?

Each requirement is then compared, contrasted and scored against the others in order to assess their importance weighting. Comparing the requirement from each row with those in each column, if the row is deemed to be more important than the column, a 1 is scored, for equal importance, 0.5 is scored and for lower importance, a zero is scored. Figure 10.2 illustrates the final importance weighting matrix for a POE sub-system design.

Non-Functional Requirements Weighting Matrix													Weighting (w)
	Degree of Fault Tolerance	Design Adaptability	Unit Cost	Space Utilisation	Energy Requirements	Ease of Manufacture	Likelihood of Acceptance	Switching Speed	Maintainability	Standardisation	Human Factors	Total	
Degree of Fault Tolerance	-	0	0.5	1	1	0.5	0	1	1	1	0.5	6.5	0.12
Design Adaptability	1	-	0	1	1	0.5	0	1	0	0.5	1	6	0.11
Whole-Life Cost	0.5	1	-	0	1	0.5	0	1	0.5	0	0.5	5	0.09
Space Utilisation	0	0	1	-	0.5	1	0	1	0.5	1	0.5	5.5	0.10
Energy Requirements	0	0	0	0.5	-	1	0	0	0	0	0	1.5	0.03
Ease of Manufacture	0.5	0.5	0.5	0	0	-	0	0	1	0.5	0	3	0.05
Likelihood of Acceptance	1	1	1	1	1	1	-	1	1	1	1	10	0.18
Switching Speed	0	0	0	0	1	1	0	-	0	0	0.5	2.5	0.05
Maintainability	0	1	0.5	0.5	1	0	0	1	-	0.5	0.5	5	0.09
Standardisation	0	0.5	1	0	1	0.5	0	1	0.5	-	1	5.5	0.10
Human Factors	0.5	0	0.5	0.5	1	1	0	0.5	0.5	0	-	4.5	0.08

Figure 10.2: Non-Functional Requirements Weighting Matrix

In preparation for evaluating a range of conceptual designs emanating from Task 2.1, the above weightings have been included within a concept evaluation matrix. Figure 10.3 demonstrates a blank concept evaluation matrix with only that benchmark set for existing state-of-the-art POE systems. The concept evaluation process will include scoring each of the non-functional requirements in comparison to the existing state of the art. This will be achieved using engineering judgement from a carefully selected panel of industry experts. Accurate completion of the concept evaluation will provide a ranking to help identify concepts suited for further detailed design and recommendations to Shift2Rail. A common outcome of this process is the combination of different concepts to achieve an optimised solution.

	State-of-the-Art			Concept									
	w	Now	Max	A	B	C	D	E	F	G	H	I	J
Degree of Fault Tolerance	0.12	5	5										
Design Adaptability	0.11	5	5										
Whole-Life Cost	0.09	5	7										
Space Utilisation	0.10	5	5										
Energy Requirements	0.03	5	6										
Ease of Manufacture	0.05	5	7										
Likelihood of Acceptance	0.18	10	10										
Switching Speed	0.05	5	6										
Maintainability	0.09	5	5										
Standardisation	0.10	5	6										
Human Factors	0.08	5	5										
Weighted Sum	5.90909	6.37273	0	0	0	0	0	0	0	0	0	0	0
Rank													

Figure 10.3: Concept Evaluation Matrix

The state-of-the-art scores are based on the full POE system, therefore careful consideration must be made for how a novel 'bolt-on' system will impact upon overall switch performance.

11. Idea Generation and Initial Concepts

In order to collect the expert knowledge contained within each of the partner organisations contributing to WP2 Task 2.1, a structured ideas generation approach was implemented. This section of the report summarises the approach taken and the outcome achieved.

11.1. Ideas Generation Process

The process adopted during the ideas generation workshop is called the 'OptiKrea Process' and is summarised within the flowchart illustrated by Figure 11.1, which also highlights the stages completed prior to and during the workshop and those progressed outside of the workshop within Task 2.1.

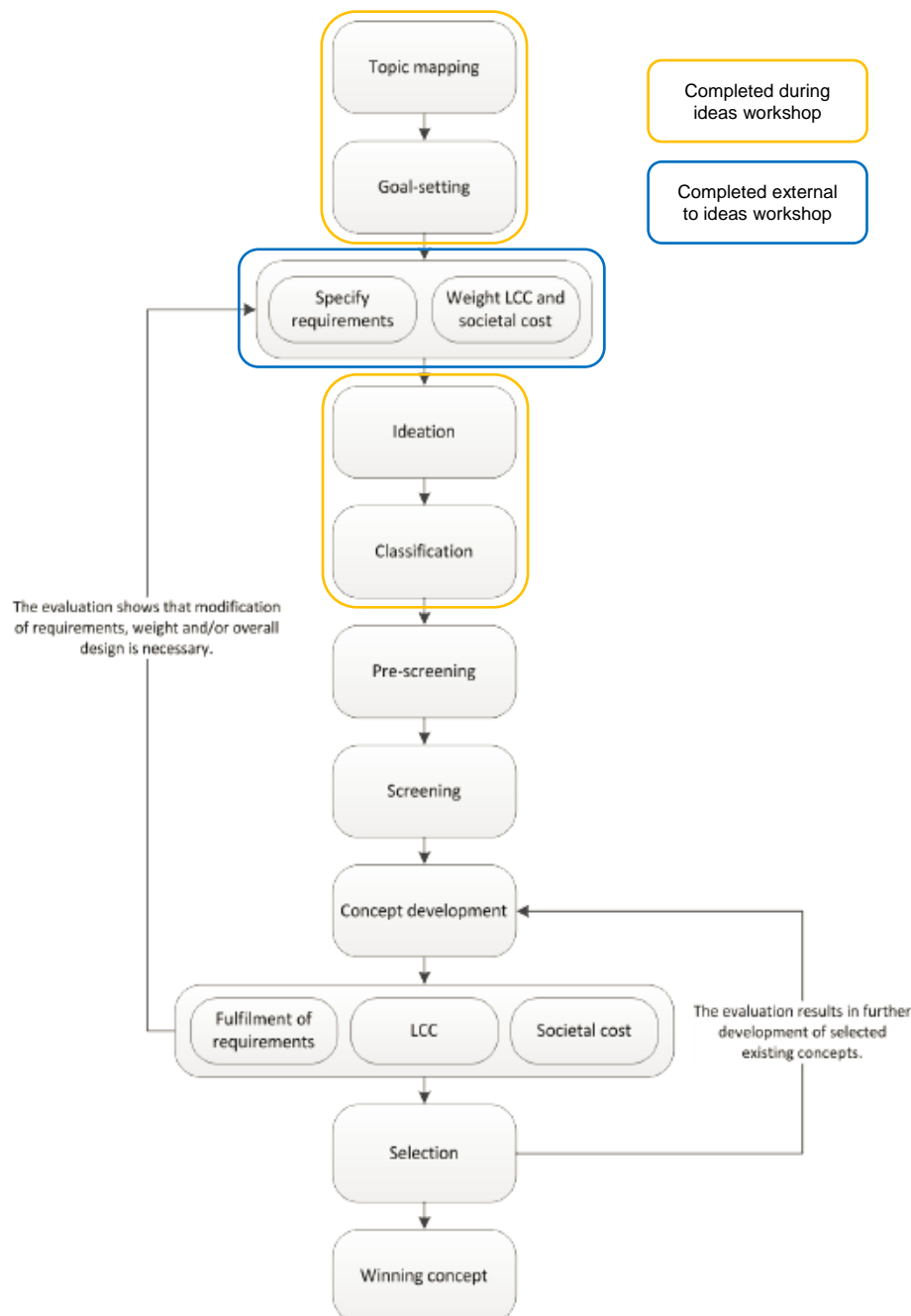


Figure 11.1: OptiKrea Idea / Concept Generation Process Flowchart

11.1.1. Topic Mapping

The first stage included describing the topic area in some detailed based upon a predefined set of topic mapping questions. The answers to each question were discussed during the workshop to help ensure that all those involved in the ideas workshop maintained a common view of what we were trying to achieve. The topic mapping questions and responses can be seen within table 10.1.

#	Topic Mapping Questions	Task 2.1 (Novel S&C Locking)
1	What are the issues with the present product? Why does it need to be exchanged or modified?	The failure of S&C locking and the consequential loss of detection is a very significant failure mode that has a profound influence on the overall performance of the rail network.
2	What is the problem really about and wherein lies the greatest need?	The assurance that the switch blade is locked in the correct position is such a fundamental safety issue that the detection of the locked position of a switch blade a critical measurement that is often unreliable.
3	Who wants the problem to be solved and why?	Infrastructure managers suffer the financial and reputational losses as a consequence of failure and need to reduce these events.
4	What are the (root) causes of the problem?	Locking and detection of the locked condition is not often measured in a reliable way resulting in both false positive and negative detection conditions.
5	What functions should the product perform, now and in the future? What tasks should the product be able to solve?	Reliable locking and reliable positive confirmation of the locked position.
6	What properties should the product have/not have?	<i>To be established during conceptual design as not to stifle innovation and creativity at this early stage</i>
7	What requirements does the environment where the product will be placed bring with it?	All equipment to be at least IP68 rated in accordance with EN 60529 and take account of the assumption that equipment will be immersion in water due to flooding at some point during its operation.
8	What non-obvious wishes, requirements and expectations are present?	Locking mechanisms could be performed by means other than mechanical obstruction.
9	What possibilities are open and which are not open in achieving the product?	Use of prime movers / locks based on: <ul style="list-style-type: none"> • Hydraulics • Electro-mechanical • Electro-magnetic
10	What alternative products exist?	Limited
11	What standard requirements exist? What legislation?	A number of NR standards exist that control the interaction of the wheel profile and rail during the passage through a switch and this is largely about prevention of derailment mechanisms.

#	Topic Mapping Questions	Task 2.1 (Novel S&C Locking)
12	What are the requirements/wishes regarding upgrading?	The objectives and desired outcomes are as stated in each of the WP tasks and link back to the core operational and cost benefits as identified in the In2Rail DoW submission.
13	What technical, organizational, environmental and ergonomic trends exist?	S&C detect failures are still the prime cause of operation disruption to the network and this is not decreasing at the desired rate. At the same time the overall LCC are increasing.
14	Are there former projects (or procurements) that are relevant for the present topic?	Not specifically, but work task to conduct thorough literature searches on relevant previous project findings.
15	How large is the product volume expected to be?	Take current population of EU S&C in Main lines.
16	Are there other aspects to consider?	Can the current main population of locking devices be improved in the short term without the introduction of a new locking and detection system?

Table 11.1: Topic Mapping for Task 2.1 - Novel S&C Locking Mechanisms

11.1.2. Goal Setting

The objective of formulating a goal-setting is to make sure that all participants have the same interpretation of what the project should achieve and to act as a reminder during the project. The goal-setting should form a high level objective for the project and be of 1-3 sentences long. Following the topic mapping session, each participant presented their view of the goal-setting, which were then discussed and a common objective agreed.

The goal-setting for WP2 Task 2.1 is to:

“Develop ideas for new ways of locking existing switch systems. Develop new detection techniques that introduce redundancy and reliability into the existing switch system”

11.1.3. Specify Requirements / Weight LCC and Societal Costs

Due to the nature of the In2Rail project and the aspiration for innovation and creativity, it was agreed that setting specific system requirements and approximating life-cycle and societal costs would not be beneficial at this stage of the project. These are essential requirements for a more detailed assessment of conceptual designs and will form part of the value analysis to be completed in the latter stages of In2Rail.

11.1.4. Ideation / Classification

This OptiKrea ideation process is described within OptiKrea Ideation Method and the outcome presented within Ideation Outcome (A3 Sheets). Following the Ideation process,

classification and grouping of the ideas was completed and is presented within Idea Classification and Grouping.

The following categories of idea emanated from the workshop:

1. **Visual / Camera:** multiple ideas for additional switch rail detection related to the use of visual aids for confirmation of switch rail position. An example includes using HD camera system mounted to a range of locations in and around the switch panel whilst using pattern recognition for switch position detection.
2. **Contact:** A range of ideas involved measuring the position of the switch rail using a physical 'block'. Examples include the use of 'intelligent' baseplates to detecting the position of the switch rail footprint, introducing a physical block to prevent the switch rail from closing / opening (i.e. similar to Autochock as described within section 4.2.2) and developing a new 'wedge' lock system to force the switch rail into the stock rail.
3. **Non-contact:** In contract, a collection of ideas used non-contact solutions for both the locking and detection aspects of the POE system. Examples include the use of electromagnets, radio frequencies and infra-red sensors.
4. **Modelling:** A more novel idea that came out of the workshop, which did not fit within the previous categories, was the use of modelling techniques to predict the shape and position of the switch rail. This idea, termed 'Data-Fusion'.

11.1.5. Screening

At this stage in the project, it was decided not to exclude any of the ideas through the screening process until a degree of further feasibility work was completed. A selection of ideas are currently being expanded upon and will form a discrete set of concepts for further work and aligning to the system requirements established within section 10, above. Chapter 12 presents some of the preliminary work in this area and will be concluded within In2Rail WP2 Deliverable D2.2.

11.1.6. Identification of Technology Used in Other Industries

A review of external industry sectors has been completed to understand if other technology solutions that align with the requirements for actuation, locking or detection systems exist.

Identified technology solutions have been evaluated for the possible transfer to a railway environment. Further detailed investigation of those solutions that have been assessed as having the potential to work in a railway environment will be carried out.

Table 11.2 collates a range of existing technologies, from other industries, that have the potential to be transferred into the rail industry as part of a novel switch locking and / or detection system.

	Technology	Industry	Application
Actuation	Door lock actuator	Automotive	Used in central locking systems for automobiles. Works in conjunction with the locking mechanisms found in the doors to unlock/lock the mechanism so that the door can be opened or kept locked.
	Magnetic door lock	Security locks	Used for access control, usually found on. Button operated magnetic lock release.
Locking	Interference fit (Friction fit)	Various industries	One application where interference fit can be done and undone is anti-loosening fastening systems such as Hard Lock nuts. Performance may degrade after a number of cycles.
	Electronic contact plates	Automotive	Used as a part of central locking systems for automobiles to detect whether the door is closed which forms a circuit or gives a warning on the dashboard.
Detection	Cable actuated displacement sensor	Various industries including Aerospace	Used to measure linear displacement of bellows in manned (MAV) and unmanned aerial vehicles (UAV).
	Ultrasonic displacement sensor	Various industries including Automotive	Mounted on car bumpers to aid drivers during parking. Also available with electromagnetic technology.
	Laser sensor	Various industries including manufacturing	Used to measure the thickness of mineral cotton. Also used to measure thickness of pre stressed steel.
	Colour cameras	Various industries including Manufacturing and Food industry	Used in optical sorting machines for food applications and other commodities such as rice. The machines are able to distinguish the colour of rice grains and can separate the bad grains of rice from good ones while they pass through at a very high flow rate.
	Eddy current sensors for distance, displacement and position	Automotive Manufacturing	Used to detect rotor dynamics of turbochargers. Also used to monitor secondary movement of pistons and piston rings. Used in milling machines to compensate for axial extension of milling spindles.

Table 11.2: Existing technology across other industries

Table 11.3 then identifies the possible options that will be under consideration for detailed design in advance of the subsequent deliverable D2.2.

Options	Technology	Advantages	Disadvantages
Laser sensor – web mounted	Laser sensor	<ul style="list-style-type: none"> • Laser beam is visible in daylight, simplifies adjustment; • Accurate; • Accounts for vertical travel in switch rail; • Non-contact – should require minimal maintenance. 	<ul style="list-style-type: none"> • Harmful to humans; • Grease and other contaminants may obstruct laser; • Requires a reflective surface which may be prone to corrosion.
Proximity sensor – Rail pad mounted	Inductive proximity sensor	<ul style="list-style-type: none"> • Can be embedded in the Rail Pad therefore not hindering the ability to tamp 	<ul style="list-style-type: none"> • Grease or other contaminants may obstruct sensor; • Capability is restricted due to limited choice of sensor type; • Not as accurate as it will not measure the distance between the Switch Rail and Stock Rail.
Magnetic locking/detection system	Electromagnetic	<ul style="list-style-type: none"> • Existing holes in the web of the rail can be used for mounting; • Can be used for locking and detection; • Compact; • Proven the application of doors for industrial and domestic purposes. 	<ul style="list-style-type: none"> • Performance affected by temperature; • Cancels the benefits of any run through safety systems; • May need adjustment over time; • Electromagnetic Interference from trains and other sources will impair performance.
Electrical contact plates – Track circuit	Electrical circuit	<ul style="list-style-type: none"> • Can be set up as an independent Track Circuit; • Existing power supply can be used • Spring system ;allows contact to be made when within the safe limit (3.5 mm). 	<ul style="list-style-type: none"> • May not function if rails are misaligned due to track geometry faults; • Prone to wear and tear as it is a contact system.

Options	Technology	Advantages	Disadvantages
Cable Actuated Displacement sensor	Inductive Encoder Potentiometric Syncro or resolver technologies	<ul style="list-style-type: none"> • Robust – Used in aircrafts including military where sensor; • Cable system can incorporate different types of sensors. 	<ul style="list-style-type: none"> • May give false reading due to not being able to take into account vertical movement of the switch rail; • Cable may break over time due to wear and tear; • Selection of suitable sensors is limited due to harsh environment.

Table 11.3: Option currently under consideration for detection redundancy

11.1.6.1. How do these technologies influence future concepts?

The combination of ideas and existing technologies presented within this report provide a basis for conceptualisation, detailed design, final option selection, risk assessment, hazard identification and finally development of virtual and / or physical prototypes. They cover a range of detection technologies, both contact and non-contact, and are a highlight of technologies that already exist in different applications. These ideas can be adapted or developed further to suit our chosen application, which is to detect the switch rail position relative to the stock rail, at all times.

Chapter 12 describes some of the early stage conceptualisation work, which will be progressed to full detailed design and feasibility assessment within Deliverable D2.2.

12. Conceptual Design

Chapter 12 begins to introduce some preliminary concepts that have been progressed from the ideas generated within Chapter 11. It should be recognised at this stage that additional concepts are under development but were not sufficiently refined to report within D2.1.

12.1. Generation of Design Concepts

12.1.1. Benchmark CAD model

A decision was taken early on within WP2 to base all In2Rail development around a benchmark switch design. The design chosen was the CVS switch, which, as illustrated within Figure 5.5 is the highest population of switches found on the UK rail network. Considering all of the requirements within WP2, the CVS switch was therefore deemed, from a UK perspective, the most suitable switch type to base all of the WP2 modelling activities. This would also allow any models developed within one task of WP2 to also be utilised within any of the other three tasks, hence aiding efficiency with the work package as a whole. Figure 12.1 illustrates the CVS Computer Aided Design (CAD) model developed by Network Rail.



Figure 12.1: Benchmark CVS switch model to be used during Task 2.1 conceptual design work

The study of existing ALD systems presented in Section 3.1 highlights forces and weaknesses of those systems. In general, the less reliable parts of the ALD systems are the actuator and the detection devices, which represents respectively 29% and 24% of the failure cases. The locking systems represent about 10% of the failure cases. Locking systems which seem to be the most reliable are passive mechanical locking systems, generally including lock dogs, such that those used in HW POE system or in Style 63 system.

The most reliable actuator seems to be the one of HPSS, because it has the lowest failure rate. Besides this actuator is operated by an Electrical Control Unit, which enables to monitor the system. For the actuator, good ideas from the existing POE rely on lead screws

performing a monitored movement, potentially with a gearbox between the motor and the rod.

Regarding the detection system, the detection system of the HPSS is poorly reliable. Closed circuit should be preferred, such as those used in HW of in Style 63 POE.

12.2. Initial Concept Exploration

For the purpose of this deliverable, two early stage concepts are presented. Other concepts relating to the ideas and technologies identified within Section 11.1 are under developments. Once a sufficient level of conceptualisation and subsequent detailed design work has been achieved, each concept will be scored and ranked using the process described within section 10.

12.2.1. Model-Based Estimator Concept

This is radically different to the other ‘mechanical design’ ideas as it represents a data fusion concept for bringing together measured inputs and applying some understanding of the behaviour of the system before reporting the system status.

At the workshop in Paris, in two of the ideation sessions, the idea of the model-based estimator was introduced as a tool for improved decision-making in control systems. A model-based estimator imports many measurements of position and other physical parameters and subjects them to analysis including comparison with a mathematical model of the subsystem. It can deal with uncertainty and redundancy.

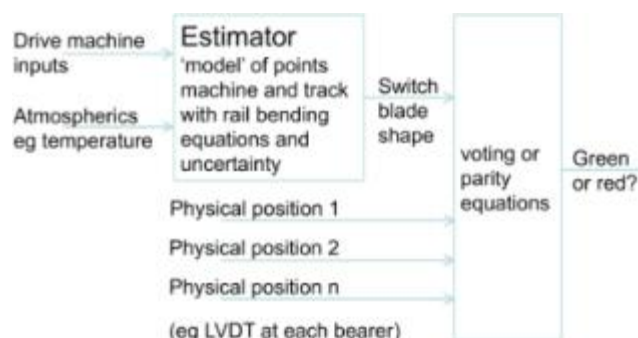


Figure 12.2: Schematic for Model Based Estimator Concept

The suggestion was added to the idea that the mathematical model F-Melba currently used as a design tool for optimising switches [8] could inform the development of the model-based estimator. There is already a body of knowledge around the development and application of this tool to switches of all types and sizes and in various conditions [2]. The mathematical model manages the relationships between switch dimensions and material properties, distribution of actuation and effectiveness of detection.

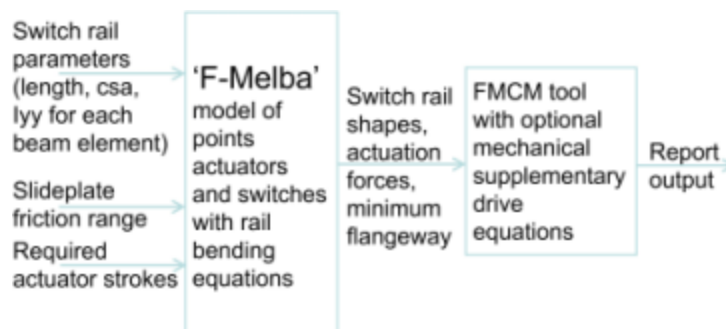


Figure 12.3: Schematic showing 'F-Melba' modelling tool integrated into the Model Based Estimator Concept

In a real-time situation the model-based estimator would have to compare a multiplicity of diverse inputs, deal with sensor failure, and make decisions with redundant yet incomplete data. It would help if each item of input could be compared with an appropriate parameter in the model-based estimator until, in a learning application, a 'signature' dataset could be assimilated. Comparing real data captured from a network of sensors, it may be possible to identify dry slide plates or an out-of-balance setup, for example.

Particular benefits were identified in railway switch detection systems, railway switch remote control monitoring, and vehicle based steering. The latter arose in synergy with the simple fixed blade concept for switches without moving parts.

12.2.2. ScrewLock Concept

In this section, a first design concept for a new ALD system is provided. This concept, which is called Screwlock concept, is classified as a mechanical locking mechanism and aims at fulfilling the requirements given in Section 9. The goal of providing this first concept is to illustrate the process of the ideation method and to provide a first CAD model of a new design concept, as a proof of concept for the ideation method.

This ALD system is implemented on a CVS switch with the usual detection system. First, the movement is generated by a gear motor which rotates a screw. The rotation of the screw is transformed to a translation using a nut. When the screw turns, the nut moves transversally, which enables the actuation. But when the screw is not turning, the nut is fixed thanks to the screw thread. The nut translation moves another piece, which is called transmitter arm, around a pivot. This new piece is linked to the nut by a pin. At the other end of the transmitter arm there is a hole through which the driving rod passes. The driving rod is the usual driving rod of a CVS switch, but it has a square section at its centre. The driving rod is linked to the transmitter arm by a pin, which enables the transmitter arm to rotate until the edge of the hole touches the driving rod. Thanks to the principle of butting, the translation movement of the transmitter arm drags the driving rod along, and finally the driving rod moves the blades. The butting prevents the driving rod to move back in the transmitter arm.

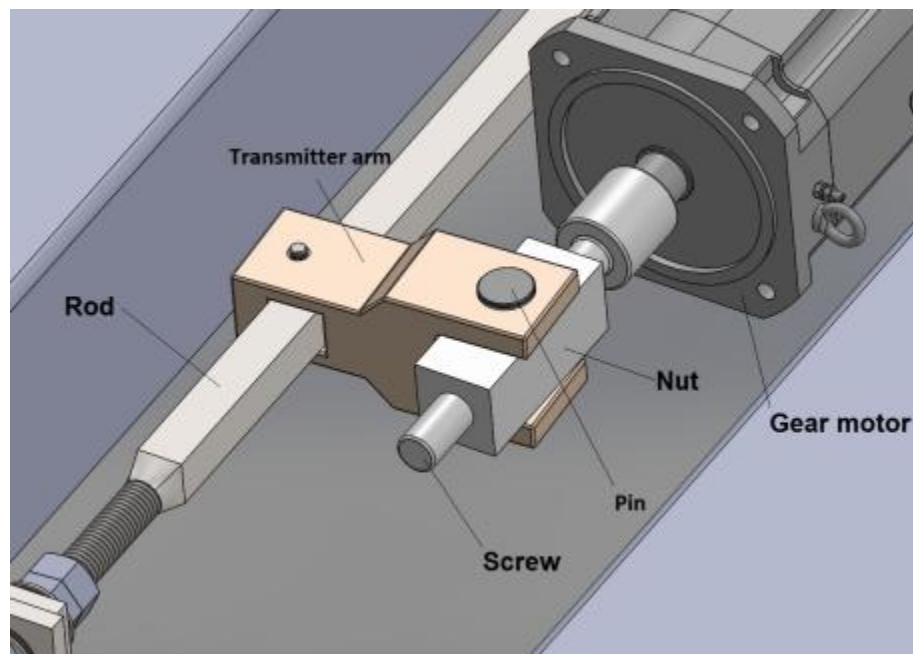


Figure 12.4: Assembly of the ScrewLock

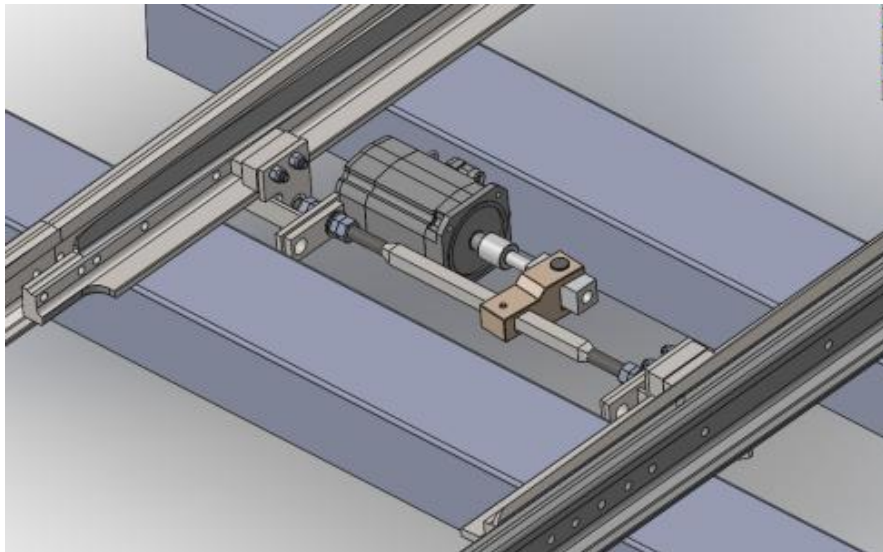


Figure 12.5: CAD model of the ScrewLock

It can be noticed that this locking system can still work in a degraded situation: if the actuator fails, the switch rails remain locked, because the driving rod cannot move in the transmitter arm, and the nut cannot move either. The Screwlock requires little space to be implemented on the driving rod, and thus is compatible with another locking system, enabling it to be used as a redundant concept. The Screwlock shall be strong enough to withstand existing POE forces: actually the screw makes the nut move and transmit the movement, but the opposite is impossible due to the screw thread, because the nut cannot transmit any movement to the worm drive. The driving arm cannot move back into the transmitter arm neither, thanks to the butting principle. However, a detection system and a monitoring system still have to be added to this locking concept.

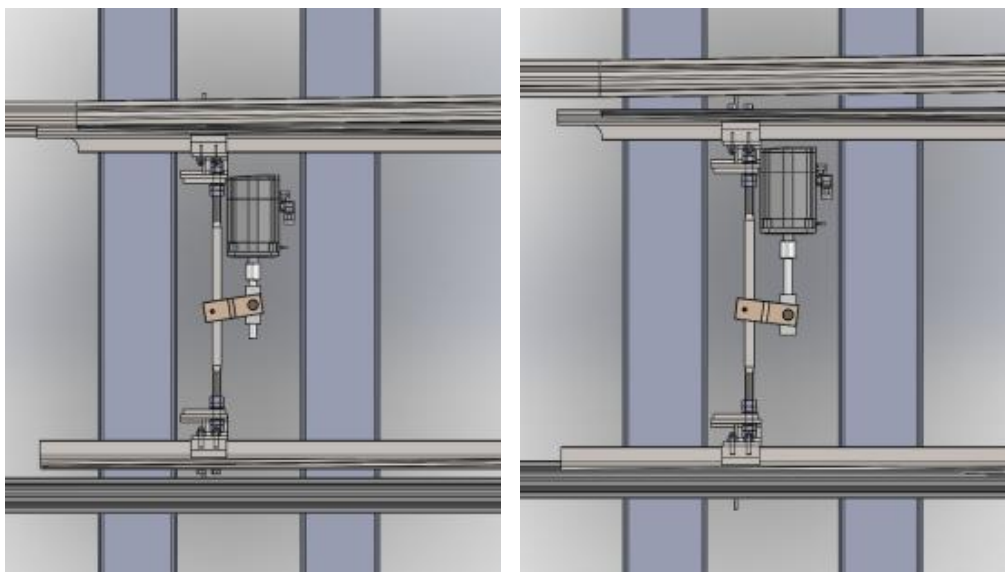


Figure 12.6: Both locked positions of the ScrewLock

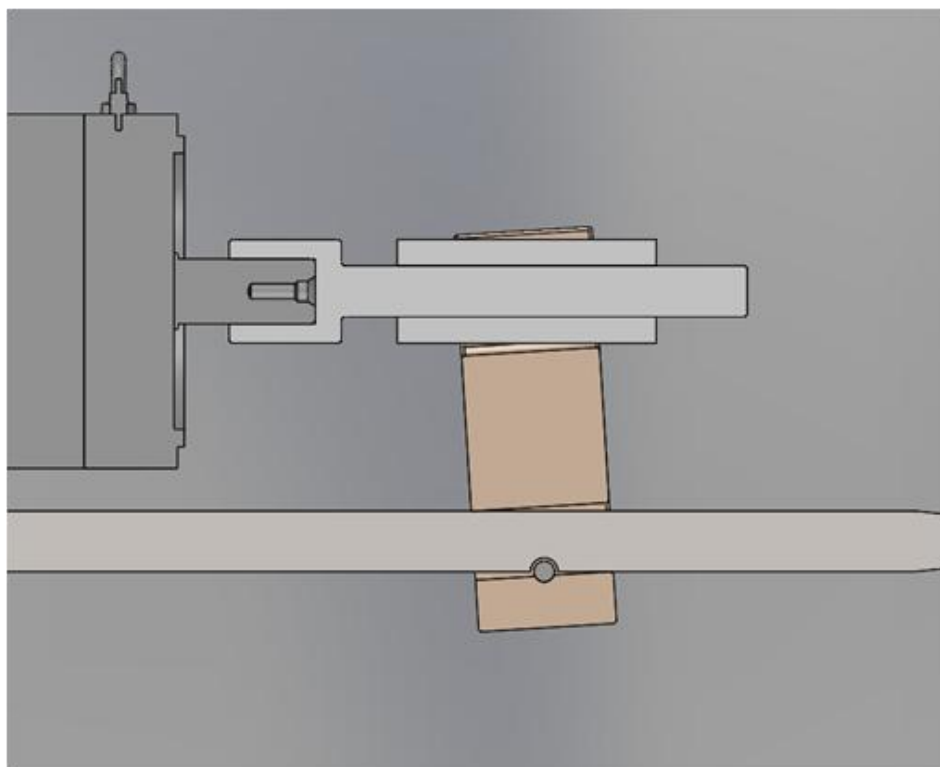


Figure 12.7: Sectional view of the locking system

The comparison of the Screwlock concept with the requirements given in Appendix C gives some good results for many requirements, but also shows that all requirements are not fulfilled. That is why the ScrewLock concept needs further developments, which could not be carried out in this deliverable but will be done in deliverable 2.2. For example, the requirement #13 (“The locking system shall be independent of the actuator system and remains locked in event that the actuator fails”), is not fulfilled completely yet: in the ScrewLock the locking system relies on the screw, which is also used by the actuator. Looking at existing actuator and locking devices, a few ideas can be given to fulfil this requirement, and deserve to be explored. For instance, a clutch could be inserted between the motor and the screw, such that the motor is separated from the screw when the actuator is not functioning. This option could include a brake in order to prevent the screw from moving in locked position.

Nevertheless, it should be noted that the requirements aim at designing the ideal ALD system, and the fulfilment of all requirements by a new system may not be mandatory. The fulfilment of the requirements given in Appendix C was not aimed first, in order not to stifle innovation and creativity, but only requirements of Section 10. The requirements have been challenged to sort between mandatory (must) and non-mandatory requirements (shall). For the non-mandatory requirements, the related risk has been identified and included within future hazards identification and risk assessment work during detailed design.

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Further development work will enhance the design concept to fulfil at least all the mandatory requirements or even provide the necessary justification to challenge them. Table below summarizes the comparison between the Screwlock concept and the requirements:

Req. ID I2R_WP#'_TSK#_xxxx	In2Rail Requirement Description	Must/shall (associated risk)	Associated risk	Verified by ScrewLock
I2R_WP2_TSK2.1_0001	Locking of switch rails - providing the means to hold the switch rail toes securely, relative to the stock rails	Must		Moving rod locked
I2R_WP2_TSK2.1_0002	Once the required Normal or Reverse position has been achieved, each Switch Rail shall be securely locked, relative to its Stock Rail, until a valid new external command is received	Must		Moving rod locked after actuation
I2R_WP2_TSK2.1_0003	Once the required Normal or Reverse position has been achieved, each Switch Rail shall be securely locked, relative to its Stock Rail, at all times when a train is passing over the POE	Must		Moving rod locked after actuation
I2R_WP2_TSK2.1_0004	Loss of electrical power to the POE shall not result in the release of Switch Rail Locking	Must		Mechanical locking
I2R_WP2_TSK2.1_0005	Closed Side - To be no greater than 3.5mm from its associated Stock Rail at the toe	Must		Ok

Req. ID I2R_WP#'_TSK#_xxxx	In2Rail Requirement Description	Must/shall (associated risk)	Associated risk	Verified by ScrewLock
I2R_WP2_TSK2.1_0006	Closed Side - To be a maximum of 12 mm (15mm for CEN 60 layouts) from the Stock Rail at all other locations along the length of the Switch Rail Head planing	Must		Ok
I2R_WP2_TSK2.1_0007	Open Side – To be no less than 102mm and no greater than 120mm from its associated fixed rail at the toe	Must		Ok
I2R_WP2_TSK2.1_0008	The equipment shall work within - 40°C/70°C	Shall		Thermal expansion should not modifying the system
I2R_WP2_TSK2.1_0009	Open Side – To be a minimum of 50 mm at all other locations along the length of the Switch Rail Head planning	Must		Ok
I2R_WP2_TSK2.1_0010	It shall not be possible to lock and detect the lock effective unless the toe of the closed Switch Rail is less than 3.5mm from its associated stock or wing rail	Must		NO: locked when no opposite actuating force
I2R_WP2_TSK2.1_0011	The Switch Rails shall be securely locked following the completion of either powered or	Shall (no manual movement: no movement		NO: switch rails are only moved with power

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Req. ID I2R_WP#'_TSK#_xxxx	In2Rail Requirement Description	Must/shall (associated risk)	Associated risk	Verified by ScrewLock
	manual movement of the rails	if the actuator fails)		
I2R_WP2_TSK2.1_0012	The switch rails shall be securely locked, without damage to the POE equipment, with a minimum restraining force in facing moves, of 20kN and a maximum force of 35kN in trailing moves	Must		Ok : butting principle does not depend on forces
I2R_WP2_TSK2.1_0013	The locking system shall be independent of the actuator system and remains locked in event that the actuator fails.	Shall (a failure of the actuator can imply a failure of the lock. The system thus would be out of order)		NO: Locked by the butts, the screw and the actuator
I2R_WP2_TSK2.1_0014	There should be an individual locking device for both switch blades, or a redundant locking system of both switch blades with two independent locking devices	Shall (lack of reliability)		NO: redundancy of the actuator needed
I2R_WP2_TSK2.1_0015	The locking system shall allow manual override in the event of failure to permit degraded working for the safe passage of trains. Enables response teams to	Shall (no degraded working if the actuator fails)		No

Req. ID I2R_WP#'_TSK#_xxxx	In2Rail Requirement Description	Must/shall (associated risk)	Associated risk	Verified by ScrewLock
	reduce delay impacts			
	Detection			Detection not yet designed
I2R_WP2_TSK2.1_0016	Detection of switch rails - providing confirmation that the switch rails are held securely by the locking mechanism in either the Normal or Reverse positions within the specified tolerances	Must		
I2R_WP2_TSK2.1_0017	Failure to achieve a valid detection state for either Normal or Reverse positions shall not restrict the system from being commanded to return to the opposite position and provide a valid detection output	Shall		
I2R_WP2_TSK2.1_0018	The POE shall continuously detect and confirm that the Switch Rails are locked, once the required Normal or Reverse position has been achieved	Must		
I2R_WP2_TSK2.1_0019	In both Normal and Reverse positions, the POE shall continuously	Shall (the open position is not		

Req. ID I2R_WP#'_TSK#_xxxx	In2Rail Requirement Description	Must/shall (associated risk)	Associated risk	Verified by ScrewLock
	monitor the lateral position of each switch Rail relative to its associated Stock Rail	monitored)		
I2R_WP2_TSK2.1_0020	The POE shall provide confirmation of Switch Rail position to the signalling system via the Apparatus Case, by a continuous confirmation of its detection state representing Normal or Reverse	Must		
I2R_WP2_TSK2.1_0021	A valid Normal or Reverse detection state shall only be reported if the Switch Rails are securely locked in position	Must		
I2R_WP2_TSK2.1_0022	The detection system shall allow manual override in the event of failure to permit degraded working for the safe passage of trains. Enables response teams to reduce delay impacts	Shall (no degraded working)		
I2R_WP2_TSK2.1_0023	Supplementary detection for switch rails - where necessary, providing confirmation that the rear parts of	Shall (only one detection)		

Req. ID I2R_WP#'_TSK#_xxxx	In2Rail Requirement Description	Must/shall (associated risk)	Associated risk	Verified by ScrewLock
	the switch rail are in their respective positions, within the specified tolerances			
I2R_WP2_TSK2.1_0024	The Switch Rail Position Detection shall confirm that the demanded Switch Rail position has been achieved and maintained along the switch length	Shall		
Installation				
I2R_WP2_TSK2.1_0025	Ability to install in combination with existing switch actuation systems	Shall	needs new actuation system	Yes
I2R_WP2_TSK2.1_0026	Installation of equipment shall be compatible with the existing switch footprint (physical space envelope)	Shall (needs to modify the switch)		Yes
I2R_WP2_TSK2.1_0027	Equipment shall be compatible with existing switch profiles	Must		Yes
I2R_WP2_TSK2.1_0028	Equipment shall be compatible with all existing bearers	Shall (needs to modify the bearers)		Yes
I2R_WP2_TSK2.1_0029	Equipment shall be independent of track gauge	Must		Yes
I2R_WP2_TSK2.1_0030	Equipment shall be compatible with all type of vehicles (high speed, heavy haul, conventional)	Must		Yes

Req. ID I2R_WP#'_TSK#_xxxx	In2Rail Requirement Description	Must/shall (associated risk)	Associated risk	Verified by ScrewLock
I2R_WP2_TSK2.1_0031	Ability to install with minimum disruption to operation railway, ie within maximum possession time of 4hrs	Shall (long delay of installation)		Yes: only rod need to be changed
Fault tolerance				Not able to answer
Maintenance				Not able to answer
I2R_WP2_TSK2.1_0037				
I2R_WP2_TSK2.1_0038	The system shall be designed such that the scheduled maintenance can be completed within an Allocated Maintenance Period per point end of 45 minutes maximum per visit	Shall	Longer maintenance operation	
I2R_WP2_TSK2.1_0039	The system shall be designed such that the scheduled maintenance can be completed within Total Allocated Maintenance Period per year of 3 hours (additional to any mandatory safety requirements such as Facing Point Lock Testing).	Shall	Longer maintenance operation	
I2R_WP2_TSK2.1_0040	The system shall be designed such that the scheduled maintenance can be completed with	Shall	More maintenance operations	

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Req. ID I2R_WP#'_TSK#_xxxx	In2Rail Requirement Description	Must/shall (associated risk)	Associated risk	Verified by ScrewLock
	a maximum number of 6 visits per year			
I2R_WP2_TSK2.1_0041	Planned component changes shall not be more frequent than 1 year	Shall	More maintenance operations	
I2R_WP2_TSK2.1_0042	Any modules or sub-assemblies of the POE, which during their replacement, require disturbance of the track or track support shall be designed to withstand Category 1 traffic conditions for a minimum of 25 years	Shall	More maintenance operations	
I2R_WP2_TSK2.1_0043		Shall		
I2R_WP2_TSK2.1_0044	Modular structure, to allow installation and replacement in a short time	Shall	Longer maintenance operation	
I2R_WP2_TSK2.1_0045	Greasing shall be occur no more than once a month	Shall	More greasing	
Likelihood of acceptance				
I2R_WP2_TSK2.1_0047	Meets processes and standards applicable to the design of products for use on the network	Must		no
Energy supply				
I2R_WP2_TSK2.1_0048	Requires an energy supply which	Must		Yes: electrical

Req. ID I2R_WP#'_TSK#_xxxx	In2Rail Requirement Description	Must/shall (associated risk)	Associated risk	Verified by ScrewLock
	existing power supply instalations are capable of supplying			power supply
Environment				
I2R_WP2_TSK2.1_0049	The POE will be required to operate when subject to dust and sand particles (particularly coal and train brake dust). The design of the unit shall be such that it shall prevent ingress of these particles on particularly vulnerable items e.g. micro switches and electrical contacts. If this is impractical then the design of the POE should ensure that these items are not affected by the build up of such contaminants	Must		No: dust and sand affect the operation and can make the system fail
Reliability				Not able to answer

Table 12.1: Screwlock cross-matching to Appendix C Requirements

13. Conclusions

The aim of this report has been to explore the topic of railway Points Operating Equipment (POE) Actuation, Locking and Detection (ALD) faults and sources of potential unreliability. The final goal of Task 2.1 is to develop a range of conceptual designs for novel switch locking mechanisms that can be help to address the significant unreliability issue surrounding existing European POE assets.

Sources of POE unreliability have been identified and the concept of introducing additional sub-system (i.e. Actuation, Lock and Detection) redundancy has been adopted and explored further. There are many opportunities to improve the existing POE system, for reliability and availability, including:

- Independent laser position detection system with redundancy, to permit a degree of degraded working, but maintaining safety;
- Screw type locking system capable of holding the switch rail in the closed otr open position through friction from thread forms;
- Proximity sensors to constantly detect the position of each switch relative to the stock rails.

By designing the whole-system for fault tolerance and the ability to operate under degraded conditions.

The potential savings of 40,675,000 € per year have been estimated within the UK rail network alone. This figure will be updated once equivalent data is available from other European railway Infrastructure Managers.

A range of ideas for pursuing this goal have been presented and a firm set of functional and non-functional requirement set. Deliverable D2.1 has therefore established the background knowledge and set a systems engineering framework for progressing the development of novel switch locking mechanisms. A range of preliminary conceptual designs are already in progress, some of which have been presented within this deliverable.

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Appendix A Review of EN 13232

#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
1	gauge (st)	EN 13232-2	§3.2.3		according to customer spec
2		EN 13232-2	§3.3		according to customer spec
3		EN 13232-4	§4.2.2		1435 +2/-1 mm ?
4		EN 13232-5	§5.1		1435 +2/-1 mm ?
5		EN 13232-6	§5.1		1435 +2/-1 mm ?
6		EN 13232-7	§5.1		1435 +2/-1 mm ?
7		EN 13232-9	§6.4.1		1435 +2/-1 mm ?
8		EN 13232-9	§7.5.1		1435 +2/-1 mm ?
9	speed	EN 13232-2	§3.3	V max calculated with formula (4) indicated in standard EN 13232-2 §3.3 with s_w recommended value for track gauge 1435 mm : $s_w = 1500$ mm , $h_d = 105$ mm and radius defined in the VCSA geometry drawings (see annex 2)	
10		EN 13232-4	§4.1		
11		EN 13232-5	§5.2.2		
12		EN 13232-6	§5.2.3		
13		EN 13232-7	§5.2.2		
14		EN 13232-9	§6.1		
15		EN 13232-9	§6.4.5		
16	maximum lateral acceleration	EN 13232-2	§3.2.3		according to customer spec
17	cant deficiency	EN 13232-2	§3.2.3		according to customer spec
18	maximum rate of change of lateral acceleration	EN 13232-2	§3.2.3		according to customer spec
19	maximum rate of change of cant deficiency	EN 13232-2	§3.2.3		according to customer spec
20	turnout intersection point and angle	EN 13232-2	§3.2.3		according to customer spec
21	limits of supply	EN 13232-2	§3.2.3		
22	low side gauge variation	EN 13232-2	§3.2.3		according to customer spec
23		EN 13232-2	§3.2.3		according to

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
					customer spec
24	distance between main line track centrelines	EN 13232-2	§3.2.3		according to customer spec
25	main line curvature	EN 13232-2	§3.2.3		according to customer spec
26		EN 13232-5	§5.1		
27	main line and branch line cant through turnout	EN 13232-2	§3.2.3		according to customer spec
28	origin of switch curve	EN 13232-2	§3.2.3		according to customer spec
29	real switch toe (RP)	EN 13232-2	§3.2.3		according to customer spec
30	theoretical intersection (of crossing)	EN 13232-2	§3.2.3		according to customer spec
31	centreline radii	EN 13232-2	§3.2.3		according to customer spec
32	origin of switch curve to positions changes of radii	EN 13232-2	§3.2.3		according to customer spec
33	tangent offset (if any)	EN 13232-2	§3.2.3		according to customer spec
34	maximum local velocity	EN 13232-2	§3.3		according to customer spec
35	maximum permitted cant	EN 13232-2	§3.3		according to customer spec
36	deficiency	EN 13232-4	§4		according to customer spec
37		EN 13232-5	§5.2.2		according to customer spec
38	change of lateral acceleration	EN 13232-2	§3.4		according to customer spec
39	type and location of transition curve	EN 13232-2	§3.4		according to customer spec
40	length of transition (Lt)	EN 13232-2	§3.4		according to customer spec
41	length between bogies centres (Lb)	EN 13232-2	§3.4		according to customer spec

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
42	rules for steady changes curvature (A1&A2)	EN 13232-2	§3.4		according to customer spec
43	Reff (effective radius)	EN 13232-2	§3.4		according to customer spec
44	Req (equivalent radius)	EN 13232-2	§3.5		according to customer spec
45	Minimum	EN 13232-4	§4.1	Calculation to be done based on the formula $f_f = G - b_{min} - a_{min} + s$ in standard EN 13232-4 §4.2.2, this calculation need the rolling stock material characteristics (a_{min} and b_{min}). The value f_f will be included in the turnout layout drawing Indicative table on Annex B	
46	flange way (f_f)	EN 13232-4	§4.2.2		40, 50, 55, 58, 60
47	trailability	EN 13232-4	§4.1		
48	conceptual dimensions of actuator	EN 13232-4	§4.1		
49	conceptual dimension of locking device	EN 13232-4	§4.1		
50	drive locking device position	EN 13232-4	§4.1		
51	detection	EN 13232-4	§4.1		
52	position system	EN 13232-7	§5.4		
53	actuator capacity (c cap or F cap)	EN 13232-4	§4.1		
54	maximum actuation force applied ca	EN 13232-4	§4.1		
55	mechanical interfaces of all actuating devices	EN 13232-4	§4.1		

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
56	mechanical interfaces of all locking and control devices	EN 13232-4	§4.1		
57	toe movement (fp)	EN 13232-4	§4.1		
58	switch opening at drive position (fd)	EN 13232-4	§4.1		
59	maximum gap at switch toe (dtoe)	EN 13232-4	§4.1		
60	actuator displacement	EN 13232-4	§4.1		
61	object detection at first detection point (d_{gap1})	EN 13232-4	§4.2.1	indicative annex A	table, 1, 2, 3, 6, 10
62	object detection in rest of machined are (d_{gap2})	EN 13232-4	§4.2.1	indicative annex A	table, 4, 8, 10, 12
63	minimum back to back (a min)	EN 13232-4	§4.2.2		
64	minimum flange width (worn wheel) b min	EN 13232-4	§4.2.2		
65	margin (s)	EN 13232-4	§4.2.2	This safety margin is used in the calculation on the minimum flangeway defined by the formula $f_f = G - b_{min} - a_{min} + s$ in standard EN 13232-4 §4.2.2	$s = 3 \text{ mm}$
66 67	minimum free wheel passage (f_w)	EN 13232-9	§6.4.2	Calculation to be done based on the formula $f_w = a_{min} + b_{min} - s$ in standard EN 13232-4 §4.2.2, this calculation need the rolling	

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
				stock material characteristics (a min and b min). This calculation permit to define the minimum flangeway indicated in the turnout layout drawing	
68	distance between gauge reference plane and running surface (zp)	EN 13232-4	§4.2.2		zp = 14 mm
69	stud gap ≤ 1 mm	EN 13232-4	§4.2.3		
70	gap between contact surfaces stock and switch rail ≤ 1 mm	EN 13232-4	§4.2.3		
71	gap between contact surfaces stock and switch rail toe $\leq 0,5$ mm	EN 13232-4	§4.2.3		
72	neutral position (f_N) nominal value	EN 13232-4	§4.2.4		
73	neutral position (f_N) limits values	EN 13232-4	§4.2.4		1 mm maxi
74	negative force (at actuator position)	EN 13232-4	§4.2.5	the negative force is not taken into account in compliance with §4.2.5 of standard EN 13232-4 due to locking device required in "Supplier purchase agreement" §1.2 page 23	
75	mechanical	EN 13232-4	§4.2.6		

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
	integrity guarantee				
76	switch and crossing panel obstacle detection test (d gap)	EN 13232-4	§5.1		
77	minimum flangeway test	EN 13232-4	§5.2		
78	correct closing test (switch panel and CMP crossing panel)	EN 13232-4	§5.3 & §6.2		
79	actuation force measurement (Fa)	EN 13232-4	§5.4 & §6.2		
80	actuation force (Fa)	EN 13232-9	§6.4.3		
81	neutral position test	EN 13232-4	§5.5 & §6.2		
82	negative force measure	EN 13232-4	§5.6 & §6.2		
83	trailability test in factory	EN 13232-4	§5.7		
84	testing for change in flexibility	EN 13232-4	§6.4		
85	rail grade	EN 13232-5	§4.2		
86	according	EN 13232-6	§4.2		
87	EN13674	EN 13232-9	§7.5.1		
88	Bolts and other	EN 13232-5	§4.2		
89	fixing devices grade 5.6 minimum	EN 13232-6	§4.2		
90	rail inclination	EN 13232-5	§5.1		
91		EN 13232-6	§4.3		
92		EN 13232-6	§5.1		
93		EN 13232-7	§5.1		
94		EN 13232-9	§6.1		
95		EN 13232-9	§6.4.5		
96	gauge variation permitted	EN 13232-5	§5.1		
97	hand of the turnout (LH or RH or	EN 13232-5	§5.1		

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
	symmetrical)				
98	overall rail	EN 13232-5	§5.1		
99	lengths	EN 13232-9	§7.5.1		
100	stock rail	EN 13232-5	§5.1		
101	profile	EN 13232-6	§5.1		
102		EN 13232-7	§5.1		
103		EN 13232-9	§6.1		
104		EN 13232-9	§6.4.5		
105		EN 13232-9	§7.4		
106		EN 13232-9	§7.5.1		
107	switch rail	EN 13232-5	§5.1		
108	profile	EN 13232-9	§6.1		
109		EN 13232-9	§7.5.1		
110	geometry	EN 13232-5	§5.1		
111	details in	EN 13232-9	§6.4.1		
112	switch	EN 13232-9	§7.5.1		
113	type of	EN 13232-5	§5.1		
114	geometry form	EN 13232-9	§6.1		
115	(tangential, intersecting, not intersecting following EN13232-1 §7.2)	EN 13232-9	§6.4.1		
116	type of construction (flexible, spring or loose heel)	EN 13232-5	§5.1		
117	bearer layout in	EN 13232-5	§5.1		
118	switch panel	EN 13232-9	§7.5.1		
119	machining detail of switch rail	EN 13232-5	§5.1		
120	machining detail of stock rail	EN 13232-5	§5.1		
121	axle loading	EN 13232-5	§5.2		
122	and spacing	EN 13232-6	§5.2.2		
123	(tonnage)	EN 13232-7	§5.2.1		
124		EN 13232-9	§6.1		
125		EN 13232-9	§6.4.5		
126	supports and	EN 13232-5	§5.3		
127	fastenings	EN 12323-6	§5.3		
128	compliant with 13230; 13145,	EN 13232-7	§5.3		

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
	13146, 13481)				
129	interface switch and operating systems	EN 13232-5	§5.4		
130	others requirements (electrical insulation, LWR, special maintenance requirements)	EN 13232-5	§5.5		
131	machining profiles in drawing	EN 13232-5	§5.6		
132	bending details in drawing	EN 13232-5	§5.6		
133	position of running edge and machining reference plan	EN 13232-5	§5.6		
134	drilling with tolerances in drawing	EN 13232-5	§5.6		
135	surface marking in drawing	EN 13232-5	§5.6		
136	stock rail length (LS)	EN 13232-5	§ 6.3	stock rail	+/-3 mm up to 24 m & +/- 4 mm greater than 24 m
137		EN 13232-9	§6.4.4	stock rail	
138	straightness running edge (SR)	EN 13232-5	§ 6.3	stock rail	+/- 1 mm and 0,5/1500
139	course of curve edge (SR)	EN 13232-5	§ 6.3	stock rail	+/- 1 mm and 0,5/1500
140	Height of machining (HM)	EN 13232-5	§ 6.3	stock rail	+/-0,5 mm + rail height tolerance
141	inclination of machined contact (IM)	EN 13232-5	§ 6.3	stock rail	+/- 0,5 °
142	diameter of fishbolt holes	EN 13232-5	§ 6.3	stock rail	+1/- 0,5 mm
143	holes position to fishing	EN 13232-5	§ 6.3	stock rail	+/- 1 mm

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
	surface				
144	holes position to end rail	EN 13232-5	§ 6.3	stock rail	+/- 1,5 mm & +/- 3 mm (temporary)
145	chamfer of the holes	EN 13232-5	§ 6.3	stock rail	min 0.5
146	roughness of machined running surface	EN 13232-5	§ 6.3	stock rail	Ra 6,3
147	length of switch rail (LA)	EN 13232-5	§ 6.3	switch rail	+/-3 mm up to 24 m & +/- 4 mm greater than 24 m
148		EN 13232-9	§6.4.4	switch rail	
149	switch straightness running edge (SR)	EN 13232-5	§ 6.3	switch rail	+/- 1 mm and 0,5/1500
150	switch course of curve edge (SR)	EN 13232-5	§ 6.3	switch rail	+/- 1 mm and 0,5/1500
151	switch height of machining (HM)	EN 13232-5	§ 6.3	switch rail	+/-0,5 mm + rail height tolerance
152	switch thickness in machined area TM	EN 13232-5	§ 6.3	switch rail	+/- 0,5 mm
153	switch inclination of machined contact (IM)	EN 13232-5	§ 6.3	switch rail	+/- 0,5 °
154	switch diameter of fishbolt holes	EN 13232-5	§ 6.3	switch rail	+1/- 0,5 mm
155	switch holes position to fishing surface	EN 13232-5	§ 6.3	switch rail	+/- 1 mm
156	fish plate surface machined	EN 13232-5	§ 6.3	switch rail	according to rolled rail section
157	switch holes position to end rail	EN 13232-5	§ 6.3	switch rail	+/- 1,5 mm & +/- 3 mm (temporary)
158	switch chamfer of the holes	EN 13232-5	§ 6.3	switch rail	min 0.5
159	flatness of the underside of	EN 13232-5	§ 6.3	switch rail	1 mm

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
	the switch rail				
160	switch roughness of machined running surface	EN 13232-5	§ 6.3	switch rail	Ra 6.3
161	running table in transition section (flatness)	EN 13232-5	§ 6.3	transition section	0,3 mm/1000 mm
162	running edge alignment in transition section (straightness)	EN 13232-5	§ 6.3	transition section	0,5 mm/1000 mm
163	end profile in transition section (rail profile)	EN 13232-5	§ 6.3	transition section	tolerances compliant with EN 13674-1 table 8
164	head profile in transition section (HC)	EN 13232-5	§ 6.3	transition section	area of concavity allowed on the opposite of the running edge, max 2mm
165	transition length (LT)	EN 13232-5	§ 6.3	transition section	+/- 10 %
166	height difference between rail foot to other rail foot (HF)	EN 13232-5	§ 6.3	transition section	+/- 1 mm
167	spread at heel end (SH)	EN 13232-5	§ 6.3	switch	+/-2
168	contact switch - stock rail allowance (CH)	EN 13232-5	§ 6.3	switch	max 1 mm (excepting special requirements in tenders, up to max 2mm)
169		EN 13232-9	§8.2.2.3.4	switch	
170	contact switch studs (CS)	EN 13232-5	§ 6.3	switch	
171		EN 13232-9	§8.2.2.3.4	switch	
172	max allowance between switch rail and slide baseplate (CP)	EN 13232-5	§6.3	switch	1 mm
173	squareness of toes at the drive position	EN 13232-5	§6.3	switch	+/- 2 mm

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
	(SQ)				
174	gauge (G)	EN 13232-5	§6.3	switch	+/- 2 mm
175	methods of	EN 13232-5	§6.5		
176	examination for	EN 13232-6	§6.5		
177	structural defects (visual, dye penetrant, magnetic particle, ultrasound, radiography)	EN 13232-7	§6.5		
178	identification marks	EN 13232-5	§8		
179	geometry of	EN 13232-6	§3.2		
180	crossing (straight, curve, double junction type, non-standard)	EN 13232-9	§6.4.1		
181	construction	EN 13232-6	§3.3		
182	joints	EN 13232-6	§3.4		
183	cast austenitic manganese monobloc crossings	EN 13232-6	§4.2.2.1		
184	geometry	EN 13232-6	§5.1		
185	tangent at the	EN 13232-6	§5.1		
186	theoretical point	EN 13232-9	§7.5.1		
187	bearer layout in	EN 13232-6	§5.1		
188	crossing panel	EN 13232-9	§7.5.1		
189	position of the	EN 13232-6	§5.1		
190	gauge plate/check rail strut	EN 13232-6	§5.1		
191	depth of the crossing (shallow/full depth)	EN 13232-6	§5.1		
192	check gauge	EN 13232-6	§5.1		
193		EN 13232-7	§ 5.1		
194	nose profile	EN 13232-6	§5.1		
195	flangeway width	EN 13232-6	§5.1		
196	others requirements	EN 13232-6	§5.4		

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
	(environmental condition, electrical insulation, LWR, special maintenance requirements)				
197	machining detail drawing	EN 13232-6	§5.5		
198	bending details in drawing	EN 13232-6	§5.5		
199	position of the running edge and machining reference plane	EN 13232-6	§5.5		
200	drilling with tolerances in drawing	EN 13232-6	§5.5		
201	surface marking in drawing	EN 13232-6	§5.5		
202	running table flatness (h1)	EN 13232-6	§6.3	fixed & obtuse crossing	0/-1 mm
203	intermediate running table flatness (1 m length) h2	EN 13232-6	§6.3	fixed & obtuse crossing	0,2 mm
204	underside flatness (h3)	EN 13232-6	§6.3	fixed & obtuse crossing	2 mm
205	underside transverse flatness (h4)	EN 13232-6	§6.3	fixed & obtuse crossing	1 mm
206	running edge straight and curved) d5	EN 13232-6	§6.3	fixed & obtuse crossing	+/- 1 mm ; non monobloc : +/-1.5
207	length (nose to wing end opening) l6	EN 13232-6	§6.3	fixed & obtuse crossing	+/- 2 mm
208	vee length (l7)	EN 13232-6	§6.3	fixed & obtuse crossing	+/-2
209	overall crossing length (l8)	EN 13232-6	§6.3	fixed & obtuse crossing	+2/-3
210		EN 13232-9	§6.4.4	fixed & obtuse crossing	
211	diameter of fishbolt holes	EN 13232-9	§6.4.4	fixed & obtuse crossing	+1/-0.5

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
	(d9)				
212	hole position relative to foot (h10)	EN 13232-9	§6.4.4	fixed & obtuse crossing	+/- 1 mm
213	hole position relative to crossing end (l11)	EN 13232-9	§6.4.4	fixed & obtuse crossing	+/- 1,5 mm & +/- 3 mm (temporary)
214	chamfering of the holes (r12)	EN 13232-9	§6.4.4	fixed & obtuse crossing	mini 0.5
215	flangeway of wing flare (b13)	EN 13232-9	§6.4.4	fixed & obtuse crossing	+2 / -1 mm
216	parallel or minimum flangeway width (b14)	EN 13232-9	§6.4.4	fixed & obtuse crossing	+2 / -1 mm
217	throat opening (b15)	EN 13232-9	§6.4.4	fixed & obtuse crossing	+/- 2 mm
218	straightness of the wing rails (b16)	EN 13232-9	§6.4.4	fixed & obtuse crossing	+/- 1 mm
219	shape of the vee (transverse) d17	EN 13232-9	§6.4.4	fixed & obtuse crossing	+/-1
220	shape of the vee topping (h18)	EN 13232-9	§6.4.4	fixed & obtuse crossing	+ 2 / -1 mm
221	vee opening gauge (b19)	EN 13232-9	§6.4.4	fixed & obtuse crossing	+/- 1 mm ; non monobloc : +/-2
222	wing front opening (b20)	EN 13232-9	§6.4.4	fixed & obtuse crossing	+/- 1 mm ; non monobloc : +/-2
223	crossing foot width at baseplate position (b21)	EN 13232-9	§6.4.4	fixed & obtuse crossing	+ 1 / -2 mm
224	relative position foot edge/running edge at baseplate position (b22)	EN 13232-9	§6.4.4	fixed & obtuse crossing	+/- 1 mm
225	radius of wing rail head (r23)	EN 13232-9	§6.4.4	fixed & obtuse crossing	+/- 2 mm
226	maximum roughness of	EN 13232-9	§6.4.4	fixed & obtuse crossing	Ra 6,3

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
	machined contact surface				
227	identification marks	EN 13232-6	§8		
228	geometry	EN 13232-7	§5.1		
229	tangent at the theoretical point	EN 13232-7	§5.1		
230	bearer layout at the crossing	EN 13232-7	§5.1		
231	position of the gauge plate/strut	EN 13232-7	§5.1		
232	height of the crossing	EN 13232-7	§5.1		
233	machining profile of nose and wing rails	EN 13232-7	§5.1		
234	minimum flange way width	EN 13232-7	§5.1		
235	minimum throat opening	EN 13232-7	§5.1		
236	opening at the	EN 13232-7	§5.1		
237	drive position	EN 13232-9	§6.4.3		
238	wheel profile, diameter, back to back & set dimensions	EN 13232-7	§5.2.3		
239	transfer of longitudinal track forces	EN 13232-7	§5.5		
240	others	EN 13232-7	§5.6		
241	requirements (heaters, environmental conditions, electrical insulation, LWR, GIJ, cant applied, special maintenance requirements)	EN 13232-7	§5.6		
242	machining profiles in drawing	EN 13232-7	§5.7		

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
243	sets	EN 13232-7	§5.7		
244	bending details in drawing	EN 13232-7	§5.7		
245	position of the running edge and machining reference plane	EN 13232-7	§5.7		
246	drilling with tolerances	EN 13232-7	§5.7		
247	surface finished and tolerances	EN 13232-7	§5.7		
248	limits and extent of supply	EN 13232-7	§7		
249	identification marks	EN 13232-7	§8		
250	point rail length (L1)	EN 13232-7	§8	complete with point	frog moveable +/- 3 mm
251	point rail toe to wing rail front (L2)	EN 13232-7	§8	complete with point	frog moveable +/- 2 mm
252	point rail toe to wing rail end (L3)	EN 13232-7	§8	complete with point	frog moveable +/- 3 mm
253	point rail toe to splice rail end (L4)	EN 13232-7	§8	complete with point	frog moveable +/- 3 mm
254	point rail toe to splice rail toe (L5)	EN 13232-7	§8	complete with point	frog moveable +/- 2 mm
255	overall length wing rail front to point rail/splice rail end (L6)	EN 13232-7	§8	complete with point	frog moveable +/- 5 mm
256	opening running edge measured at the crossing front (b1)	EN 13232-7	§8	complete with point	frog moveable +/- 1 mm ; +/-2 for non monobloc
257	opening running edge measured at the crossing end (b2)	EN 13232-7	§8	complete with point	frog moveable +/- 1 mm ; +/-2 for non monobloc

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
258	throat opening (b3)	EN 13232-7	§8	complete with point	frog moveable +/- 2 mm
259	flangeway width at various positions (b4)	EN 13232-7	§8	complete with point	frog moveable +2 / -1 mm
260	distance between running edge to running edge at various positions (b5)	EN 13232-7	§8	complete with point	frog moveable +/- 1 mm ; +/-2 for non monobloc
261	crossing foot width at bearers positions (b6)	EN 13232-7	§8	complete with point	frog moveable +1 / -2 mm
262	relative position foot edge/running edge at bearers positions (b7)	EN 13232-7	§8	complete with point	frog moveable +/- 1 mm
263	contact point rail/splice rail to cradle or wing rail (CH)	EN 13232-7	§8	complete with point	frog moveable 1 mm max
264	contact point rail to splice rail (CH1)	EN 13232-7	§8	complete with point	frog moveable 1 mm max
265	contact splice rail to extend splice rail (CH2)	EN 13232-7	§8	complete with point	frog moveable 1 mm max
266	contact point to studs (CS)	EN 13232-7	§8	complete with point	frog moveable 1 mm max
267	contact splice rail to studs (CS)	EN 13232-7	§8	complete with point	frog moveable 1 mm max
268	alignment of the running edge (straight track) SR	EN 13232-7	§8	complete with point	frog moveable +/- 1 mm
269	alignment of running edge (curved track) SR	EN 13232-7	§8	complete with point	frog moveable +/- 1 mm

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
270	local alignment of running edge (straight track) SR1	EN 13232-7	§8	complete with point	frog moveable +/- 0,5 /1500 mm
271	local alignment of running edge (curved track) SR1	EN 13232-7	§8	complete with point	frog moveable +/- 0,5 /1500 mm
272	flatness/max allowance between point rail: splice rail and base plate (CP)	EN 13232-7	§8	complete with point	frog moveable 1 mm max
273	relative position between the top of base plates and machining reference plane (HM1)	EN 13232-7	§8	complete with point	frog moveable +/- 0,5 mm
274	relative position between the top of base plates and the running plane (HM2)	EN 13232-7	§8	complete with point	frog moveable +/- 0,5 mm
275	thickness of the crossing foot (TF)	EN 13232-7	§8	complete with point	frog moveable +/- 1 mm
276	running table flatness (h1)	EN 13232-7	§8	complete with point	frog moveable ≤ 1 mm
277	intermediate running table flatness (h2)	EN 13232-7	§8	complete with point	frog moveable < 0,2 /1000 mm
278	underside flatness at bearer positions (h3)	EN 13232-7	§8	complete with point	frog moveable ≤ 1 mm
279	underside transverse flatness at bearer	EN 13232-7	§8	complete with point	frog moveable ≤ 1 mm

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
	positions (h4)				
280	point rail & splice rail length L1	EN 13232-7	§8	complete frog with moveable point - point rail/splice rail and vee	+/- 3 mm
281	hole position relative to end of rail (l11)	EN 13232-7	§8	complete frog with moveable point - point rail/splice rail and vee	+/- 1,5 mm & +/- 3 mm (temporary)
282	alignment of the running edge (straight track) SR	EN 13232-7	§8	complete frog with moveable point - point rail/splice rail and vee	+/- 1 mm
283	alignment of running edge (curved track) SR	EN 13232-7	§8	complete frog with moveable point - point rail/splice rail and vee	+/- 1 mm
284	local alignment of running edge (straight track) SR1	EN 13232-7	§8	complete frog with moveable point - point rail/splice rail and vee	+/- 0,5 /1500 mm
285	local alignment of running edge (curved track) SR1	EN 13232-7	§8	complete frog with moveable point - point rail/splice rail and vee	+/- 0,5 /1500 mm
286	height of machined area of point rail /splice rail (HM)	EN 13232-7	§8	complete frog with moveable point - point rail/splice rail and vee	+/- 0,5 mm + rail height tolerance
287	thickness at machined area of point rail /splice rail TM	EN 13232-7	§8	complete frog with moveable point - point rail/splice rail and vee	+/- 0,5 mm
288	inclination of machined area (IM)	EN 13232-7	§8	complete frog with moveable point - point rail/splice rail and vee	+/- 0,5 °

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
289	diameter of fish bolt holes (d1)	EN 13232-7	§8	complete frog with moveable point - point rail/splice rail and vee	+1 / -0,5 mm
290	chamfer holes	EN 13232-7	§8	complete frog with moveable point - point rail/splice rail and vee	0,5 mm min
291	running table flatness (h1)	EN 13232-7	§8	complete frog with moveable point - point rail/splice rail and vee	≤ 1 mm
292	intermediate running table flatness (h2)	EN 13232-7	§8	complete frog with moveable point - point rail/splice rail and vee	< 0,2 /1000 mm
293	hole position relative to rail foot (h5)	EN 13232-7	§8	complete frog with moveable point - point rail/splice rail and vee	+/- 1 mm
294	roughness of machined running surface	EN 13232-7	§8	complete frog with moveable point - point rail/splice rail and vee	Ra 6,3
295	overall length of wing rail	EN 13232-7	§8	complete frog with moveable point	+/- 5 mm
296	wing rail knuckle to end	EN 13232-7	§8	complete frog with moveable point	+/- 3 mm
297	running table (forging area)	EN 13232-7	§8	complete frog with moveable point - transition forging area	<0.3/1500
298	running edge alignment (forging area)	EN 13232-7	§8	complete frog with moveable point - transition forging area	0,5 mm/1000 mm

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
299	end profile (forging area)	EN 13232-7	§8	complete frog with moveable point - transition forging area	0,5 mm/1000 mm
300	head profile (HC)	EN 13232-7	§8	complete frog with moveable point - transition forging area	max cavity 2 mm placed only opposite running edge because of the limitation in front of the straightness control achieved on running edge side
301	height difference between rail foot to other rail foot (HF)	EN 13232-7	§8	complete frog with moveable point - transition forging area	+/- 1 mm
302	transition length (LT)	EN 13232-7	§8	complete frog with moveable point - transition forging area	+/- 10 %
303	vee length (nose to heel) (L1)	EN 13232-7		complete frog with moveable point - complete crossing	+/-3
304	nose to wing rail front (L2)	EN 13232-7		complete frog with moveable point - complete crossing	+/-2
305	overall length wing rail front to vee rail end (L3)	EN 13232-7		complete frog with moveable point - complete crossing	+/-5
306	overall length of wing rail	EN 13232-7	§8	complete frog with moveable point - complete crossing	+/- 5 mm
307	opening running edge at crossing front (b1)	EN 13232-7		complete frog with moveable point - complete crossing	+/-2
308	opening running edge at crossing end (b2)	EN 13232-7		complete frog with moveable point - complete crossing	+/- 1 mm ; +/-2 for non-cast vee

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
309	throat opening (b3)	EN 13232-7		complete frog with moveable point - complete crossing	+3/-4
310	flangeway width at drive positions (b4)	EN 13232-7		complete frog with moveable point - complete crossing	+3/-4
311	distance between running edge to running edge at various positions (b5)	EN 13232-7		complete frog with moveable point - complete crossing	+/- 1 mm ; +/-2 for non-cast vee
312	crossing foot width at bearers positions (b6)	EN 13232-7		complete frog with moveable point - complete crossing	+1/-2 for indirect fastenings
313	relative position foot edge/running edge at bearers positions (b7)	EN 13232-7		complete frog with moveable point - complete crossing	+/- 1 mm for indirect fastenings
314	contact wing rail to vee rail (CH)	EN 13232-7		complete frog with moveable point - complete crossing	max 1mm
315	contact wing rail stops to supporting bar (CS)	EN 13232-7		complete frog with moveable point - complete crossing	max 1mm
316	alignment of running edge (curved and straight track) SR	EN 13232-7		complete frog with moveable point - complete crossing	+/-1
317	local alignment of running edge (curved and straight track) SR1	EN 13232-7		complete frog with moveable point - complete crossing	+/- 0,5 /1500 mm
318	flatness / max allowance between wing rail and base plates (CP)	EN 13232-7		complete frog with moveable point - complete crossing	max 1mm

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
319	thickness of the crossing foot (TF)	EN 13232-7		complete frog with moveable point - complete crossing	+/-1
320	running table flatness (h1)	EN 13232-7		complete frog with moveable point - complete crossing	max 1mm
321	intermediate table flatness (h2)	EN 13232-7		complete frog with moveable point - complete crossing	max 0.2 / 1000mm
322	underside flatness at bearer positions (h3)	EN 13232-7		complete frog with moveable point - complete crossing	max 1mm
323	underside transverse flatness at bearer positions (h4)	EN 13232-7		complete frog with moveable point - complete crossing	max 1mm
324					
325	dimensions for crossing with moveable parts / obtuse crossing	EN 13232-7			(not analysed)
326					
327	maximum angle of attack (for UIC wheels)	EN 13232-9	§5.3.3		<40km/h : 2° max ; <100km/h : 1.41° max ; >100km/h : reserved
328	maximum entry angle (prEN 13803-2 : track)	EN 13232-9	§5.3.3		<40km/h : 1° max ; <100km/h : 0.41° max ; >100km/h : reserved
329	general design process	EN 13232-9	§4		
330	gross tonnage	EN 13232-9	§6.1		
331		EN 13232-9	§6.4.5		
332	use in continuously welded rail	EN 13232-9	§6.1		
333	use and positions of GIJ or other	EN 13232-9	§6.1		

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
	signalling system equipment				
334	standard subgrade conditions	EN 13232-9	§6.1		
335	bearer type (EN 13230-4)	EN 13232-9	§7.4		
336		EN 131232-9	§7.5.1		
337	bearer spacing (minimum, maxi)	EN 13232-9	§6.1		+/- 10 mm in compliance with standard EN 13232-9 §8.2.2.3.4
338	bearer spacing (nominal)	EN 13232-9	§6.4.4		
339	rail fastening system (EN 13481)	EN 13232-9	§6.1		
340		EN 13232-9	§6.4.5		
341	main switch design	EN 13232-9	§6.1		
342	crossing type	"	"		
343		EN 13232-9	§7.5.1		
344	baseplate type	EN 13232-9	§6.1		
345		EN 13232-9	§7.5.1		
346	insulation	EN 13232-9	§6.1		
347	switch heating	EN 13232-9	§6.1		
348	system	EN 13232-9	§6.1		
349	baseplate fastening system	EN 13232-9	§6.1		
350	similar applications and/or relevant references	EN 13232-9	§6.2.1		
351	distance	EN 13232-9	§6.2.3		
352	between rail foot and bearer end	EN 13232-9	§7.5.1		
353	minimum distance between screw axis and bearer end and side	EN 13232-9	§6.2.3		
354	minimum distance	EN 13232-9	§6.2.3		50 mm

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
	between bearers end respectively				
355	bearer length (minimum and maximum)	EN 13232-9	§6.2.3		
356	nominal bearer spacing at joints	EN 13232-9	§6.2.3		
357	maximum rail length	EN 13232-9	§6.2.3		
358	minimum number of fastening between unfastened rail section and weld or joint	EN 13232-9	§6.2.3		
359	minimum distance between weld position and bearer	EN 13232-9	§6.2.3		
360	gauge necessary for fastening machines equipment	EN 13232-9	§6.2.3		
361	actuation, locking and detection design	EN 13232-9	§6.3		
362	detail check-rail geometry	EN 13232-9	§6.4.1		
363	nose protection in crossing	EN 13232-9	§6.4.2		
364	flangeway	EN 13232-9	§6.4.2		
365	ALD layout	EN 13232-9	§6.4.3		
366	overall length	EN 13232-9	§6.4.4		
367	checkrail length	EN 13232-9	§7.5.1		
368	welds	EN 13232-9	§7.4		
369	screw	EN 13232-9	§7.4		
370	studs	EN 13232-9	§7.4		
371	sliding chairs	EN 13232-9	§7.4		
372	baseplate	EN 13232-9	§7.4		
373	insulating joint	EN 13232-9	§7.4		

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
374	wood sleepers and bearers (EN 13145)	EN 13232-9	§7.4		EN 13145
375	concrete sleepers and bearers	EN 13232-9	§7.4		EN 13230-4
376	aluminothermic welding (prEN 14730)	EN 13232-9	§7.4		prEN 14730
377	checkrail (EN 13674-3)	EN 13232-9	§7.4		EN 13674-3
378	vignol rail 27kg up to 46 kg/m	EN 13232-9	§7.4		EN 13674-4
379	switch rail 46kg/m and above (EN 13674-2)	EN 13232-9	§7.4		EN 13674-2
380	vignol rail 46kg /m and above (EN 13674-1)	EN 13232-9	§7.4		EN 13674-1
381	fastening systems	EN 13232-9	§7.4		EN 13481
382	assembly drawing	EN 13232-9	§7.5.1		
383	part list for the layout	EN 13232-9	§7.5.1		
384	offset at given dimensions	EN 13232-9	§7.5.1		
385	running edge openings at switches and crossings	EN 13232-9	§7.5.1		
386	position of change of rail inclination	EN 13232-9	§7.5.1		
387	position of parallel check rail length	EN 13232-9	§7.5.1		
388	position and type of joints and welds	EN 13232-9	§7.5.1		
389	joint gaps	EN 13232-9	§7.5.1		
390	position and type of anti-creep devices	EN 13232-9	§7.5.1		
391	bearer position	EN 13232-9	§7.5.1		

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#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
	and number				
392	bearer length	EN 13232-9	§7.5.1		
393	baseplate position	EN 13232-9	§7.5.1		
394	type and location of rail pads and baseplate pads	EN 13232-9	§7.5.1		
395	actuation, locking and detection positions	EN 13232-9	§7.5.1		
396	rail length (LS)	EN 13232-9	§8.2.1	general tolerances for components	+/-3 mm up to 24 m & +/- 4 mm greater than 24 m
397	diameter of fishbolt holes	EN 13232-9	§8.2.1	general tolerances for components	+1/- 0,5 mm
398	holes position to fishing surface	EN 13232-9	§8.2.1	general tolerances for components	+/- 1 mm
399	holes position to end rail	EN 13232-9	§8.2.1	general tolerances for components	+/- 1,5 mm & +/- 3 mm (temporary)
400	chamfer of the holes	EN 13232-9	§8.2.1	general tolerances for components	min 0.5
401	roughness of machined running surface	EN 13232-9	§8.2.1	general tolerances for components	Ra 6,3
402	alignment of reference rail	EN 13232-9	§8.2.2	general geometry tolerances	+/-3
403	offset to reference rail	EN 13232-9	§8.2.2	general geometry tolerances	+/-1
404	gauge	EN 13232-9	§8.2.2	general geometry tolerances	+/-2
405	deviation of track gauge	EN 13232-9	§8.2.2	general geometry tolerances	max 1 between 2 bearers, max 3 on the overall layout
406	lead	EN 13232-9	§8.2.2	general geometry tolerances	+/-10mm for <36m ; +/-15mm for >36m
407	track distance	EN 13232-9	§8.2.2	general geometry tolerances	+5/0
408	geometry checking	EN 13232-9	§8.2.2.3.2		
409	free wheel passage in switch area (F wps)	EN 13232-9	§8.2.2.3.3	see indicative table in Annex C (p73)	max 1365, 1373, 1375, 1380




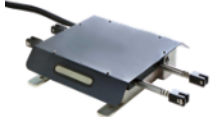


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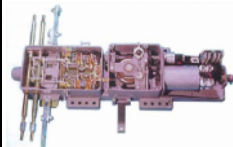

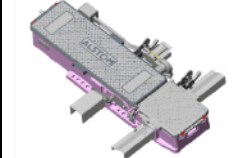

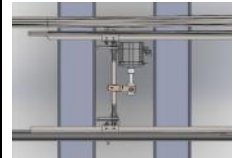
#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
410	flangeway at the open switch tongue (f_s)	EN 13232-9	§8.2.2.3.3	see indicative table in Annex C (p73)	min 58, 60
411	fixed common crossing nose protection (N pcf))	EN 13232-9	§8.2.2.3.3	see indicative table in Annex C (p73)	1391 +3/0, 1394 +3/0, 1395 +/-0.5, 1396 +/-1
412	free wheel passage at the common crossing nose (F wpcf / F wpccmp)	EN 13232-9	§8.2.2.3.3	see indicative table in Annex C (p73)	max 1350, max 1356, 1354 +2/-1
413	free wheel passage at check rail entry (Fwpcr)	EN 13232-9	§8.2.2.3.3	see indicative table in Annex C (p73)	1370 +/-3
414	flangeway at check rail entry (f cre)	EN 13232-9	§8.2.2.3.3	see indicative table in Annex C (p73)	58 -1/+3, 60 0/+3, 65 0/+3, 75 0/+3, 80 0/+3
415	flangeway at wing rail entry (f wre)	EN 13232-9	§8.2.2.3.3	see indicative table in Annex C (p73)	58 -1/+3, 60 0/+3, 65 0/+3, 75 0/+3, 80 0/+3
416	fixed obtuse crossing nose protection (N pof)	EN 13232-9	§8.2.2.3.3	see indicative table in Annex C (p73)	1391 +3/0, 1394 +3/0, 1395 +/-0.5, 1396 +/-1, 1397 +2/-0.5
417	free wheel passage at fixed obtuse crossing nose (F wpof)	EN 13232-9	§8.2.2.3.3	see indicative table in Annex C (p73)	max 1353, max 1356, 1354 +2/-1
418	switch point relief (A2)	EN 13232-9	§8.2.2.3.3	see indicative table in Annex C (p73)	22, 23, 25
419	lateral point retraction (E)	EN 13232-9	§8.2.2.3.3	see indicative table in Annex C (p73)	0, 3, 5
420	tolerance of squareness of toes at the drive position (SQ)	EN 13232-9	§8.2.2.3.3		
421	squareness of front and heel	EN 13232-9	§8.2.2.3.3		+/- 5 mm



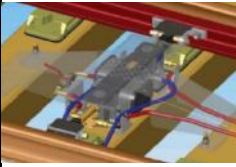



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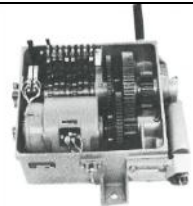



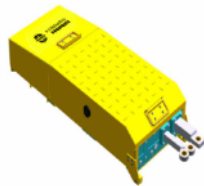
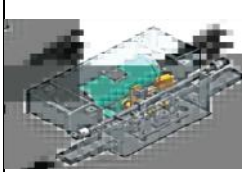
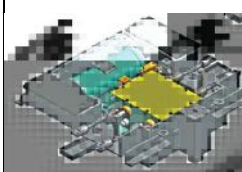
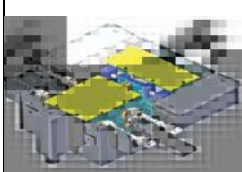
#	European Requirement	European Standard Reference	Chapter Reference for Requirement	Comments	Values
	joints				
422	bearer squareness	EN 13232-9	§8.2.2.3.3		+/- 5 mm
423	bearer spacing	EN 13232-9	§8.2.2.3.3		+/-10
424	switch/stock rail allowance	EN 13232-9	§8.2.2.3.3		max 1mm
425	contact at switch studs	EN 13232-9	§8.2.2.3.3		max 1mm
426	vertical gap at sliding chairs	EN 13232-9	§8.2.2.3.3		max 1mm
427	bearer number marking	EN 13232-9	§8.3.3		
428	bearer position marking at rail position	EN 13232-9	§8.3.3		
429	relative position from switch to its stock rail	EN 13232-9	§8.3.3		+/- 1 mm




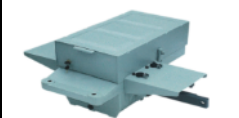

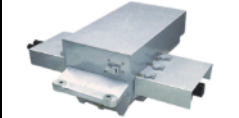

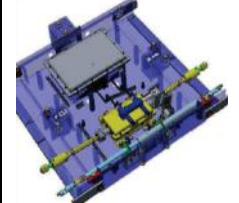
Appendix B European Points Operating Equipment Database

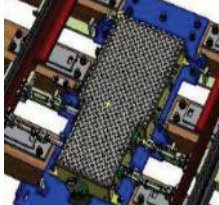
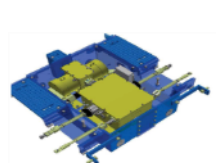






			ERGONOMICS						STROKE					TRAILING	LOCKING CHARACTERIS TICS	SIL&MTBF STANDARDS		SWITCH TIME	BACKDRIVE			
Photo	Manufacturer	Model	Integration	Crossing solution	Actuation	Auto-tamping	Changing side possibility	Power output source	Stroke Min	Stroke Max	Stroke settable on site	Operating Force (kN)	Application	PM Trailable?	Locking Type	SIL	IP level	Switch Time Min	Type	Reference countries	Advantages	Disadvantages
	Vossloh Cogifer	MCEM 91	Way side	Yes		No	Yes without any modification	mechanical	100	260	Yes	10	Metro Conventional High Speed	No	VCC	4	54	3	Mechanical	France Australia India Brasil	IP 67 possible Security level due to VCC	Nb of cables 4 wires mode not available yet
	Vossloh Cogifer	MCE M 91	Way side	Yes				mechanical	100	260	Yes		Metro Conventional High Speed	Yes			54			France Singapore		
	Vossloh Cogifer	Easyswitch-R	Insleeper	Yes				hydraulic					Metro Conventional High Speed	both	VCC		56		Multimotors	France Sweden	Insleeper Integrated VCC	Cost References
	Vossloh Cogifer	Easydrive-i	Intrack, over the tie	No		No	Yes	hydraulic	100	160			Metro Conventional	both			67		No	France	IP67 Intrack	No backdrive No autotamping possible References
	Vossloh Cogifer	EH50	Way side			No	Yes	hydraulic	110	140	Yes	2.27	Conventional	Yes			55		No	France Chile Taiwan USA Singapore		
	Vossloh Cogifer	EH55	Way side			No	No	hydraulic	30	70		4	Metro Conventional	Yes	Internal lock				No	France Algeria		










	Vossloh Cogifer	EH58	Way side			No	Yes	hydraulic	110	170		2.5	Metro Conventional	Yes	Internal lock		55		No	France		
	Vossloh Cogifer	EH61	Intrack	No		No	No	hydraulic	30	70		10	Tram	both			67	1	No	France Portugal		
	Vossloh Cogifer	VSM 24	Way side					mechanical					Conventional Freight							USA	AREMA Standart	
	ACTOM	C1H	Way side					hydraulic		250		8.8	Conventional Freight	Yes			54	3		South Africa Vietnam		
	ACTOM	B1 Switchmatic	Way side					mechanical		140		6.5	Conventional Freight					2.7		South Africa		
	Alstom	MATR 68	Way side					mechanical	100	140			Metro Conventional			None	54			France		
	Alstom	GM 4000 A	Way side	No	tooth gear, reduction ratio	No		mechanical					Conventional Freight					4	No	USA	Easy hand crank in the improved design version	PM mass
	Alstom	MJ 80/81	Way side	Yes	tooth gear, reduction ratio	No	Yes	mechanical		260	Yes	4	Metro Conventional High Speed	both			54		Mechanical	France		Delivery time
	Alstom	TM 100	insleeper	No		Yes	Yes	mechanical	100	160			Conventional					3		USA		

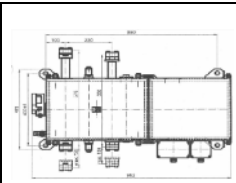

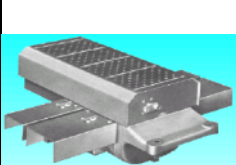

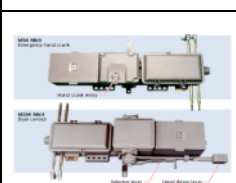



	Alstom	P 80	Way side			No	Yes	mechanical	149	153	No	2	Metro Conventional Freight	Yes	Claw-Lock		"Water resistant"	2.5		Italy Denmark Greece Turkey Brazil Kazakhstan Bangladesh Tunisia Vietnam Chile Argentina	Delocalized production in Kazakhstan and plan to expand this product worldwide	No external lock until 180 km/h
	Alstom	P 80	Way side			No	Yes	mechanical	220	250	No	3	High Speed	Yes	Claw-Lock		"Water resistant"	3	Mechanical	Italy Denmark Greece Turkey Brazil Kazakhstan Bangladesh Tunisia Vietnam Chile Argentina	Delocalized production in Kazakhstan and plan to expand this product worldwide	No external lock until 180 km/h
	Alstom	HY-Drive	insleeper Over the tie			Yes	Yes	hydraulic		115	Yes	10	Conventional High Speed Very High Speed	No			54	4	hydraulic	Italy UK Spain Russia	Over the tie No modification on civil construction Intrack backdrive	IP 54
	Alstom	HW	Way side					mechanical	95	150		6.7	Conventional High Speed Freight	No				1,7/2,7		Australia Bangladesh Brazil Canada Ireland Malaya UK South Africa Iraq Zambia Zimbabwe		
	Alstom	MET	insleeper			Yes	Yes	hydraulic	60	160		5.5	Metro Conventional High Line	both versions available	2 Claw-Locks	4	54	3	Multimotors	Italy Sweden Spain Saudi Arabia U.S. Market	with three available trailing configurations: -permanently trailable(standard) -permanently untrailable -trailable/untrailableat command	IP Level Only multimotor option for the backdrive Weight
	ANSALDO / CSEE	T80	Way side	Yes				mechanical	90	150			Conventional Freight	both						Algeria Belgium France Luxembourg Venesuela Brazil		








	ANSALDO / CSEE	TR44	Way side	No				mechanical					Conventional Freight	Yes				0.5		Algeria Belgium France Luxembourg Venesuela Brazil		
	ANSALDO	T 72	Way side		tooth gear, reduction ratio	No		mechanical	100	260		02-Jun	Metro Conventional High Speed Freight	both						France Belgium Luxembourg Egypt Brazil Algeria Venezuela Mexico Chili		
	ANSALDO	YM-2000	Way side			No	No	mechanical		150			Conventional Freight	Yes				2	No	USA	Low cost AREMA	
	AZD	EP 600	Way side insleeper			Yes	Yes	mechanical	110	240	No	6	Metro Conventional High Speed	both	Jaw lock		65 (with the ball screw version)	0.5	mechanical	Czech Republic Turkey	permanently untrailable insleeper possibility	
	Bombardier	EEA-5	Way side				Yes	mechanical	125	220		6	Metro Conventional Freight	both	Claw-Lock		54			Poland	low maintenance costs	IP54
	Bombardier	EEA-6	Intrack	No		No	No	mechanical	36	70		2,6-3,5	Tram	yes			67	0.5			IP67	
	Bombardier	EEA-6	Intrack	No		No	No	mechanical	36	70		2,6-3,5	Tram	yes			67	0.5			IP67 additional locking detector rod	
	Bombardier	EEA-6	Intrack	No		No	No	hydraulic	36	70		2-4,1	Tram	yes			67	0.5			IP67	


	Bombardier	EBI Switch	Way side Insleeper			Yes	Yes, ~45 min.	hydraulic	80	220	Yes, adjustable with a 35 mm step	7	Conventional High Speed Very High Speed Freight	both			54	2	hydraulic	Austria Germany Croatia Slovenia Spain Poland	low maintenance costs Intrack hydraulic backdrive Autotamping Lifetime trailing detection possible	IP54
	Bombardier	EBI Switch	insleeper	Yes		Yes	Yes	hydraulic	20	160		10	Metro Conventional High Speed	No	Worn locking unit	4	55	3	Multimotors Mechanical	Netherlands Russia South Africa	insleeper autotamping possible Mechanical intrack backdrive	IP55
	Bombardier	JEA	Way side			No	Yes	mechanical	94	250		10	Conventional Freight		Claw-Lock		54	3	multimotors			Multimotors backdrive
	Crompton Greaves	CG01	Way side	No		No	Yes	mechanical		220	No	5.5	Conventional	Yes	Claw-Lock	None	43		No	India	Trailable Low cost 4 wires mode possible	No security standards Low IP level Materials quality
	Crompton Greaves	RDL1	Way side	No		No	Yes	mechanical		143	No	4.5	Conventional	No		None	43		No	India	Trailable Low cost 4 wires mode possible	Weight
	Crompton Greaves	RDL2	Way side	No		No	Yes	mechanical		220	No	4.5	Conventional High Speed	No	TWS	None	43		No	India	RDL1+ Thick Web Switch (TWS) Blades	Weight
	CRSC	ZD(J) 9	Way side					mechanical	150	220		2,5-4,5	Conventional	both				6.5	Multimotors	China	Price Trailable/Non trailable versions	Switch time
	DT	6	Intrack	No		No	No	hydraulic	35	75		5	Tram	Yes			"waterproof"	0.9	No	Czech Republic	Long service life "Good Price"	





	DT	7	Intrack	No		No	No	hydraulic	32	100		5	Tram	Yes			"waterp roof housing "	1	No	Czech Republic	Low noise level	Speed of trailing??
	DT	10	Intrack	No		No	No	mechanical	32	70		5	Tram	Yes	Spring mechan ism		"waterp roof"	0.5	No	Czech Republic	on request temperature range from -40	
	ELEKTROLINE	TSH 106	Intrack	No		No		hydraulic					Tram	Yes		3			Czech Republic UK Hungary Turkey Greece Netherlands	6 position sensors + humidity sensor (LC) waterlight separation of electrical part References		
	ELTESA	SP 6	Way side	No				mechanical		94		4	Conventional							1520 zone	Low price	Old timer Frequent maintenances needed Poor quality
	ELTESA	SP 12	Way side	No				mechanical		220		6.5	Conventional High Speed							1520 zone	Low price	Poor quality
	FRIEDRICH HIPPE	WH	Intrack Way side			worm gear	No	mechanical	70	240		3-5	Metro Conventional	both	Claw- lock		67	2	Mechan ical	Germany	Mechanical PM for tram&vignole trailable/non trailable available IP67 DB certified	not much references
	GE TRANSPORTATIO N	CTS-2	insleep er				Yes	hydraulic		160		5.5	Conventional High Speed Very High Speed	both	calage à rouleau x		67			Italy USA China Norway Denmark	fast switch auto-tamping possible No preventive maintenance Low maintenance costs (less than 900€/unit/year)	
	Gomeli	SP 6	Way side					mechanical					Conventional							1520 zone		





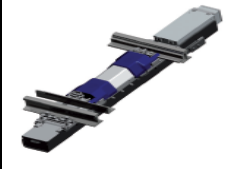


	Hanning & Kahl	H715	Way side insleeper			Yes	Yes	hydraulic	120	240		3-9	Metro Conventional	Yes	Vertical lock	4	54	2		Germany	optional heating Delivery time 1 cable	not many references IP 54
	Hanning & Kahl	61.1	Intrack					mechanical hydraulic	32	70		3.5	Metro Tram Conventional			4	67	0.5		Germany	Tram+Train Delivery time	
	Hanning & Kahl	61.1	Intrack					hydraulic	32	100		3.5	Metro Tram Conventional			4	67	0.5		Germany	Tram+Train Delivery time	
	Hanning & Kahl	162	Way side					hydraulic	100	160		6	Tram Conventional			2	67				Delivery time	
	KOLSTER	JEA-29	Way side			No	Yes	mechanical					Conventional Freight	Yes	Claw- Lock				mechanical	Poland		
	KYOSAN	ES2	Way side					mechanical							Escape cam					Japan		
	KYOSAN	MES	Way side					mechanical				3					waterproof structure			Japan		
	MAHARAN	S700K	Way side	No				mechanical					Conventional	Yes	Claw- Lock		NA			Iran	Good quality for a copy	Very poor Claw-Lock
	MUSZER	MA-HVK-01	Wayside					hydraulic					Conventional Freight	Yes	Spherolock Claw-Lock				Hydraulic	Hungary Irak	Hydrolink backdrive Spherolock possible Trailable	






	PRAZSKA STROJIRNA	VSP-12-k	Intrack	No		No	No	hydraulic	36	100		5	Tram	Yes	Spring mechanism			1	No	Czech Republic	PM heigh	
	SEHWA	MCE M 91	Way side					mechanical					Conventional		VCC					South Korea		
	SIEMENS	BSG 9	Way side			No	Yes	mechanical	94	143 163 trailable	No	4	Conventional	both		None	43			India Pakistan Germany Denmark Indonesia Sweden Turkey	Low cost (India version) Strong referencies Trailable/Non trailable	Security standards Low IP level
	SIEMENS	ITS700	Insleeper	No		Yes	No	mechanical					Conventional Freight							USA Australia Asia Europe		
	SIEMENS	M3A / M23A	Way side		gear ratio (189:1 or 360:1)	No		mechanical		152			Conventional Freight	No	Internal lock						Gold-plated switch contacts for maximum reliability	Machine mass
	SIEMENS	MD-2000	Way side		worm gear	No	Yes	mechanical	140	220 240 VCC	No	4	Metro Conventional	both	VCC Claw-Lock		43	2.5		Singapore	VCC possible	IP 43 Height No insleeper possibility
	SIEMENS	S700 K	Way side	Yes				mechanical	150	220	No	5.5	Metro Conventional High Speed Freight	Yes	Claw-Lock		54	5		Germany Poland South Africa	Long service life Long maintenance intervals Short maintenance times Weight	High cost of maintenance and repair
	SIEMENS	S700 VA	insleeper	Yes		Yes		mechanical					Conventional Freight	both	Claw-Lock				Mechanical	Germany Russia Australia	Insleeper 4 wire interlocking 1 cable Axle load Hardchromed Claw-Lock mechanisms	

	SIEMENS	ELS7 10	Way side		motor chain			mechanical	120	240		2-6,5	Conventional High Speed Freight	both	Claw-lock			2.8		Germany	PM mass "A very high-speed point machine with a throwing time of 0.6 s will be available soon"	References
	SIEMENS	SURE LOCK	Way side Intrack			No		mechanical				8	Conventional Freight	No	Vertical lock		67	2.5	mechanical	UK	IP 67 Maintenance durations Intrack possibility	
	SIEMENS	84M	Way side			No	Yes	mechanical		180		9	Conventional Freight	both	Claw-Lock			4				
	SPIACT	EM-5	Way side	No	tooth gear, reduction ratio	No		mechanical					Conventional Freight	Yes					No	Romania	Cost AC/DC versions available	Ergonomics No crossing solutions
	TERMOTRON	UVP	Way side		worm gear	No	Yes	mechanical	60	220	Yes	7	Conventional High Speed Very High Speed Freight	No						1520 zone	For speed until 400 km/h	
	TERMOTRON	SPM-150	insleeper			Yes		mechanical				6.5	Conventional until 150 km/h						Multimotors Mechanical	1520 zone	Insleeper	References Weight
	TERMOTRON	SPM-220	insleeper			Yes		mechanical				6.5	Conventional High speed until 220 km/h						Multimotors Mechanical	1520 zone	Insleeper Max speed	References Weight

	THALES	L700H	Way side		2 hydraulic jacks			hydraulic					Conventional High Speed Freight	both	Claw- Lock					Austria Bosnia-H Bulgaria Canada Colombia Croatia Denmark Dominican R Finland France Germany UK Greece Iran Italy Luxembourg Malaysia Mexico Netherlands Nigeria Norway Poland Portugal Romania Saudi Arabia Slovenia Spain Switzerland Thailand Turkey USA	Price	
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	THALES	L710H	Way side				Yes	hydraulic		160		1,9-6	Conventional High Speed Freight	Yes	Internal Lock		67		Multi motors	Austria Bosnia-H Bulgaria Canada Colombia Croatia Denmark Dominican R Finland France Germany UK Greece Iran Italy Luxembourg Malaysia Mexico Netherlands Nigeria Norway Poland Portugal Romania Saudi Arabia Slovenia Spain Switzerland Thailand Turkey USA	IP 67 1 million operations	Just trailable version References Expensive
	THALES	L826H	Way side	Yes	2 hydraulic jacks		Yes	hydraulic	80	260	Yes, adjusta ble with a 5 mm step	7	Conventional High Speed Freight	Yes	Claw- Lock	None	67		Multi motors	Germany Spain (approx. 6500 pm) Poland Denmark Israel	IP 67 Stroke settable on site Insleeper possibility	
	THALES	L826H	Way side	Yes	2 hydraulic jacks		Yes	hydraulic	80	260	Yes, adjusta ble with a 5 mm step	7	Conventional High Speed Freight	No	VCC Claw- Lock	None	67		Multi motors	Germany Spain (approx. 6500 pm) Poland Denmark Israel	IP 67 Stroke settable on site Insleeper possibility	
	Transsignal	SP 6	Way side	No				mechanical					Conventional Freight							1520 zone		

	VAE-CONTEC	UNIS TAR	insleeper Over the tie	Yes		Yes	Yes	hydraulic	60	163	No	15 17 for NG version (heavy rail)	Metro Conventional High Speed Freight (NG version)	both	Adjustable internal locking device	4	67	1	Hydraulic	Germany Denmark Italy Chile Netherlands Brazil Spain U.A.E. Saudi Arabia Iran	No modification to the trackwork required IP 67; SIL4 Prolonged maintenance intervals Backdrive intrack Hydraulic coupling switch Nice looking All type of turnouts All type of voltages Delivery time	Expensive
	VAE-CONTEC	UNIS TAR	insleeper intrack over the tie			Yes	Yes	mechanical	60	163			Metro Conventional High Speed			4	67	1	Multi motors	Vietnam	Over the tie in track Low profile design Delivery time	No single unit for backdrive
	VAE-CONTEC	UNIS TAR	Way side			No		hydraulic					Freight				67			Brazil Switzerland	Cheaper than the standard version Same parts as the standard version Delivery time	Not insleeper
	VAE-MKE	AH950	Way side insleeper			No	Yes	hydraulic	90	240	No	5	Conventional High Speed	both	Claw-Lock			2	Mechanical	Austria Germany Hungary Turkey Philippines UK Salvador	Delivery time	oil leakage in Salvador (maybe due to environment =>corrosion)
	VAE	Ecostar	insleeper	Yes		Yes	Yes	hydraulic		240	No	10	Metro Conventional High Speed	both	Spherolock	4	54		Hydraulic	Austria Germany	Compact; insleeper; Intrack backdrive Delivery time	No direct locking (for the Spherolock 1st version)
	VAE-CONTEC	CSV-24	Intrack, but not over the tie Way side	No		No		hydraulic	38	120	No	5	Tram Conventional	Yes	internal prismlock	4	67	0.5	No	Germany Switzerland Portugal Spain Romania Turkey Austria U.S. France UK Italy Taiwan	Structure interne entièrement modulable TRAM + TRAIN Fast switch time <1s No pipes Delivery time	No direct locking
	VAE	Hydrostar	insleeper	Yes		Yes	Yes	hydraulic	29	120	No	6.5	Metro Conventional High Line Very High Line		Spherolock		67	3/4 (backdrive version)	hydraulic	Austria Germany	Combi-1 interface for both ZV&HB sides Delivery time	Korea case

	VIALIS	HWS/ Z	Way side	No		No	Yes	mechanical	95	130		16.5	Freight	Yes				2.5			axle loads up to 60 tons Low maintenance Trailable	Weight & Dimensions
	VIALIS	NSE2	Way side	No		No	Yes	mechanical	76	163	No	5	Metro Conventional	both		4	54			Netherlands UK Australia Indonesia Tanzania Sri Lanka	Simple construction, high reliability Presence on UK, Netherland market	IP 54
	WANQUAN	ZD(J) 6	Intrack	No		No	No	mechanical					Tram							China		
	WEGH	MET	insleep er	Yes		Yes	Yes	hydraulic	60	160		5.5	Metro Conventional High Line	both versions available	2 Claw- Locks	4	54	1.5	Multimo tors	Italy Spain Saudi Arabia	with three available trailing configurations: -permanently trailable (standard) -permanently untrailable -trailable/untrailableat command Autotamping	IP Level Only multimotor option for the backdrive Weight
	WEGH	METR A	insleep er over the tie	Yes		Yes	Yes	hydraulic					Metro Conventional High Line	both versions available		4				Italy Spain Saudi Arabia	Over the tie => maybe train-tram possibility	

Appendix C Novel S&C Locking Mechanism Requirements

Req. ID I2R_WP#_TSK#_xxxx	Level	Title	In2Rail Requirement Description
I2R_WP2_TSK2.1_0001	1	Locking	Locking of switch rails - providing the means to hold the switch rail toes securely, relative to the stock rails.
I2R_WP2_TSK2.1_0002	2		Once the required Normal or Reverse position has been achieved, each Switch Rail shall be securely locked, relative to its Stock Rail, until a valid new external command is received.
I2R_WP2_TSK2.1_0003	2		Once the required Normal or Reverse position has been achieved, each Switch Rail shall be securely locked, relative to its Stock Rail, at all times when a train is passing over the POE.
I2R_WP2_TSK2.1_0004	2		Loss of electrical power to the POE shall not result in the release of Switch Rail Locking.
I2R_WP2_TSK2.1_0005	3	Closed side tolerance - Toe	Closed Side - To be no greater than 3.5mm from its associated Stock Rail at the toe
I2R_WP2_TSK2.1_0006	3	Closed side tolerance - Switch length	Closed Side - To be a maximum of 12 mm (15mm for CEN 60 layouts) from the Stock Rail at all other locations along the length of the Switch Rail Head plaining.
I2R_WP2_TSK2.1_0007	3	Open side tolerance - Toe	Open Side – To be no less than 102mm and no greater than 120mm from its associated fixed rail at the toe.
I2R_WP2_TSK2.1_0008	3	Temperature tolerance	The equipment shall work within -40°C / 70°C
I2R_WP2_TSK2.1_0009	3	Open side tolerance - Switch length	Open Side – To be a minimum of 50 mm at all other locations along the length of the Switch Rail Head plaining
I2R_WP2_TSK2.1_0010	4		It shall not be possible to lock and detect the lock effective unless the toe of the closed Switch Rail is less than 3.5mm from its associated stock or wing rail.
I2R_WP2_TSK2.1_0011	4		The Switch Rails shall be securely locked following the completion of either powered or manual movement of the rails.
I2R_WP2_TSK2.1_0012	4		The switch rails shall be securely locked, without damage to the POE equipment, with a minimum restraining force in facing moves, of 20kN and a maximum force of 35kN in trailing moves.
I2R_WP2_TSK2.1_0013	4		The locking system shall be independent of the actuator system and remains locked in event that the actuator fails.
I2R_WP2_TSK2.1_0014	4	Redundancy	There should be an individual locking device for both switch blades, or a redundant locking system of both switch blades with two independent locking devices
I2R_WP2_TSK2.1_0015	4		The locking system shall allow manual override in the event of failure to permit degraded working for the safe passage of trains. Enables response teams to reduce delay impacts.
I2R_WP2_TSK2.1_0016	1	Detection	Detection of switch rails - providing confirmation that the switch rails are held securely by the locking mechanism in either the Normal or Reverse positions within the specified tolerances
I2R_WP2_TSK2.1_0017	2		Failure to achieve a valid detection state for either Normal or Reverse positions shall not restrict the system from being commanded to return to the opposite position and provide a valid detection

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Req. ID I2R_WP#_TSK#_xxxx	Level	Title	In2Rail Requirement Description
			output
I2R_WP2_TSK2.1_0018	2		The POE shall continuously detect and confirm that the Switch Rails are locked, once the required Normal or Reverse position has been achieved.
I2R_WP2_TSK2.1_0019	2		In both Normal and Reverse positions, the POE shall continuously monitor the lateral position of each switch Rail relative to its associated Stock Rail.
I2R_WP2_TSK2.1_0020	3		The POE shall provide confirmation of Switch Rail position to the signalling system via the Apparatus Case, by a continuous confirmation of its detection state representing Normal or Reverse.
I2R_WP2_TSK2.1_0021	2		A valid Normal or Reverse detection state shall only be reported if the Switch Rails are securely locked in position
I2R_WP2_TSK2.1_0022			The detection system shall allow manual override in the event of failure to permit degraded working for the safe passage of trains. Enables response teams to reduce delay impacts.
I2R_WP2_TSK2.1_0023	1	Supplementary detection	Supplementary detection for switch rails - where necessary, providing confirmation that the rear parts of the switch rail are in their respective positions, within the specified tolerances
I2R_WP2_TSK2.1_0024		Supplementary Detection of the rear parts of the Switch Rails	The Switch Rail Position Detection shall confirm that the demanded Switch Rail position has been achieved and maintained along the switch length.
I2R_WP2_TSK2.1_0025		Installation	Ability to install in combination with existing switch actuation systems
I2R_WP2_TSK2.1_0026			Installation of equipment shall be compatible with the existing switch footprint (physical space envelope)
I2R_WP2_TSK2.1_0027			Equipment shall be compatible with existing switch profiles
I2R_WP2_TSK2.1_0028			Equipment shall be compatible with all existing bearers
I2R_WP2_TSK2.1_0029			Equipment shall be independent of track gauge
I2R_WP2_TSK2.1_0030			Equipment shall be compatible with all type of vehicles (high speed, heavy haul, conventional)
I2R_WP2_TSK2.1_0031			Ability to install with minimum disruption to operation railway, i.e. within maximum possession time of 4hrs.
I2R_WP2_TSK2.1_0032		Fault Tolerance	
I2R_WP2_TSK2.1_0033			System redundancy to allow switch to continue operating, limiting the impact of individual component failures
I2R_WP2_TSK2.1_0034			Ability to communicate any component failures to the signalling system
I2R_WP2_TSK2.1_0035			The Mean Time To Repair (MTTR) for attributable faults shall not exceed 1 hour, excluding logistic delay time (i.e. not including the time taken for staff to arrive on-site or the time lost through interruptions when trains are passing).
I2R_WP2_TSK2.1_0036			The MTTR for replacement of connections to the switch rail, which are damaged during a Run-Through, shall not exceed 4 hours.
I2R_WP2_TSK2.1_0037		Maintenance	
I2R_WP2_TSK2.1_0038		maximum maintenance	The system shall be designed such that the

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Req. ID I2R_WP#_TSK#_xxxx	Level	Title	In2Rail Requirement Description
		time per visit	scheduled maintenance can be completed within an Allocated Maintenance Period per point end of 45 minutes maximum per visit.
I2R_WP2_TSK2.1_0039		maximum maintenance time per year	The system shall be designed such that the scheduled maintenance can be completed within Total Allocated Maintenance Period per year of 3 hours (additional to any mandatory safety requirements such as Facing Point Lock Testing).
I2R_WP2_TSK2.1_0040		Maximum number of visits per year	The system shall be designed such that the scheduled maintenance can be completed with a maximum number of 6 visits per year.
I2R_WP2_TSK2.1_0041		Component changes	Planned component changes shall not be more frequent than 1 year.
I2R_WP2_TSK2.1_0042			Any modules or sub-assemblies of the POE, which during their replacement, require disturbance of the track or track support shall be designed to withstand Category 1 traffic conditions for a minimum of 25 years.
I2R_WP2_TSK2.1_0043		Standardised replacement parts	
I2R_WP2_TSK2.1_0044		Modular structure	Modular structure, to allow installation and replacement in a short time
I2R_WP2_TSK2.1_0045		Greasing	Greasing shall be occur no more than once a month
I2R_WP2_TSK2.1_0046			The locking device have to be designed so that automatic tamping of the switch is possible
I2R_WP2_TSK2.1_0047		Likelihood of acceptance	Meets processes and standards applicable to the design of products for use on the network
I2R_WP2_TSK2.1_0048		Energy Supply	Requires an energy supply which existing power supply installations are capable of supplying
I2R_WP2_TSK2.1_0049		Environment	The POE will be required to operate when subject to dust and sand particles (particularly coal and train brake dust). The design of the unit shall be such that it shall prevent ingress of these particles on particularly vulnerable items e.g. micro switches and electrical contacts. If this is impractical then the design of the POE should ensure that these items are not affected by the build-up of such contaminants.
I2R_WP2_TSK2.1_0050		Reliability	
I2R_WP2_TSK2.1_0051			The toe detection and locking shall be designed to attain a Mean Time Before Attributable Faults (MTBAF) of 10 service years minimum or 250,000 switch operations.
I2R_WP2_TSK2.1_0052			The MTBAF of the manual operation facility shall be 100 years minimum or 10,000 operations.
I2R_WP2_TSK2.1_0053			Major components which are subjected to wear and tear during operational service shall have a life of 10 years or 350,000 operations, whichever occurs sooner.

Appendix D OptiKrea Ideation Method

Modified 635

(10 min * number of participants)

- During 10 minutes, each participant comes up with at least three ideas on how to address the ideation topic. Each participant documents their ideas by sketches and/or text on a sheet of A3 paper.
- Each participant sends their sheet of paper to their (left) neighbour.
- The neighbour reads through the ideas and adds at least three improvements, combinations of the ideas and/or new ideas on the sheet of paper during 10 minutes. It is OK to ask the (right) neighbour what he/she meant by an idea that is not possible to understand.
- The sheets pass all participants (i.e. step 1 ends when you receive the sheet of paper than you started out with).

Presentation of Ideas and Feedback

(5 min + 10 min * number of participants)

- The participants use 5 minutes to read through the ideas that have been added to the sheet of paper they started out with.
- Each person presents the ideas on the sheet of paper they started out with, if necessary, the other participants help to explain something the presenter has not been able to understand.
- After each presentation, the presented sheet is sent around among the participants and each participant gives feedback on the ideas (i.e. questions, improvements, potential etc.). Remaining available time is used for discussions.
- Maximum 10 min/sheet of paper for presentation and feedback.

Gallery viewing

(10 min)

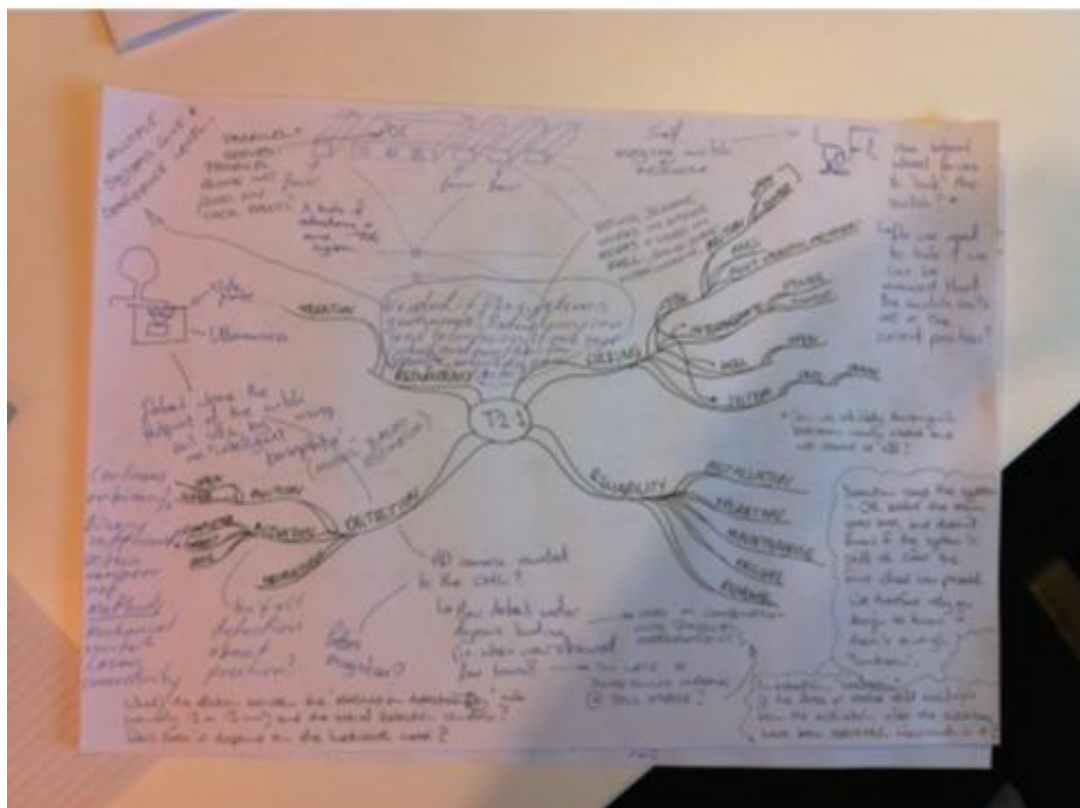
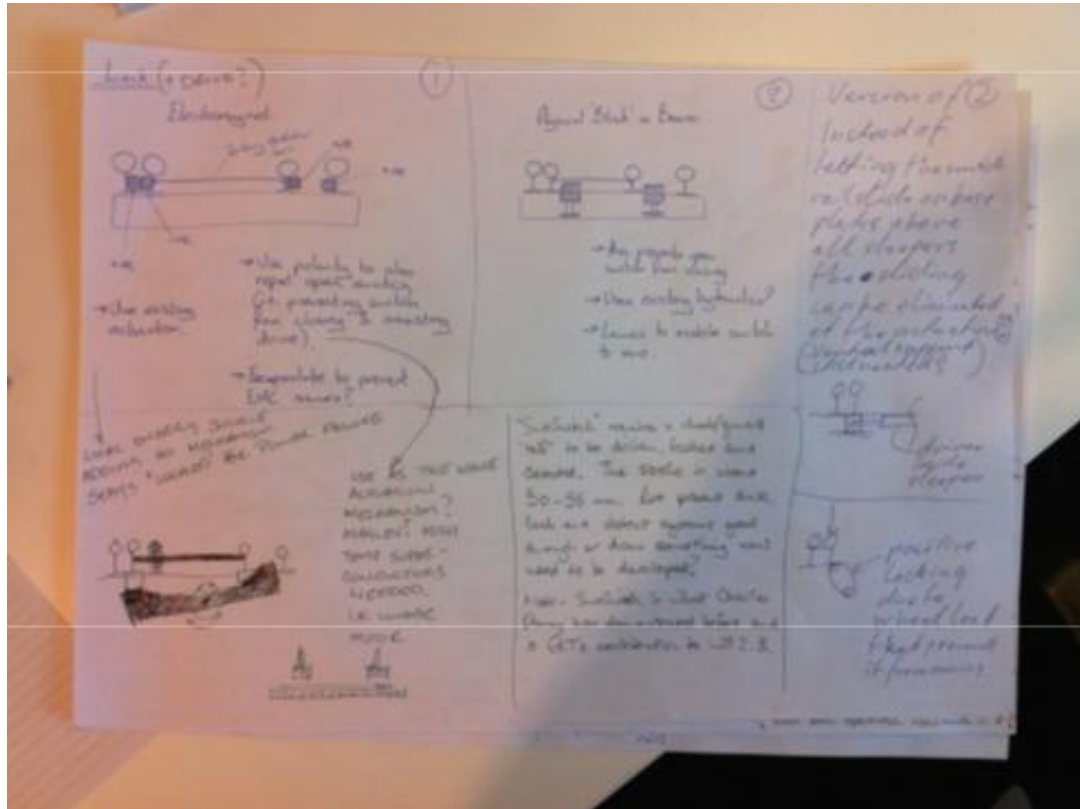
- The sheets of paper from step 1 are put up on a wall or some other place where all participants can easily view them.
- Each participant work individually to develop or combine ideas from the collection of ideas from step 1. New ideas are also welcome. Use new sheets of A3 paper to document the ideas by means of sketches and/or text (10 min).
- Keep in mind that we are still aiming to collect as many ideas as possible!

Presentation of Ideas and Feedback

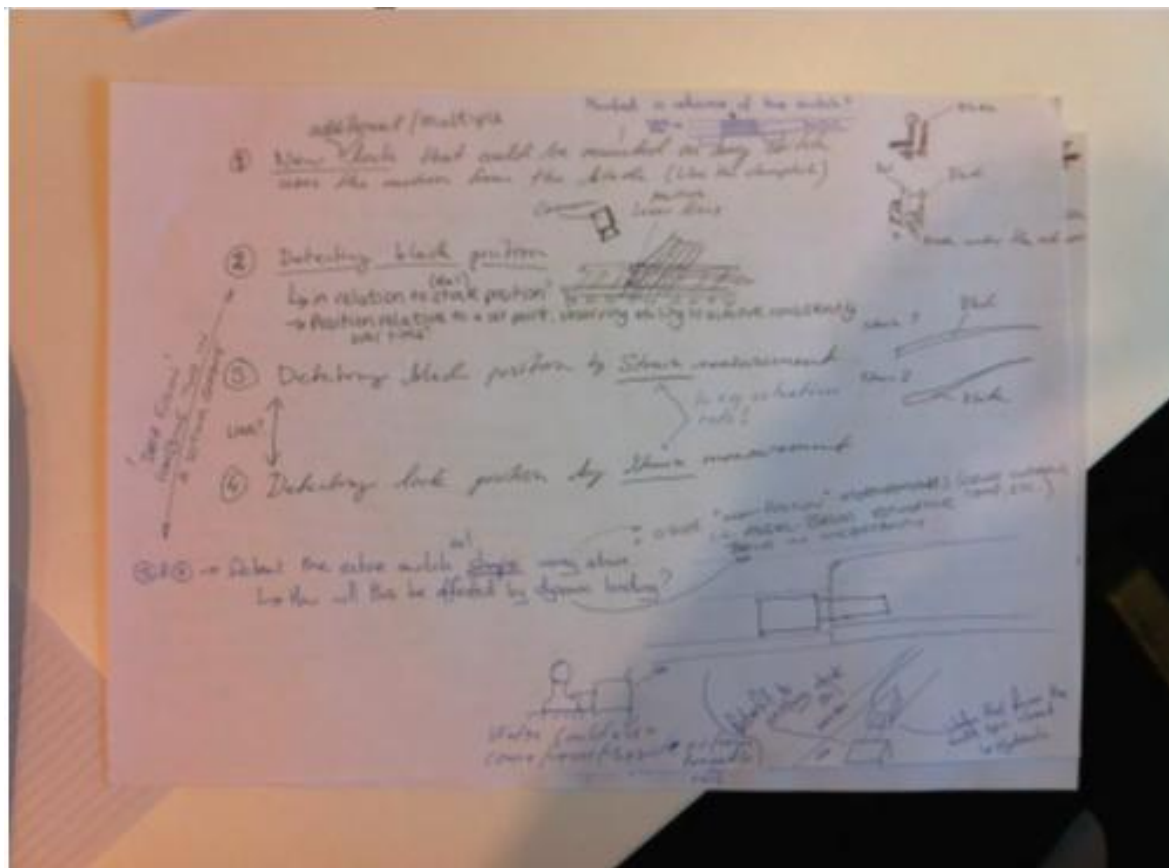
(5 min * number of participants)

- Each participant presents their own ideas from step 3.
- After each presentation the presented sheet of A3 paper is sent around among the participants and each participant gives their feedback on the ideas (questions, improvements, potential etc.). Remaining available time is used for discussions.
- Maximum 5 min/participant (presentation and feedback).

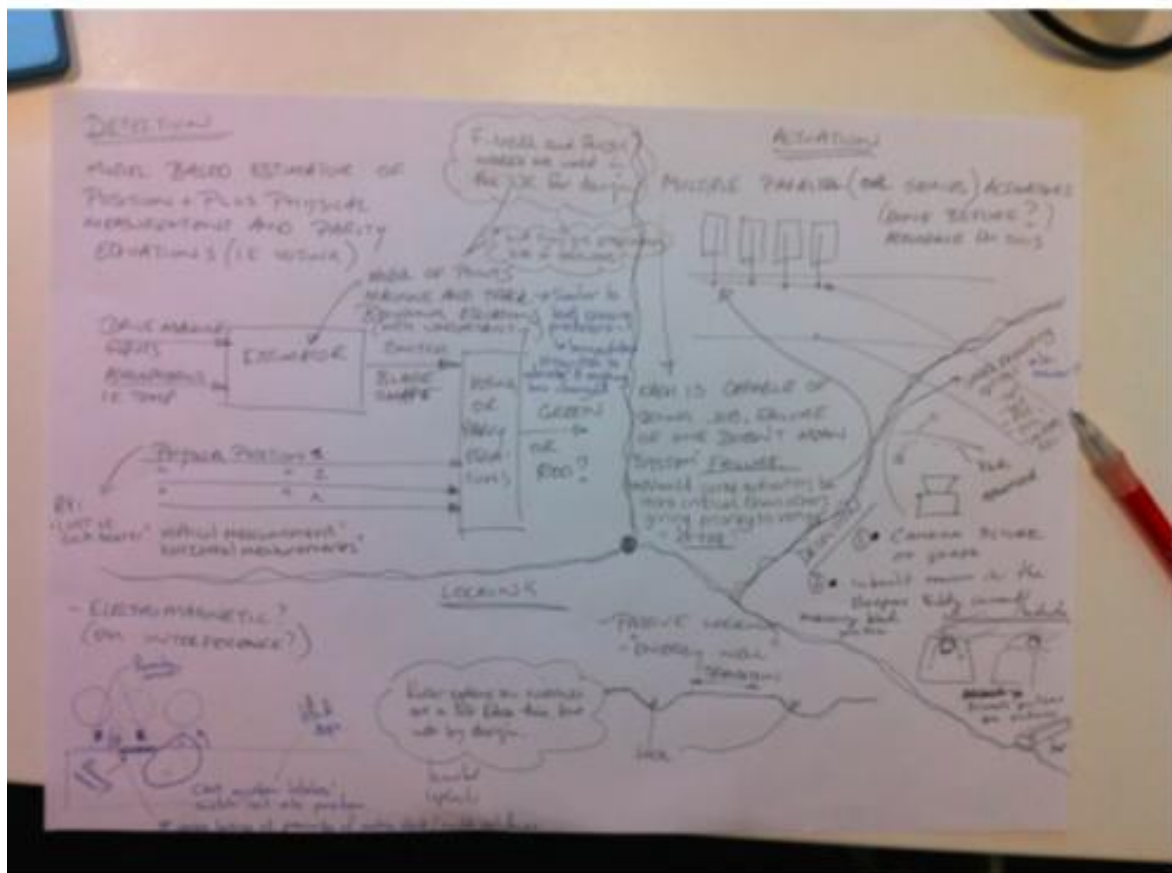
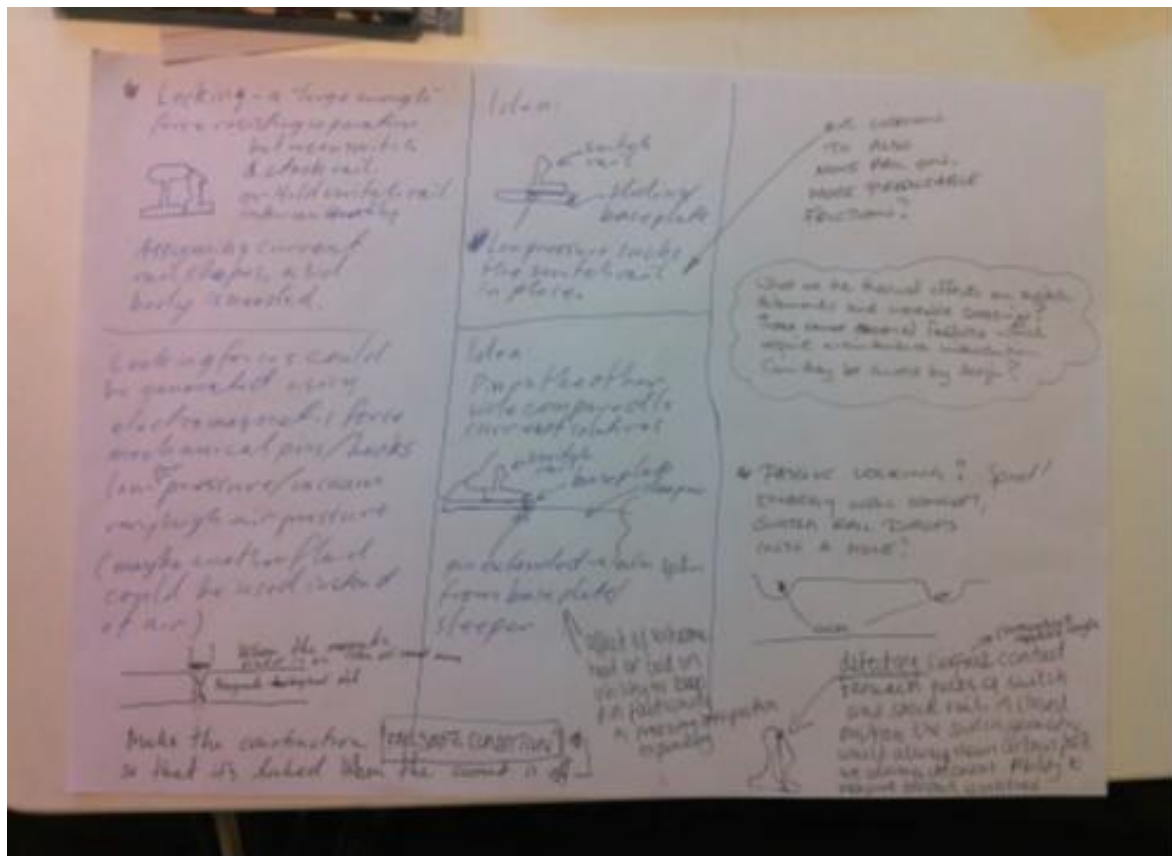
Appendix E Ideation Outcome (A3 Sheets)



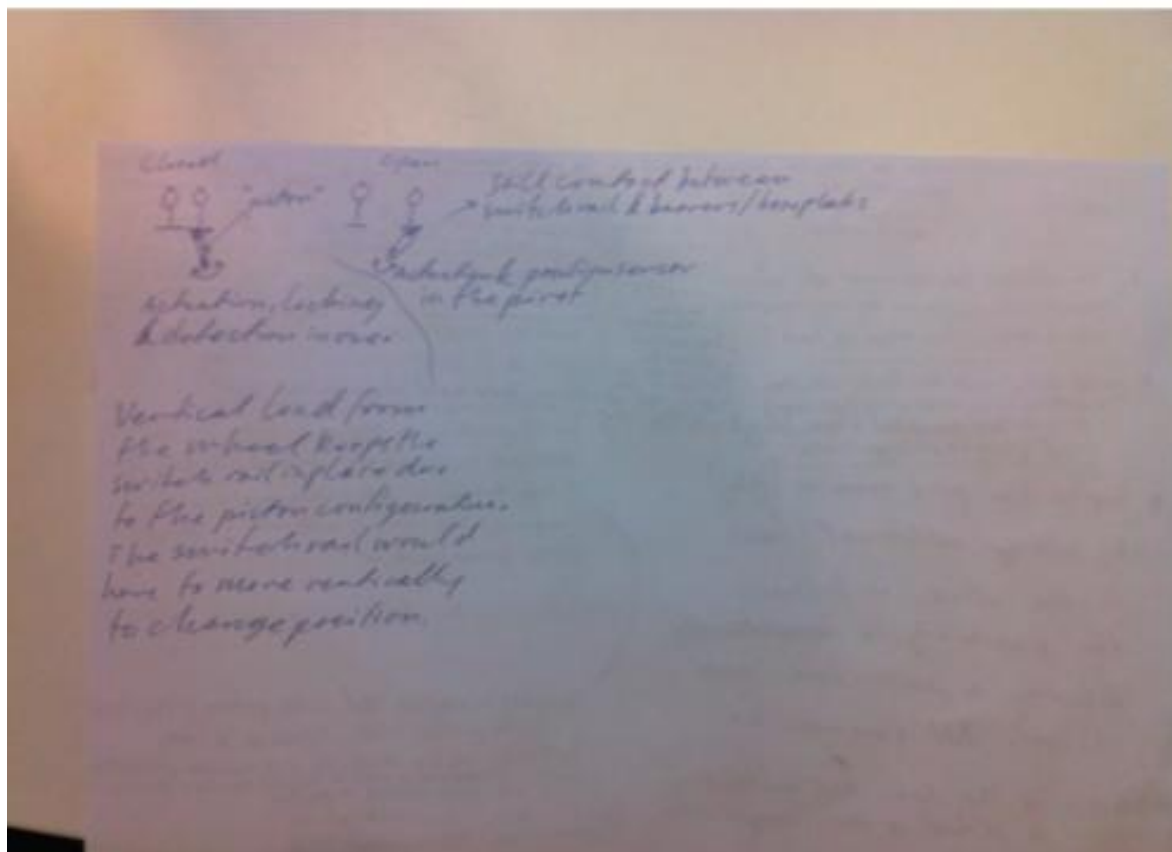
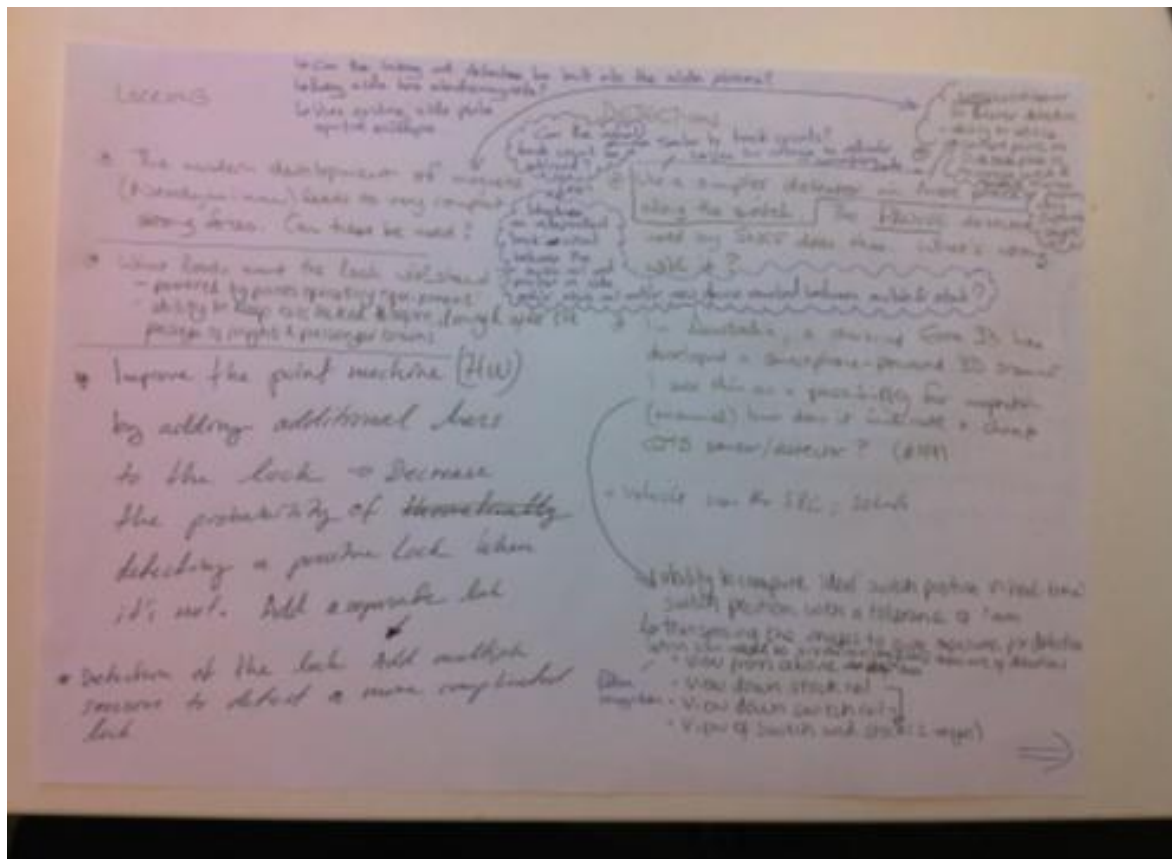
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Appendix F Idea Classification and Grouping

Visual / Camera (Note: grease could obscure vision)

- a. In Australia, a start-up Eora 3D, has developed a smart phone powered 3D scanner. I see this as a possibility for inspection (manual) but does it indicate a cheap COTS sensor/detector.
- b. Vehicle scan the S&C; 20mph
- c. Ability to compare 'ideal' switch position vs 'real time' switch position, with a tolerance of \pm mm. Transposing the images to give a measure for detection – Pattern recognition.
- d. HD camera mounted on OHL used in combination with physical measurements
 - i. How to detect under dynamic loading (*i.e.* when view is obscured by train)
 - ii. Too late if something is wrong at this stage?
- e. Detecting switch blade position in relation to stock rail position using a camera and multiple laser lines
- f. Detection – camera picture of shape and inbuilt sensors in the sleepers; eddy current/induction measuring blade position. Discrete positions or continuous?
- g. Camera mounting location options, require an accurate measure of detection:
 - i. From OHL
 - ii. View down stock rail; 4ft / 6ft
 - iii. View down switch rail; 4ft / 6ft
 - iv. View of switch rail and stock rail (2 images)
 - v. In bearer
 - vi. From POE

Contact

- h. Track circuit
 - i. Utilizing the existing track circuit
 - ii. Introducing an independent 'track circuit' between the switch rail and position on the slide and/or stock rail and/or new device between switch & stock
 - iii. In-bearer detection on ever switch bearer. Ability to utilize contact points on slide base plate to recognise switch & stock relative positions along the moveable length
- i. Use a simple detector in most places along the switch
 - i. The Paulve detector used by SNCF does this, what is wrong with it?
- j. Combined roller and detection for switch rail, gives position of switch rail & supports
- k. Detecting blade and lock positions by strain measurement,

- i. in actuation rods?
- l. Detect the entire switch rail shape using strain
 - i. And detect other 'non-position' measurements (drive current, temp, etc.) i.e. model based estimator to build in uncertainty
 - ii. How will this be affected by dynamic loading?
- m. Detect where the footprint of the switch rail sits by using an 'intelligent baseplate' (model based estimator)
- n. Can the locking and detection be built into the slide plates electromagnets on every slide plate

Non-Contact

- o. Change in induction between open & closed could be used for detection
 - i. Or other electromagnetic phenomena
- p. Use proximity sensors along the length of the switch
- q. Radio antenna (grid) to detect the presence of the switch blade
- r. Use of infra-red sensors? Optical?
- s. Similar to electronic diagnostics on motor vehicles, plug in the computer to establish faulty components.

Modelling

- t. Model based estimator of position and plus physical measurement and parity equation (e.g. voting).