Project no. TIP5-CT-2006-031415

INNOTRACK

Integrated Project (IP)

Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

D3.3.1 – List of key parameters for switch and crossing monitoring

Due date of deliverable: 2007/05/31

Actual submission date: 2008/11/04

Start date of project: 1 September 2006 Duration: 36 months

Organisation name of lead contractor for this deliverable: University of Birmingham

Final

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Table of Contents

Table of figures

1. Introduction

The purpose of this document is to identify the key parameters for optimising the performance of switch and crossing systems. The key parameters are those which, when altered, have the largest impact on the resulting performance of a switch and crossing system and hence provide indication of incipient failure.

This document first outlines the process followed for the identification of the key parameters. Further details are then presented on particular switch systems, the results of the identification process and the conclusions about what parameters are fundamental for optimisation. The focus has been on switch systems rather than crossings, because automated monitoring, which forms the basis of a realistic optimization effort, is most easily installed in the switch actuator system. The key parameters for optimization are therefore the parameters measured within this system.

2. Overview of the process for identification of key parameters

A systems approach has been taken in identifying the key parameters. S&C are viewed as systems with components and functions. The system is decomposed into fundamental components and functions. Known failures are then traced to the non-performance of particular functions. In this way it is possible to identify which functions and components contribute most to system failures and therefore the key optimisation parameters are discovered. Figure 1 shows this process in more detail.

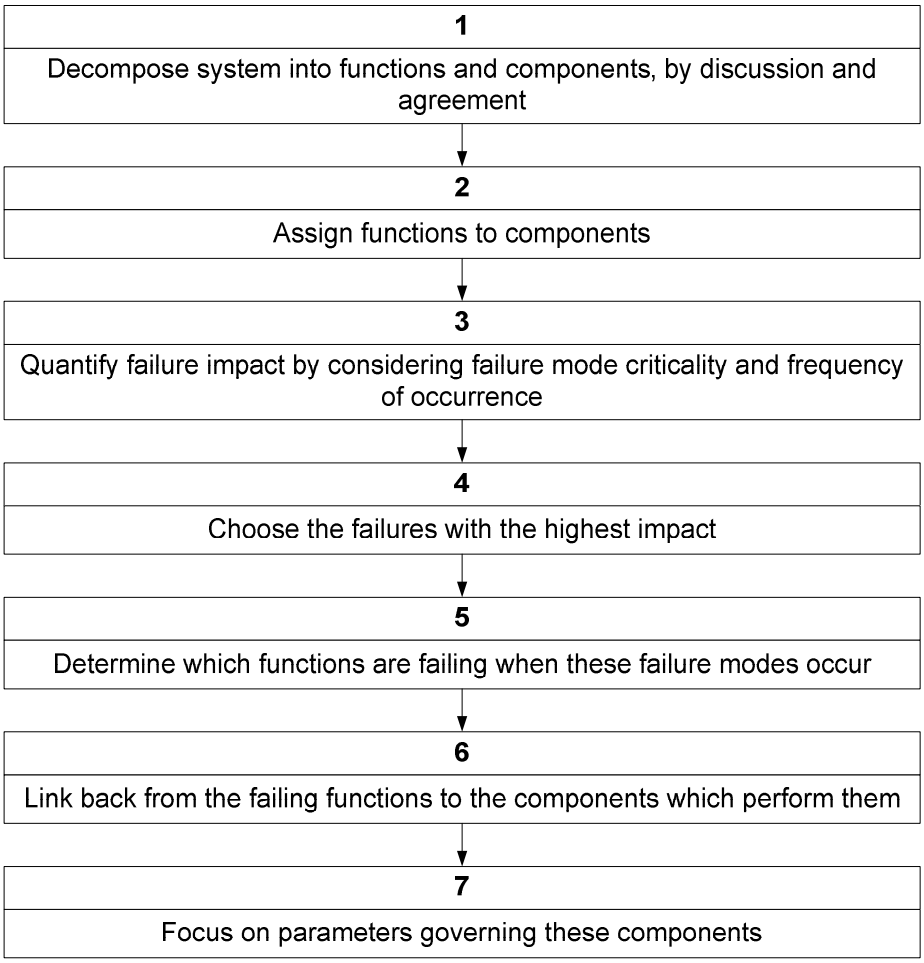


Figure 1 - Process for identifying key parameters

The decomposition process was one of discussion and mutual agreement as to what functions are performed by S&C and what generic components are present. The results of these discussions are presented as block diagrams in sections 4 and 5. These block diagrams are entity-relation diagrams. Functions and components are represented as entities (blocks) with unique numbers. The entities are connected by relations (arrows) which describe how the system parts fit together.

An example diagram is shown in Figure 2. Entities of different types are assigned a letter which makes the number of each entity unique. Subentities (entities which are parts of a larger entity) take the number of their parent entity followed by a further level of numbering, as shown in the diagram. Relations are labelled with a word or short phrase.

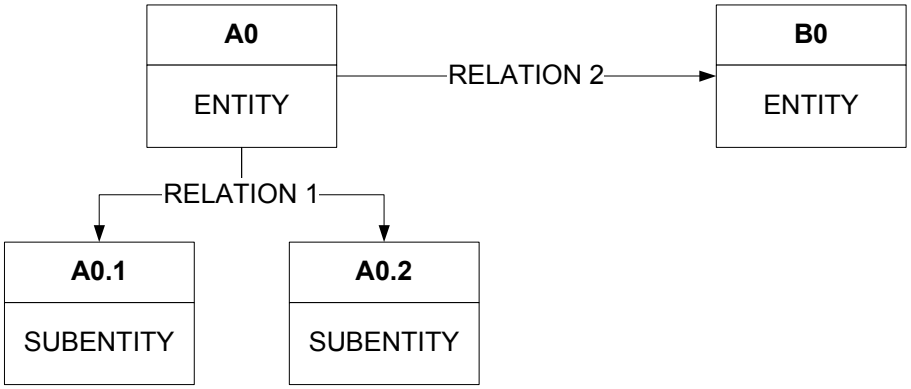


Figure 2 - Example of an entity-relationship diagram

3. Overview of European switch systems

3.1 Panels in S&C

Switch and crossing systems are divided up into three ‘panels’ as shown in Figure 3.

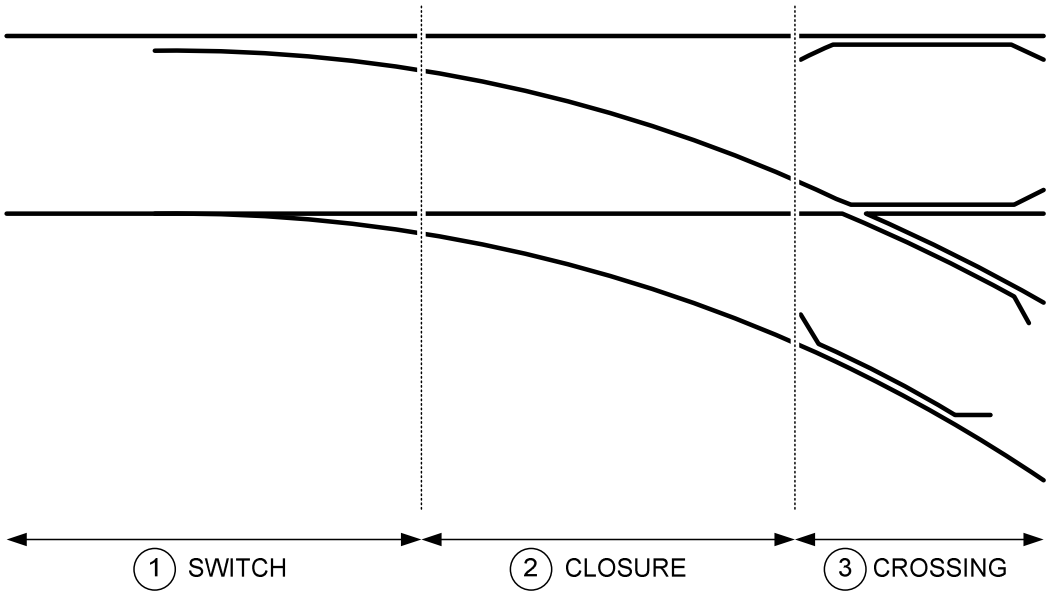


Figure 3 - The switch system partitioned into three panels

3.1.1 Switch panel

This is the part of the layout which ensures the continuity of any one of two or three diverging tracks, at the beginning of the divergence. The permanent way components are shown in Figure 4. The following components also belong in this panel:

Point machine (actuator)

This is a mechanical system which induces the switching movement between the two extreme positions. Table 1 shows the common types of point machines considered during the Innotrack project. Further details of some actuator systems are provided later in the report, as specified in Table 1.

Locking device

This locks the switch in one position to prevent movement of the switch rails as traffic passes.

Position detection

These devices detect the position of the switch. They are linked to the signalling system.

Driving devices

These are mechanical components which assist in the movement of the switch rails. They include drive rods, slide chairs and rollers.

Heater

These are used in cold countries to prevent the switch from freezing solid.

1 Left-hand half-set of switches
2 Right-hand half-set of switches
3 Left-hand curved switch rail
4 Right-hand straight switch rail
5 Left-hand straight stock rail
6 Right-hand curved stock rail
7 Heel baseplate
8 Block or heel block
9 Fishplate block
10 Stud/distance block
11 Slide baseplate
12 Stretcher bar bracket
13 Stretcher bar
14 Anti-creep device (not shown)
15 Switch toe/tip
16 Switch heel
17 Switch rail joint
18 Stock rail joint
19 Stock front joint
20 Soleplate
21 Bearers (not shown)

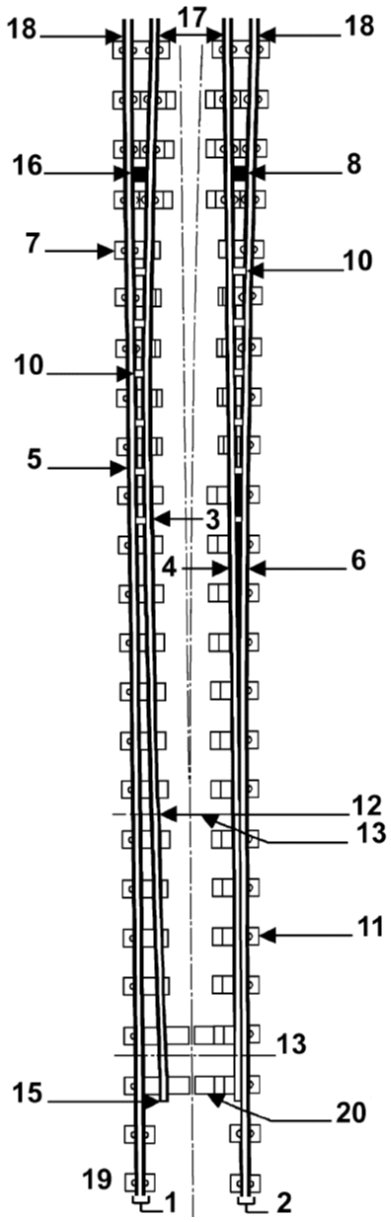


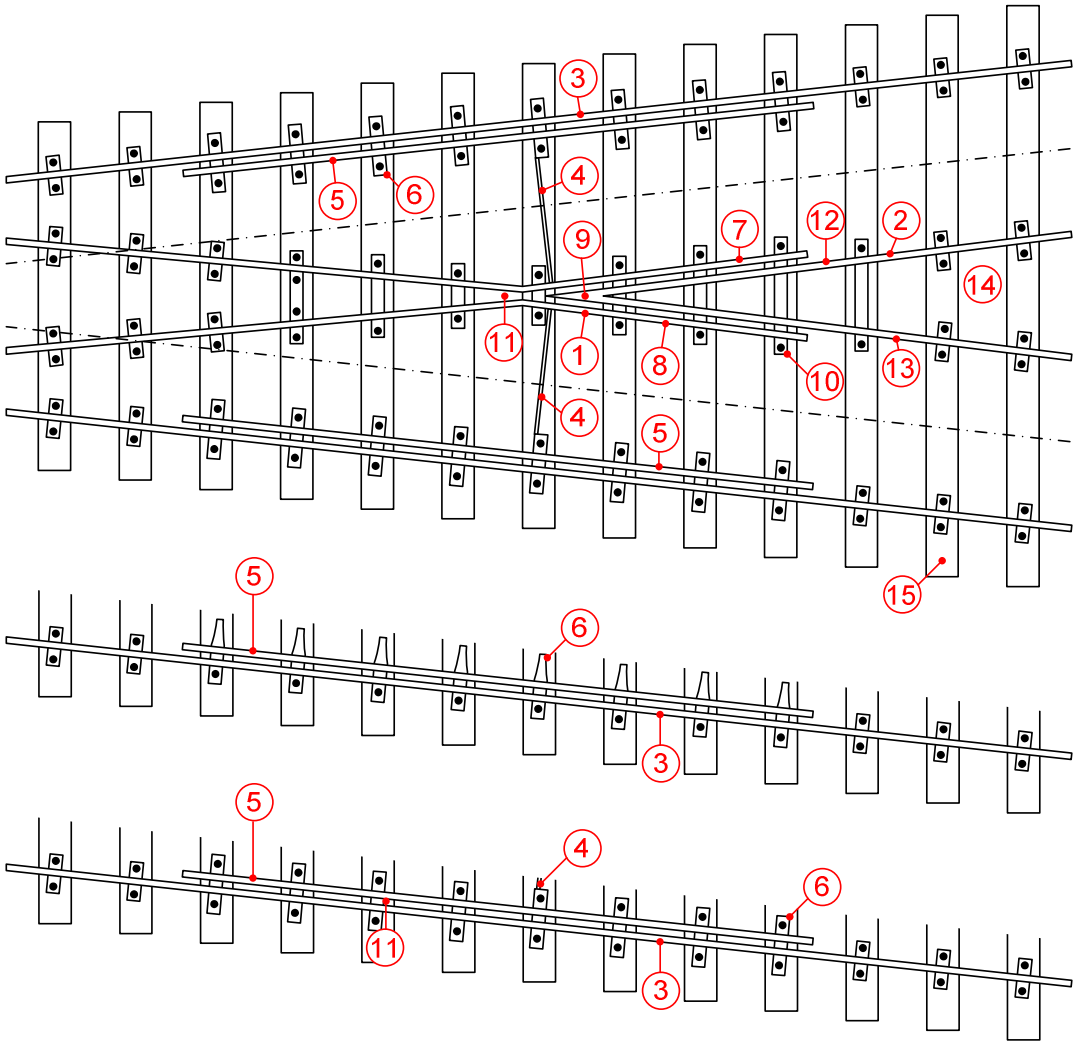
Figure 4 - Switch panel permanent way components

Name	Manufacturer	Subsystems included	Power	Further details
S700K	Siemens	Actuator, detection, locking	Electric AC/DC	
S700V	Siemens	Actuator, detection, locking	Electric AC/DC	
MCEM91	Vossloh	Actuator	Electric DC	
HW	Alstom	Actuator, detection, locking	Electric DC	
M63	Westinghouse	Actuator, detection, locking	Electric DC	
Clamp Lock	SPX	Actuator, detection, locking	Electro-hydraulic DC	

Table 1 - Common European switch systems considered in the Innotrack project

3.2 Crossing components

Figure 5 shows the detailed parts of a typical crossing panel.



1	Common crossing	**9**	Crossing vee
2	Crossing nose	**10**	Crossing baseplate
3	Outside rail	**11**	Block
4	Check rail strut	**12**	Point rail
5	Check rail	**13**	Splice rail
6	Check rail support	**14**	Heel of crossing
7	Left hand wing (rail)	**15**	Bearers
8	Right hand wing (rail)		

Figure 5 - Components of the crossing panel

4. S&C functional decomposition

The purpose of functional decomposition is to categorise the functions performed by the system so that deviations from intended functionality (faults) can be traced to a particular subfunction and to a particular component or group of components. It is this which will allow the determination of the key parameters for monitoring.

4.1 Initial functional representation

The first step is to define the function of the system as a whole. The function of an S&C system is to allow trains to run along varying routes. This defines the system's function on level 0 – the level where the system is viewed as a black box. Figure 6 represents this graphically. Inputs and outputs are drawn as entities, with number prefixes I and O respectively. All three inputs shown on the level 0 diagram originate from outside the S&C system, so they are shown on the top level diagram.

The functional flow is from left to right on the diagram and is shown by the dashed arrows.

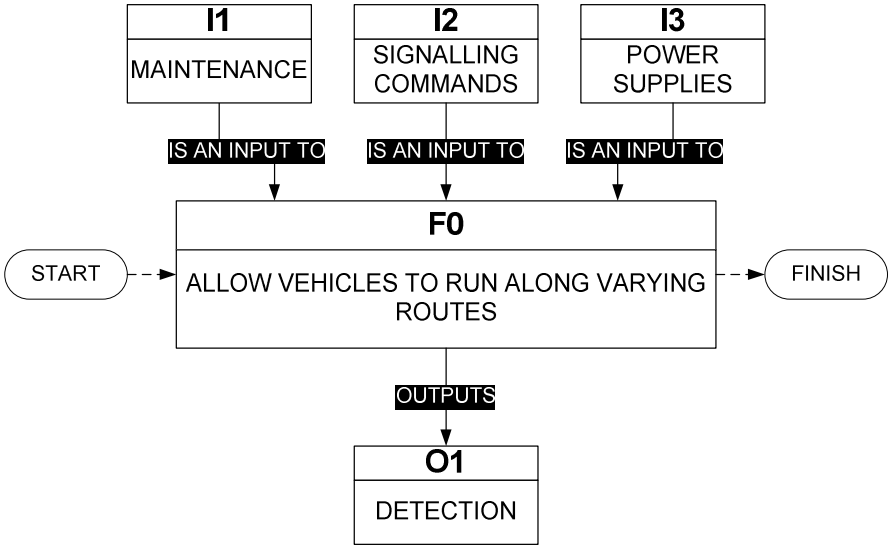


Figure 6 - Level 0 functional representation of the S&C system

4.2 First level decomposition

The level 0 function is then decomposed into levels of increasing complexity, where the individual functions have smaller and smaller scope. It is then possible to determine which subfunctions are failing when a particular fault occurs. The level 1 decomposition is shown in Figure 7. The external inputs can now be seen to feed to separate functions. Both functions are performed concurrently; this is shown by the parallel functional flow paths from left to right on the diagram.

Two functions were agreed upon at the first level. Function 1 is to support the movement of trains. This fulfils the requirements originating from the fact that S&C are part of the permanent way and must therefore support the movement of trains just as plain track would. Function 2 is to direct the path of trains according to the signalling system's commands. This is the primary function of S&C. Maintenance is an input to each of these functions. Signalling commands and power are additional inputs to function 2.

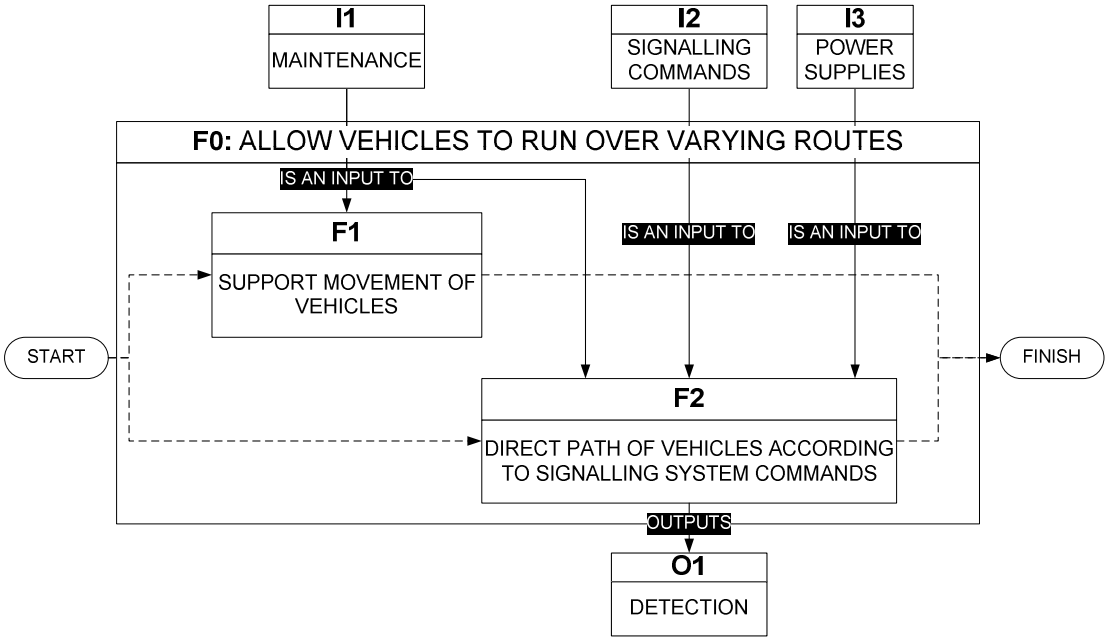


Figure 7 - Level 1 functional representation of the S&C system

4.3 Second level decomposition

4.3.1 Function 1

Function 1 can be intuitively split into three distinct subfunctions, each referring to a different dimension of motion. The motion of the train must be supported in each of the three physical dimensions, as illustrated in Figure 8. The resulting functions are shown in Figure 9. They are:

- to mechanically guide vehicles in the correct lateral direction
- to have negligible effect on the longitudinal motion of vehicles (i.e. not to accelerate or decelerate vehicles)
- to maintain the correct vertical motion of vehicles

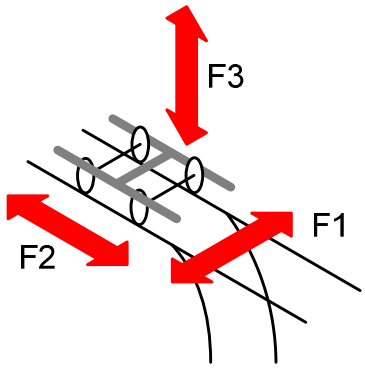


Figure 8 - Dimensions of motion supported by function 1

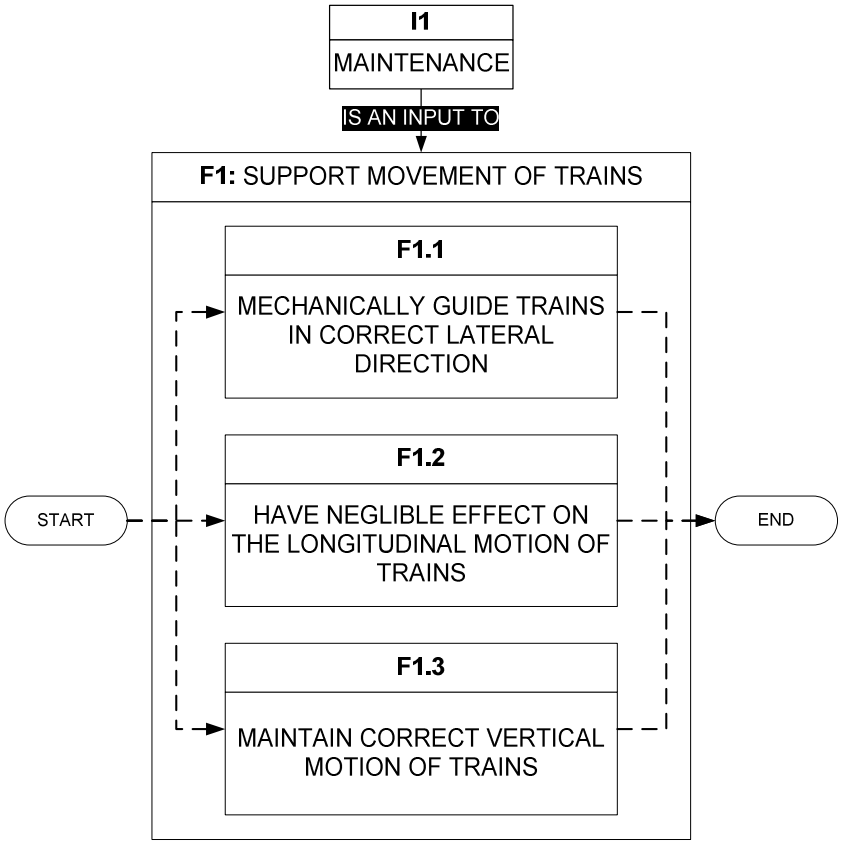


Figure 9 - Level 2 representation for function 1

4.3.2 Function 2

This function is concerned with the switching nature of S&C i.e. the fact that trains are to run on varying routes. The signalling system requires accurate detection (2.1) of the state of the S&C. Given an accurate knowledge of the S&C's position, the signalling system may or may not then require movement of the switch. Commands from the signalling system are interpreted (2.2) and if a switch is required, the switch must be unlocked (2.3), moved (2.4), and locked (2.5) again. These five functions all belong to function 2 and their decomposition is shown in Figure 10.

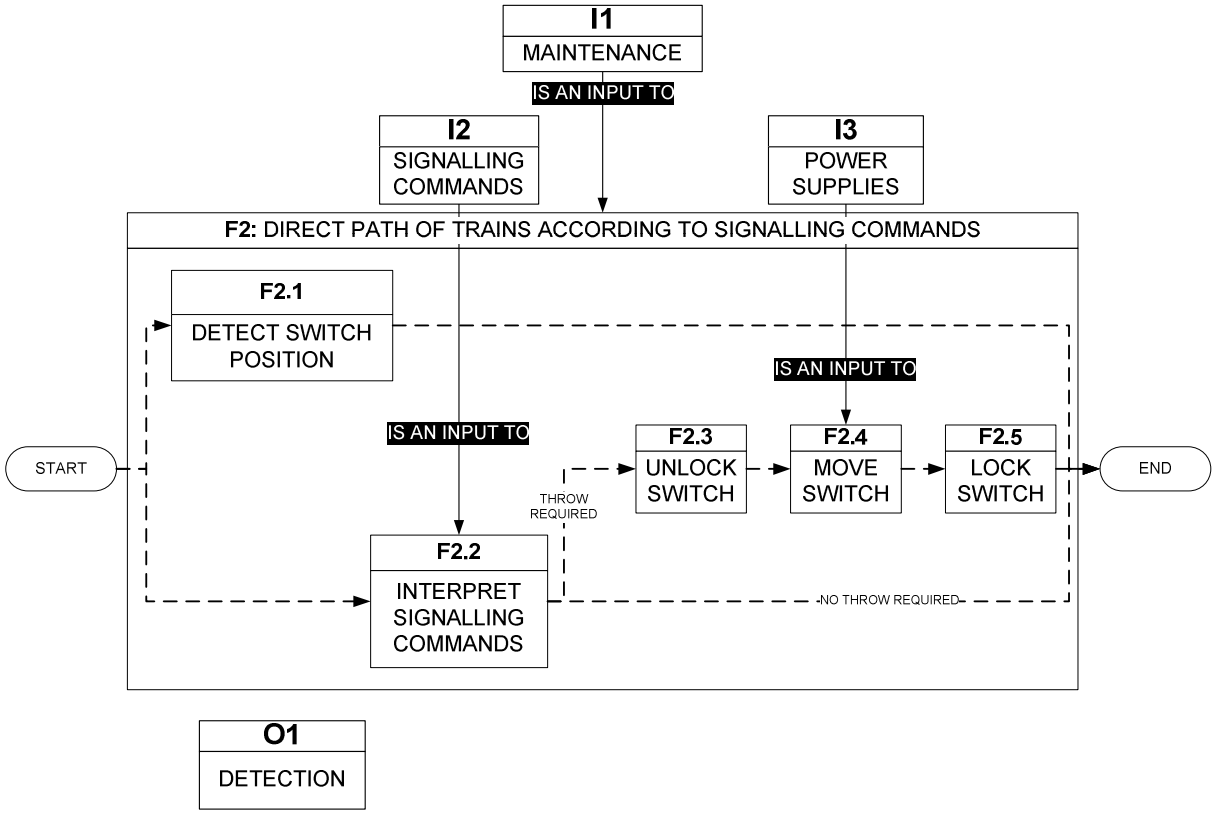


Figure 10 - Level 2 representation of function 2

5. Component decomposition of a S&C system

A generic component decomposition has been developed for S&C systems. This is shown in Figure 11. These are the components that are typically present in a S&C system, whatever type it happens to be. Each component performs one or more of the functions developed in section 4. Table 2 shows which functions are performed by which components. Those components which are not found in all S&C systems are printed in grey.

Component	Functions performed	Component	Functions performed
C1 – Switch and crossing	F1.1, F1.2, F1.3, F2.4	C3 – Actuation system	F2.2, F2.4
C1.1 – Stock rails	F1.1, F1.2, F1.3	C3.1 – Actuator	F2.4
C1.2 – Switch rails	F1.1, F1.2, F1.3	C3.2 – Drive link	F2.4
C1.3 – Crossing	F1.1, F1.2, F1.3	C3.2.1 – Primary drive	F2.4
C1.3.1 – Frog	F1.1, F1.2, F1.3	C3.2.2 – Backdrive	F2.4
C1.3.2 – Check rails	F1.1	C3.3 – Protection	F2.4
C1.4 – Switch rail support	F1.3, F2.4	C3.4 - Controller	F2.2
C1.4.1 – Slide chairs	F1.3, F2.4	C4 – Locking	F2.3, F2.5
C1.4.2 – Rollers	F2.4	C5 – Detection	F2.1
C1.5 - Stretchers	F1.1	C5.1 – Detection rods	F2.1
C2 – Substructure	F1.1, F1.3	C5.2 – Detection device	F2.1
C2.1 – Foundation	F1.1, F1.3	C5.3 – Supplementary detection	F2.1
C2.2 – Bearers	F1.1, F1.3	C6 – Heating	F2.4
C2.3 – Rail chairs	F1.1, F1.3	C6.1 – Element	F2.4
C2.4 – Fixtures	F1.1, F1.3	C6.2 – Sensor	F2.4
		C6.3 – Controller	F2.4

Table 2 - Functions allocated to components of the S&C system

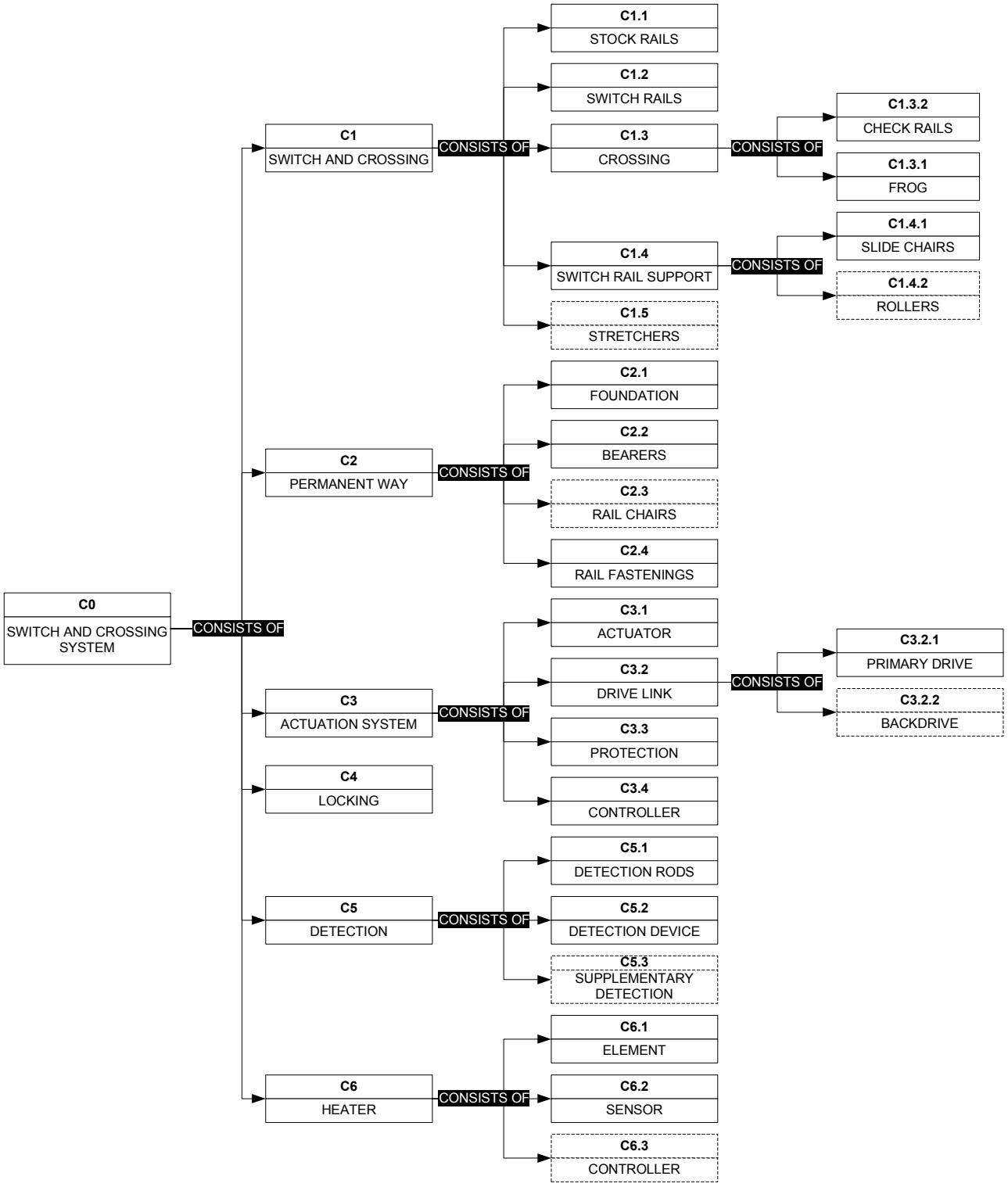


Figure 11 - Component decomposition for a generic S&C system

6. Failure mode effects and criticality analysis

Failure Modes, Effects and Criticality Analysis (FMECA) is the process of evaluating all possible faults a system can exhibit, the effects (i.e. the functions which are adversely affected by the fault) and the criticality (i.e. the magnitude of the fault's consequences). The key system parameters to monitor are those which are connected to functions or components whose failure modes are most critical. By using FMECA we can look at one area of the problems caused by failures, which is the effect a failure mode has on the system. The cost of repairs and the time taken can also be factors, as well as the safety implications of a failure.

In terms of maintenance planning, the key parameters to monitor are those where failure modes cost most, take longest to repair, and reduce the functionality of the system by the greatest degree. Clearly some tradeoff has to be made where these variables do not correlate well. In the railway industry the number of train delay minutes associated with each failure mode provides an indication of its financial criticality, whereas the likelihood of causing a wrong side failure (i.e. a failure that may result in an accident of loss of life) provides the safety criticality.

Appendix B shows the delay minutes per failure mode for the common types of point machines found in the UK. This information enables us to identify the key parameters for monitoring. FMECA is usually carried out separately for each type of asset, but for a system-wide key parameter view it may be advantageous to follow a more generic approach, using the functions and components identified in the previous sections as a model for switch and crossing systems throughout Europe.

The FMECAs developed during this project are provided in Appendix A.

7. Conclusions and key parameters

This document describes a process whereby the fundamental functions of a switch and crossing are considered in order to identify the key parameters for modelling. It is shown that by considering the functions and then how these are performed by the different components within the switch and crossing a direct link can be made to the failure mode effects and criticality analysis, and hence cost of delay.

Within this initial work, data on delay minutes have been provided by Network Rail. Network Rail's point machines are DC powered which make them different to most of those found in continental Europe. The results therefore allow verification of the process described but do not provide a definitive answer to which parameters are paramount for switch and crossing monitoring throughout Europe. It is hoped that in the second year of the project, now that the approach described in this document has been verified, that further data similar to that collected from Network Rail will be made available by all infrastructure managers within the project.

The results from Network Rail can be analysed in various ways. However, by considering which failure modes cause the greatest cost in terms of delay minutes it can be seen from Table 3 - Top 25 failures for the Clamp Lock switch actuatorTable 3Table 8 that the common failure modes include:

- No fault found ("Tested OK on arrival" or "no cause" recorded)
- Detection lost or out of adjustment (abbreviated to OOA in the appendix)
- Slide chair dry or poor lubrication
- Drive arm out of adjustment
- Lock out of adjustment

The large percentage of failures classified as tested OK or no cause means that maintenance technicians are unsure what has caused a particular problem, or that there is an intermittent fault. In these cases, it is likely that the fault will reoccur resulting in further delays. Therefore it is proposed that key parameters of force, time, displacement (and hence velocity and acceleration) and motor current are appropriate to aid the engineers understand more fully which failure mode has occurred.

It should be noted that this analysis has resulted from failure statistics for DC point machines in the UK and further data needs to be collected and analysed for AC systems. The remaining failure modes relate to out of adjustment faults within the detection, lock or drive. These failure modes should either be detected via specialist sensors which identify these specific faults, or algorithms should be developed to use the key parameters to identify the faults. In the second and third year of the Innotrack project, work will focus on both of these areas.

The effects of maintenance and repairs on the performance of switch systems should be examined in further detail. Periodic maintenance may have detrimental effects on machines which are operating correctly when maintenance is carried out. This is one incentive to move towards condition-based maintenance – intervention is then only carried out when necessary.

Appendix A Detailed FMECAs

A.1 Siemens S700K

Structure				Description of failure							handling of failure			
No.	Item name	Qty.	Function	Possible reason of failure	Id.	failure mode	failure effect on the subsystem	failure effect on the turnout system	significance in the standard operation	severity class [I-V]	failure detection by the system	failure detection by maintenance staff	Action after failure	Remarks
C1	Acutator Siemens S 700k													
C1.1	3-Phase AC Motor	1	Energy exchange, creation of kinetic ernergy	short circuit		no movement	no operation	no position change	limited use of track for traffic	V	Position detection	during maintence on demand	change of the motor	immediate action required
				short circuit		stop of movement during position change	no operation	undefined position of the switch	no traffic possible	V	Position detection	during maintence on demand	change of the motor	immediate action required
C1.2	Drive Link	1	Conversion of rotating energy into linear movement of the switch blades											
C1.2.1	Gear System	1	Conversion of rotating energy into linear movement	defect of material, increased wear, undetected crack		no movement	none	no position change	limited use of track for traffic	V	Position detection	during maintence on demand	change of the actuator	immediate action required
				defect of material, increased wear, undetected crack		stop of movement during position change	none	undefined position of the switch	no traffic possible	V	Position detection	during maintence on demand	change of the actuator	immediate action required
C1.2.2	Drive Rod		Driving of the switch blades	defect of material, increased wear, undetected crack		no movement	none	no position change	limited use of track for traffic	V	Position detection	during maintence on demand	change of the actuator	immediate action required
				defect of material, increased wear, undetected crack		stop of movement during position change	none	undefined position of the switch	no traffic possible	V	Position detection	during maintence on demand	change of the actuator	immediate action required
C1.3	Mechnical Clutch	1	Limiting driving force	defect of material/manufacturing, increased wear, undetected crack - force too low		stop of movement during position change	none	undefined position of the switch	no traffic possible	V	Position detection	during maintence on demand	change of the clutch / reajustment of torque-limiter	immediate action required
				defect of material/manufacturing, increased wear, undetected crack - force too high		none	none	damage of the switch blade when blocked by a stone	risk of derailment	II	none	during cyclic inspection	change of the clutch / reajustment of torque-limiter	immediate action required
C1.4	Control Board	1	Power Supply and interlocking interface	defect of material		lost contacts, no signal	no operation	no direct effect	no traffic possible	V	interlocking system	during maintence on demand	change of control board	immediate action required
C1.5	Position Detection	1	Detection of blade position							V				
C1.5.1	Detection Rods	2	Transfer of blade movement to the Detection circuit	lost contact force or geometry		no detection of end position	no internal locking of position	none	no traffic possible	V	detection circuit	during maintence on demand	grinding	immediate action required
C1.5.2	Detection Cicuit	2	detection of end position of the switch blades	break of contacts		no detection of end position	No transfer of the horizontal forces	none	no traffic possible	V	interlocking system	during maintence on demand	exchange for a new unit	immediate action required
				contacts out of position		no detection of end position	none	none	no traffic possible	V	interlocking system	during maintence on demand	adjustment of contacts	immediate action required

A.2 Alcatel L700H

Structure				Description of failure						handling of failure			
No.	Item name	Qty.	Function	Possible reason of failure	Id.	failure mode	failure effect on the subsystem	failure effect on the turnout system	significance in the standard operation	severity class [I-V]	failure detection by the system	failure detection by maintenance staff	Action after failure	Remarks
C1	Acutator Alcatel L 700H													
C1.1	3-Phase AC Motor	1	Energy exchange, creation of kinetic ernergy	short circuit		no movement	no operation	no position change	limited use of track for traffic	V	Position detection	during maintence on demand	change of the motor	immediate action required
				short circuit		stop of movement during position change	no operation	undefined position of the switch	no traffic possible	V	Position detection	during maintence on demand	change of the motor	immediate action required
C1.2	Drive Link	1	Conversion of rotating energy into linear movement of the switch blades											
C1.2.1	Hydraulic compressor	1	Conversion of kinetic enerygy into a fluid flow	sealing defect, increased wear		no movement or stop of movement during position change								
C1.2.2	Hydraulic cylinder	2	Conversion of fluid flow into linear movement	defect of material, increased wear, undetected crack		no movement	none	no position change	limited use of track for traffic	V	Position detection	during maintence on demand	change of the actuator	immediate action required
C1.2.3	pressure valve	1	Limiting driving force	defect of material/manufacturing, increased wear, undetected crack - force too low		stop of movement during position change	none	undefined position of the switch	no traffic possible	V	Position detection	during maintence on demand	change of the clutch / reajustment of torque-limiter	immediate action required
				defect of material/manufacturing, increased wear, undetected crack - force too high		none	none	damage of the switch blade when blocked by a stone	risk of derailment	II	none	during cyclic inspection	change of the clutch / reajustment of torque-limiter	immediate action required
C1.2.4	Compensator	1	Gearing between Drive rod and hydrailic cylinder	defect of material, increased wear, undetected crack		no movement	none	no position change	limited use of track for traffic	V	Position detection	during maintence on demand	change of the actuator	immediate action required
				defect of material, increased wear, undetected crack		stop of movement during position change	none	undefined position of the switch	no traffic possible	V	Position detection	during maintence on demand	change of the actuator	immediate action required
C1.2.5	Drive Rod		Driving of the switch blades	defect of material, increased wear, undetected crack		no movement	none	no position change	limited use of track for traffic	V	Position detection	during maintence on demand	change of the actuator	immediate action required
				defect of material, increased wear, undetected crack		stop of movement during position change	none	undefined position of the switch	no traffic possible	V	Position detection	during maintence on demand	change of the actuator	immediate action required
C1.4	Control Board	1	Power Supply and interlocking interface	defect of material		lost contacts, no signal	no operation	no direct effect	no traffic possible	V	interlocking system	during maintence on demand	change of control board	immediate action required
C1.5	Position Detection	1	Detection of blade position							V				
C1.5.1	Detection Rods	2	Transfer of blade movement to the Detection circuit	lost contact force or geometry		no detection of end position	no internal locking of position	none	no traffic possible	V	detection circuit	during maintence on demand	grinding	immediate action required
C1.5.2	Detection Cicuit	2	detection of end position of the switch blades	break of contacts		no detection of end position	No transfer of the horizontal forces	none	no traffic possible	V	interlocking system	during maintence on demand	exchange for a new unit	immediate action required
				contacts out of position		no detection of end position	none	none	no traffic possible	V	interlocking system	during maintence on demand	adjustment of contacts	immediate action required

A.3 Siemens ELP 319 detection device

Structure				Description of failure							handling of failure			
No.	Item name	Qty.	Function	Possible reason of failure	Id.	failure mode	failure effect on the subsystem	failure effect on the turnout system	significance in the standard operation	severity class [I-V]	failure detection by the system	failure detection by maintenance staff	Action after failure	Remarks
C3	Detection Device Siemens ELP 319													
C3.1	Detection Rods	2	Transfer of blade movement to the Detection circuit	lost contact force or geometry		no detection of end position	no internal locking of position	none	no traffic possible	V	detection circuit	during maintence on demand	grinding	immediate action required
C3.2	Detection Cicuit	2	detection of end position of the switch blades	break of contacts		no detection of end position	No transfer of the horizontal forces	none	no traffic possible	V	interlocking system	during maintence on demand	exchange for a new unit	immediate action required
				contacts out of position		no detection of end position	none	none	no traffic possible	V	interlocking system	during maintence on demand	adjustment of contacts	immediate action required

A.4 EW608b switch and crossing assembly

Structure				Description of failure							handling of failure			
No.	Item name	Qty.	Function	Possible reason of failure	Id.	failure mode	failure effect on the subsystem	failure effect on the turnout system	significance in the standard operation	severity class [I-V]	failure detection by the system	failure detection by maintenance staff	Action after failure	Remarks
1	single turnout													
1.1	switch & stock rail assembly	1	Route selection of the rail vehicles, Take up and transfer the vertical and horizontal forces											
1.1.1	half set of switches	2	Take up and transfer the vertical and horizontal forces											
1.1.1.1	stock rail	2	Take up and transfer the vertical and horizontal forces, lateral attachment of the switch rail	defect of material/manufacturing, load over specification, increased wear, undetected crack	1	rail cross break	decrease of the loading capacity	no effect, possibly no setting of the turnout due to fishplates	discontinuous area, possibly speed restriction area and interference in operation (single track working)	V	detection by driver (noise or impact)	detected by inspection of the line, early detection by ultrasonic testing	fishplates, exchange for a new unit	danger of failure propagation (derailment) if the preventive maintenance intervals are too long
		2	Take up and transfer the vertical and horizontal forces, lateral attachment of the switch rail	defect of material/manufacturing, load over specification, increased wear, undetected crack	2	large-area breakouts of the rail head	total breakdown	total breakdown	potential for derailment	I		early detection by ultrasonic testing	exchange for a new unit	comment in the maintenance manual: ultrasonic testing required
		2	Take up and transfer the vertical and horizontal forces, lateral attachment of the switch rail	defect of material/manufacturing, load over specification	3	cracks	strength of rail locally reduced	no direct effect	no direct effect, possibly speed restriction area	V		early detection by ultrasonic testing	grinding, exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.
		2	Take up and transfer the vertical and horizontal forces, lateral attachment of the switch rail	defect of material/manufacturing, poor maintenance	4	uneven running surface - corrugations	distorted / skew rail profile	Increased noise and vibration generated at wheel-rail interface	no direct effect, possible noise or degraded ride quality	V		Routine track patrol inspection. Monitoring by rolling inspection.	grinding	No immediate operational action required. Maintenance scheduled for non-traffic hours.
		2	Take up and transfer the vertical and horizontal forces, lateral attachment of the switch rail	excessive wear	5	rail head out of profile	distorted / skew rail profile	uneven loading of train wheel and uneven transmission of load to rail	no direct effect, possible noise or degraded ride quality	V		Routine track patrol inspection. Monitoring by rolling inspection.	grinding	No immediate operational action required. Maintenance scheduled for non-traffic hours.
1.1.1.1.1	distance blocks	n.d.	Horizontal support of the switch rail (Take up horizontal forces)	defect of material/manufacturing, load over specification	1	break	No transfer of the horizontal forces	increase of the switch strain	no effect, potential for derailment by failure combination and multi-failures possible	V		detected by inspection of the line	exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.

1.1.1.1.2					fasteners of the distance blocks	n.d.	Fastening of the distance blocks on the stock rail	defect of material/manufacturing, load over specification	1	break, loose	No transfer of the horizontal forces	increase of the switch strain	no effect, potential for derailment by failure combination and multi-failures possible	V		loosening detected by inspection of the turnout (in intervals), loss of the distance blocks due to a screw break will be detected by inspection of the line	fastening or exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.
1.1.1.1.3					anti-creeping device	2	limitation of the relative movement between switch and stock rail due to thermal displacements	defect of material / manufacturing	1	break of the form-fit elements	loss of the function	no effect, possibly setting problems	no effect, possibly setting problems	V	depending on the version of the switch locking devices setting problems can be detected	detected by inspection of the line	exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.
1.1.1.1.4					fasteners of the anti-creeping device	2	fastening of the anti-creeping device	defect of material / manufacturing, poor installation	1	break, loose	loss of the function	no effect, possibly setting problems	no effect, possibly setting problems	V	depending on the version of the switch locking devices setting problems can be detected	detected by inspection of the line	exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.
1.1.1.2				switch rail		2	Take up and transfer the vertical and horizontal forces, guide function	defect of material/manufacturing, load over specification, increased wear, poor maintenance	1	rail cross break in the unfixed area	total breakdown	total breakdown	potential for derailment	I	depending on the version of the switch locking devices the break can be detected	early detection of crack formation and wear condition by preventive maintenance	exchange for a new unit	comment in the maintenance manual: attention on the crack formation/wear condition
						2	Take up and transfer the vertical and horizontal forces, guide function	defect of material/manufacturing, load over specification, increased wear	2	rail cross break in the front of the fixed area (up to the 2nd fixation point)	disfunction of the fixation area	total breakdown	potential for derailment	I	depending on the version of the switch locking devices the break can be detected	early detection of crack formation and wear condition by preventive maintenance	exchange for a new unit	comment in the maintenance manual: ultrasonic testing required
						2	Take up and transfer the vertical and horizontal forces, guide function	defect of material/manufacturing, load over specification, increased wear	3	rail cross break in the back of the fixed area (after the 2nd fixation point)	decrease of the loading capacity	interference by the take up of the vertical and horizontal forces	discontinuous area, possibly speed restriction area	V	detection by driver (noise or impact)	detected by the inspection of the line	fishplates, exchange for a new unit or partial replacement	danger of failure propagation (derailment) if the preventive maintenance intervals are too long
						2	Take up and transfer the vertical and horizontal forces, guide function	defect of material, poor maintenance	4	critical breakouts according to the reference gauge	climbing of the wheel possible	total breakdown	potential for derailment	I		detected by check of turnout with reference gauges	exchange for a new unit	comment in the maintenance manual: check with reference gauges
						2	Take up and transfer the vertical and horizontal forces, guide function	defect of material, poor maintenance	5	uncritical breakouts according to the reference gauge	decrease of the loading capacity	decrease of the loading capacity	no direct effect	V		detected by check of turnout with reference gauges	grinding	comment in the maintenance manual: check with reference gauges

							2	Take up and transfer the vertical and horizontal forces, guide function	defect of material/manufacturing, load over specification	6	cracks	strength of rail locally reduced	no direct effect	no direct effect, possibly speed restriction area	V		early detection by ultrasonic testing	grinding, exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.
							2	Take up and transfer the vertical and horizontal forces, guide function	defect of material/manufacturing, poor maintenance	7	uneven running surface - corrugations	distorted / skew rail profile	Increased noise and vibration generated at wheel-rail interface	no direct effect, possible noise or degraded ride quality	V		Routine track patrol inspection. Monitoring by rolling inspection.	grinding	No immediate operational action required. Maintenance scheduled for non-traffic hours.
							2	Take up and transfer the vertical and horizontal forces, guide function	excessive wear	8	rail head out of profile	distorted / skew rail profile	uneven loading of train wheel and uneven transmission of load to rail	no direct effect, possible noise or degraded ride quality	V		Routine track patrol inspection. Monitoring by rolling inspection.	grinding	No immediate operational action required. Maintenance scheduled for non-traffic hours. Potential for climbing of wheel flange if maintenance intervals are too long.
							2	Take up and transfer the vertical and horizontal forces, guide function	switch rail deformed, object in gap	9	insufficient nearest flangeway	wheel flange impact with switch rail	damage to switch rail and/or wheel flange.	signalling system can monitor switch rail location, unlikely to have safety implication	V	signalling systems monitor switch rail location	Routine track patrol inspection.	adjustment of switch rails. Removal of foreign objects	definition of the nearest flangeway in the design
1.2		crossing					1	Enables a free passage of the wheel flange way by providing a gap in front of its crossing nose, Take up and transfer the vertical and horizontal forces	defect of material, poor maintenance(incorrect set-up of other components), increased wear	1	deformation / formation of burr / breakouts in the transition/cracks	increase of the strain, increased wear	no effect	discontinuous area, possibly speed restriction area	V		detected by the inspection of the line	grinding, build-up welding	danger of failure propagation (derailment) if the preventive maintenance intervals are too long
							1	Enables a free passage of the wheel flange way by providing a gap in front of its crossing nose, Take up and transfer the vertical and horizontal forces	defect of material, missing maintenance, increased wear	2	break	wrong guide function	up to total breakdown	potential for derailment	I		detected by the inspection of the line	exchange for a new unit	

1.3		check rail	2	Secure the correct axle-guidance through the gap of the crossing, Prevention of bumping of the wheels on the crossing nose	poor maintenance (adjustment), mechanical damage e.g. tamping works, defective design	1	check rail gauge too small	wrong guide function	damage of the crossing nose up to total breakdown	discontinuous area	V		detected by the inspection of the line	adjustment of the check rail gauge	comment in the maintenance manual: measurement of the check rail gauge, design verification by flangeway study, not in the responsibility of VAE
			2	Secure the correct axle-guidance through the gap of the crossing, Prevention of bumping of the wheels on the crossing nose	poor maintenance (adjustment), mechanical damage e.g. tamping works, defective design	2	check rail gauge too large	wrong guide function	gripping gauge, overload of the rail chair	potential for derailment	I		detected by the inspection of the line	adjustment of the check rail gauge	comment in the maintenance manual: measurement of the check rail gauge, design verification by flangeway study, not in the responsibility of VAE
			2	Secure the correct axle-guidance through the gap of the crossing, Prevention of bumping of the wheels on the crossing nose	defect of material/manufacturing	3	break	no guide function	total breakdown	potential for derailment	I		detected by the inspection of the line	exchange for a new unit	quality assurance avoids failures
1.3.1		fasteners of the check rail	n.d.	Fastening/support of the check rails, Take up of the horizontal forces	defect of material/manufacturing, load over specification	1	break, loose of the fasteners	no fastening function	no effect, increasing load of the contiguous fasteners	no effect, derailment by multi-failures possible (loss of several fastening material)	V		detected by the inspection of the line/check of the turnout	fastening or exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.
			n.d.	support of the check rail, Take up of the horizontal forces	defect of material/manufacturing, load over specification, wrong dimensioning	2	break of the rail chair	no take up of the horizontal forces	no effect, increasing load of the contiguous rail chairs	no effect, potential for derailment by multi-failures (break of several rail chairs)	V		detected by the inspection of the line	exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.

1.4	running rails	6	Take up and transfer the vertical and horizontal forces	defect of material/manufacturing, load over specification, increased wear	1	rail cross break	reduction of the loading capacity	interference by the take up of the vertical and horizontal forces	discontinuous area, possibly speed restriction area	V	detection by driver (noise or impact)	detected by the inspection of the line	fishplates, exchange for a new unit, partial replacement	danger of failure propagation (derailment) if the preventive maintenance intervals are too long
		6	Take up and transfer the vertical and horizontal forces	defect of material/manufacturing, load over specification	2	cracks	strength of rail locally reduced	no direct effect	no direct effect, possibly speed restriction area	V		early detection by ultrasonic testing	grinding, exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.
		6	Take up and transfer the vertical and horizontal forces	defect of material/manufacturing, poor maintenance	3	uneven running surface - corrugations	distorted / skew rail profile	Increased noise and vibration generated at wheel-rail interface	no direct effect, possible noise or degraded ride quality	V		Routine track patrol inspection. Monitoring by rolling inspection.	grinding	No immediate operational action required. Maintenance scheduled for non-traffic hours.
		6	Take up and transfer the vertical and horizontal forces	excessive wear	4	rail head out of profile	distorted / skew rail profile	uneven loading of train wheel and uneven transmission of load to rail	no direct effect, possible noise or degraded ride quality	V		Routine track patrol inspection. Monitoring by rolling inspection.	grinding	No immediate operational action required. Maintenance scheduled for non-traffic hours.
1.5	plates													
1.5.1	base plates	n.d.	Fastening of the rails, Take up and transfer the vertical and horizontal forces	defect of material/manufacturing, load over specification	1	break	interference of the fixation function	increasing load of the contiguous plates, by multi-failures and/or failure-propagation change of gauge possible	no effect, potential for derailment by multi-failures (break of several plates)	V		by inspection of the line hardly detectable, by measure of the gauge failure-propagation will be detected	exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.
1.5.2	slide plates	n.d.	Fastening of the stock rails, Enable the sliding operation of the switch rails, Take up and transfer the vertical and horizontal forces	defect of material/manufacturing, load over specification	1	break	interference of the fixation- and sliding function	increasing load of the contiguous plates, by multi-failures and/or failure-propagation change of gauge possible, maybe a interference of the setting function	interference in operation possible, single track working	V	depending on the version of the switch locking devices the break can be detected	by inspection of the line hardly detectable, by measure of the gauge failure-propagation will be detected	exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.

1.5.2.1				low friction sliding inserts (type ECOGLISS)	n.d.	Loss of the lubrication of the slide chairs	poor maintenance	1	pollution	bad sliding effect	higher setting forces	no effect	V	depending on the version of the switch locking devices setting problems can be detected	detected by check of the turnout	cleaning, exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.
					n.d.	Loss of the lubrication of the slide chairs	poor maintenance	2	wear over limit of wear	bad sliding effect	higher setting forces	no effect	V	depending on the version of the switch locking devices setting problems can be detected	detected by check of the turnout	exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.
1.5.3			switch roller plates		n.d.	Fastening of the stock rails, Enable the rolling operation of the switch rails, Take up and transfer the vertical and horizontal forces	defect of material/manufacturing/installation, corrosion	1	ball bearing stuck and worn out	loss of the rolling function	increase driving force	no effect, potential damage to switch machine and/or possibly setting problems	V	depending on the version of the switch locking devices setting problems can be detected	detected by check of the turnout	exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.
					n.d.	Fastening of the stock rails, Enable the rolling operation of the switch rails, Take up and transfer the vertical and horizontal forces	defect of material/manufacturing/, load over specification	2	break	interference of the fixation- and rolling function	increasing load of the contiguous plates, by multi-failures and/or failure-propagation change of gauge possible, maybe a interference of the setting function	interference in operation possible, single track working	V	depending on the version of the switch locking devices the break can be detected	by inspection of the line hardly detectable, by measure of the gauge failure-propagation will be detected	exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.

1.6	fastening material														
1.6.1	clip	n.d.	Elastic fixation of the rails on the base plates	poor installation, vibration, fatigue, defect of material/manufacturing, load over specification	1	break, loose	local loss of the fixation function	no effect, by multi-failures change of the gauge / no stable rail position	no effect, by multi-failures interference of operation	V		detected by the inspection of the line	fixation, exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.
1.6.3	IBAV-spring	n.d.	Elastic fixation of the inner side of the stock rail	defect of material/manufacturing, load over specification	1	break, loosen	loss of the fixation function	no effect, by multi-failures change of the gauge / no stable rail position	no effect, by multi-failures interference of operation	V		detected by the inspection of the line	fixation, exchange for a new unit	
1.6.4	rail pads	n.d.	Absorption of vibration and noise, insulate rail from track bed	damaged, deterioration, ageing	1	Wrong position (loss), loss of resilience	rail impact with track bed	no effect, Increased noise and vibration	no direct effect, possible noise or degraded ride quality	V		detected by the inspection of the line	exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.
		n.d.	Absorption of vibration and noise, insulate rail from track bed	insulation break down, contamination, deterioration	2	lack of rail insulation	fails to insulate rail from track bed	leakage current from track circuit, signalling control error	potential for train collision	I	signalling system to detect short circuit	detected by the inspection of the line	exchange for a new unit	interface issue between trackwork and signalling system
1.6.5	base plate pads	n.d.	protection of the track bed, absorption of vibration and noise, insulate rail from track bed	damaged, deterioration, ageing	1	Wrong position (loss), loss of resilience	plate impact with track bed	no effect, Increased noise and vibration	no direct effect, possible noise or degraded ride quality	V		detected by the inspection of the line	exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.
		n.d.	protection of the track bed, absorption of vibration and noise, insulate rail from track bed	insulation break down, contamination, deterioration	2	lack of plate insulation	fails to insulate plate from track bed	leakage current from track circuit, signalling control error	potential for train collision	I	signalling system to detect short circuit	detected by the inspection of the line	exchange for a new unit	interface issue between trackwork and signalling system

1.7		concrete sleeper	n.d.	Track positioning, Transfer the forces into the ballast	defect of material, manufacturing, wrong installation, load over specification	1	break of the fixation location	no effect, by multi-failures loss of the fixation function	no effect, by multi-failures change of the gauge / no stable rail position	no effect, by multi-failures interference of operation	V		detected by the inspection of the line	reparation of the fixation location	No immediate operational action required. Maintenance scheduled for non-traffic hours.
			n.d.	Track positioning, Transfer the forces into the ballast	climatic conditions, erosion	2	break	reduction of the loading capacity	no effect, Increased noise and vibration	no direct effect, possible noise or degraded ride quality	V		detected by the inspection of the line	exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.
			n.d.	Track positioning, Transfer the forces into the ballast	fatigue, manufacturing or installation defect	3	cracks	reduction of the loading capacity	no effect	no direct effect	V		hardly detectable	exchange for a new unit	No immediate operational action required. Maintenance scheduled for non-traffic hours.
			n.d.	Track positioning, Transfer the forces into the ballast	earthquake	4	displacement	displacement of rails	total breakdown	potential for derailment	I			criteria should be defined to specify appropriate actions that should take place depending on the magnitude of the earthquake	civil work must be designed to sustain the impact caused by earthquake occurred less then once in 1000 year

A.5 Heating

Structure				Description of failure							handling of failure			
No.	Item name	Qty.	Function	Possible reason of failure	Id.	failure mode	failure effect on the subsystem	failure effect on the turnout system	significance in the standard operation	severity class [I..V]	failure detection by the system	failure detection by maintenance staff	Action after failure	Remarks
1	single turnout													
1.4	heating system	1	Warming the switch blade and stock rail to avoid that snow and ice hinder any movement											
1.4.1	Cabinet	1	To deliver power to the heating element											
1.4.1.1	Controlling electronic	1	To control the ammount of power to be delivered	Given information run with full power all the time (connected in this way)	1	Asking for power wh	Grease on slide chairs dies out	Effects switch blade movement	No significance	IV		Usually not looked for	Adjusting or replacing electronics or sensors	Can affect the alignment of the total S&C, temperature of 60 °C might be reached if the outside tempearture is + 10 °C.
				Sensor failure; not adjusted for the enviroment/plac e	2	Not asking for enou	Snow is not melted away	The switch blade can be immoveable		IV		Temperature measuremen t and visual inspection	Adjusting or replacing electronics or sensors	
1.4.1.2	Power electronic	1	To deliver power to the heating element	Ageing of tyristors	1	To little power is distributed	Snow is not melted away	The switch blade can be immoveable		IV		Temperature measuremen t and visual inspection	Replacing power electronics	
1.4.1.3	Power cables		To distribute the power to the heating elements	defect of material/manuf acturing; over loaded mechanical by a maintenance vehicle	1	Broken	No or less current disribted	The switch blade can be immoveable /Fire hazard		III		Temperature measuremen t and visual inspection	Replacing power cables	
1.4.2	Sensors		To give information to the control unit											
1.4.2.1	Snow detector sensor	1	To establish if it is snowing or not	Bad design/badly placed	1	No indication when snow is falling or by snow drift	Less power distributed	Snow and ice is not melted in short time		V		Usually not looked for	Cleaning and replacement	
1.4.2.2	Wind detector sensor	1	To give information about wind speed		1									
1.4.2.3	Temperature sensor	1	Give information of the temperature	Ageing of sensor. Not correctly placed.	1	Showing to high tem	Less power distributed	Snow and ice is not melted in short time		IV		Temperature measuremen t and visual inspection	Replacement of sensor	
				Ageing of sensor. Not correctly placed.	2	Showing to low temp	More power distributed	System will work		V		Temperature measuremen t and visual inspection	Replacement of sensor	
				Broken sensor	3	No temperature rea	No power distributed	Snow and ice is not melted		IV		Temperature measuremen t and visual inspection	Replacement of sensor	
1.4.2.4	Humidity sensor	1	Give information of the humidity/snow fall	Clogged or broken sensor	1	Not giving indication of snow fall	No extra power is given due to snowfall	Snow and ice is not melted in short time		V		Functional test and visual inspection	Replacement of sensor	
1.4.3	Heating elements		To heat the rail above 5 °C											
1.4.3.1	Heater element		To heat the rail above 5 °C		1					IV				
1.4.3.2	Clips		To keep the heating element in close contact to the rail		1					IV				
1.4.3.3	Connector to power cable		To transfer power with low losses to the heating element		1					IV				
			To enable the replacement of a heating element with small ammount of work		2									

A.6 Vossloh actuator, locking and detection units

Structure				Description of failure						handling of failure			
No.	Item name	Qty.	Function	Possible reason of failure	Id.1 failure mode	failure effect on the subsystem	failure effect on the turnout system	significance in the standard operation	severity class II-V1	failure detection by the system	failure detection by maintenance staff	Action after failure	Remarks
1	single turnout												
1.1	Actuation	1	Moves the switch to trace routes.										
1.1.1	Actuator MCEM91	1	Eletro-mechanical system to move the switch										
1.1.1.1	3 Phase AC Motor	1	Uses electrical energy to move the switch	Failure of the clutch	Worn motor	System out of order	No command, no movement possible	discontinuous area, possibly speed restriction area and interference in operation (single track working)	I	Command and detection not in accordance	Testing the connections with a multimeter	Exchange for a new unit	
1.1.1.2	Clutch	1	Limitation of the torque to protect the motor	Excessive use	Clutch broken	Stop protection of the motor	Increase the risk of no movement	Intervention needed	III		Measure the range of the torque	Exchange for a new unit	
		1		Maintenance error	Bad setting	Change the range of the torque	Increase the risk of no movement or incomplete movement	Intervention needed	V		Check the force during the movement	Reset the clutch	
		1		Ambient temperature	Bad adherence	Change the range of the torque	Increase the risk of no movement or incomplete movement	Maintenance check	V		Check the force during the movement	Reset the clutch	
1.1.1.3	Drive link	n.d.	Ensures the mechanical link to transform the torque to a linear force that move the switch.	Maintenance error, wheather	Bad grease in the rods	Use/Wear mechanical items	Increase the force and can stop the movement	Maintenance check	V		Routine track patrol inspection. Monitoring by rolling inspection.	Grease	
				Weather conditions mixed with grease	Bad adherence	Use/wear mechanical items	Increase the force and can stop the movement	Maintenance check	III		Check the force during the movement	Do the setting of the turnout	
				A solid object	Object blocking	Stop the movement	Incomplete movement	Intervention needed	I	Loss of detection	Routine visual track inspection	Take the object off	
1.1.1.4	Switch box	1	Ensure the electrical link between the command and the motor	Vibrations	Broken wire	No electrical link with the motor	No command, no movement possible	Intervention needed	III	Command and detection not in accordance	Testing the connections with a multimeter	Change the wires, blocks in the switch box	

1.2		Locking device		Lock the switch in one position											
1.2.1		VCC	2	Ensures the locking of the closed switch rail, as well as the impossibility for the opened switch rail to be closed unless there is a movement initiated by the point machine											
1.2.1.1		C arm	2	Mechanical locker between the stock rail and the switch rail	Vibrations, Maintenance error		C Arm broken	System out of order	Loss of locking after the movement	Intervention needed	I	Loss of detection	Routine visual track inspection	Exchange for a new unit	
1.2.1.2		Body	2	Mechanical basis to fix the items	Vibrations, Maintenance error		Body badly fastened	System not reliable	Loss of locking after the movement	Intervention needed	I	Loss of detection	Routine visual track inspection	Fasten the body correctly	
1.2.1.3		Connecting rod	1	Ensures the mechanical link between the 2 VCC	Rod broken, pin missing (maintenance error)		No connection between the 2 VCC	No connection between the 2 VCC	Impossible to unlock and move the switch	Intervention needed	I	Command and detection not in accordance	Routine visual track inspection	Connect the rod	
1.3		Detection device		Informs that the switch is locked in one position											
1.3.1		KPLV (Paulvé)	n. d.	Informs that the heel of the switch is in the correct position											
		Contacts	n. d.	Electrical contact to detect the position	Vibrations, maintenance error		Contacts failure	System out of order	Loss of detection	Reduce the train speed, Intervention needed	I	Loss of detection	Testing the connections with a multimeter	Exchange for a new unit	
		Body + Rods	n. d.	Mechanical link between stock rail and blade that ensures the connection of the contacts.	Improper settings expansion		Rod broken or deformed	Mechanical link broken, system out of order	Loss of detection	Reduce the train speed, Intervention needed	I	Loss of detection	Routine visual track inspection	change the rod	
1.3.2		KVCC (inside VCC)	2	Informs that the toe of the switch is in the correct position											
1.3.2.1		Finger	2	Actuator to ensure the connection of the contacts	Vibrations, maintenance error		Finger broken	Mechanical link broken, system out of order	Loss of detection	Reduce the train speed, Intervention needed	I	Loss of detection	Routine visual track inspection	Exchange for a new unit	
1.3.2.2		Body	2	Mechanical basis to fix the items	Vibrations, outdoor conditions, maintenance error		Body badly fastened	System out of order	Loss of detection	Reduce the train speed, Intervention needed	I	Loss of detection	Routine visual track inspection	Fasten the body correctly	
1.3.2.4		Contacts	4	Electrical contact to detect the position	Vibrations, maintenance error		Contacts failure	System out of order	Loss of detection	Reduce the train speed, Intervention needed	I	Loss of detection	Testing the connections with a multimeter	Exchange for a new unit	

Appendix B Fault statistics

The following tables are part of the data needed to quantify the key parameters. They list the frequency of faults causing failures. Parameters which lead to the highest number of failures should be viewed with higher priority. The data were recovered from the FRAME fault reporting database used on the British rail network. Table 3Table 5 relate to a single type of switch actuator in common usage. Table 6Table 8 show details of the causes of the most frequent faults for each of the switch actuator types.

Sub assembly code	Subassembly text	Defect code	Defect text	Count of fail nr	%	Cum. %
000		130	T.O.K. RIGHT ON ARRIVAL	935	22.44	22.4
208	CAM ADJUSTABLE	351	OUT OF ADJUSTMENT	292	7.01	29.4
178	DETECTION ASSEMBLY	900	DEFECTIVE	229	5.50	34.9
155	ROD DRIVE	351	OUT OF ADJUSTMENT	171	4.10	39.0
196	LOCK ARM	380	POOR LUBRICATION	147	3.53	42.6
Null		Null		131	3.14	45.7
202	DETECTOR SLIDE/CAM	350	*OUT OF ADJUSTMENT/GAUGE	103	2.47	48.2
208	CAM ADJUSTABLE	350	*OUT OF ADJUSTMENT/GAUGE	80	1.92	50.1
155	ROD DRIVE	350	*OUT OF ADJUSTMENT/GAUGE	79	1.90	52.0
761	TAPPETS	351	OUT OF ADJUSTMENT	68	1.63	53.6
196	LOCK ARM	351	OUT OF ADJUSTMENT	56	1.34	55.0
186	HOSE	840	DAMAGED BY FIRE / BURNT	55	1.32	56.3
761	TAPPETS	350	*OUT OF ADJUSTMENT/GAUGE	50	1.20	57.5
000	....	200	ERROR/NEGLIGENCE	49	1.18	58.7
574	PUMP (ELECTRIC)	900	DEFECTIVE	43	1.03	59.7
186	HOSE	363	LEAKING	40	0.96	60.7
192	*HOSE/PIPE/CONNECTOR	840	DAMAGED BY FIRE / BURNT	38	0.91	61.6
191	POWER PACK ELECTROHYDRALC	900	DEFECTIVE	33	0.79	62.4
192	*HOSE/PIPE/CONNECTOR	360	*LOOSE/INSECURE/LEAKING	32	0.77	63.1
000		900	DEFECTIVE	31	0.74	63.9
200	LOCKING PIECE	351	OUT OF ADJUSTMENT	30	0.72	64.6
000		Z40	NON-FAIL (MAINTENANCE)	29	0.70	65.3
000		Z00	INSPECTED O.K.	28	0.67	66.0
178	DETECTION ASSEMBLY	310	*FRACTURED/BROKEN	27	0.65	66.6

Table 3 - Top 25 failures for the Clamp Lock switch actuator

Sub assembly code	Subassembly text	Defect code	Defect text	Count of fail nr	%	Cum. %
000		130	T.O.K. RIGHT ON ARRIVAL	258	18.86%	18.9%
156	FACING POINT LOCK	351	OUT OF ADJUSTMENT	103	7.53%	26.4%
154	ROD DETECTOR	351	OUT OF ADJUSTMENT	93	6.80%	33.2%
155	ROD DRIVE	351	OUT OF ADJUSTMENT	91	6.65%	39.8%
154	ROD DETECTOR	350	*OUT OF ADJUSTMENT/GAUGE	61	4.46%	44.3%
156	FACING POINT LOCK	350	*OUT OF ADJUSTMENT/GAUGE	57	4.17%	48.5%
155	ROD DRIVE	350	*OUT OF ADJUSTMENT/GAUGE	54	3.95%	52.4%
Null		Null		52	3.80%	56.2%
172	MOTOR	340	WORN/DET/OUT OF TOLERANCE	25	1.83%	58.0%
172	MOTOR	900	DEFECTIVE	25	1.83%	59.9%
172	MOTOR	370	DIRTY	17	1.24%	61.1%
000	....	900	DEFECTIVE	16	1.17%	62.3%
172	MOTOR	411	HIGH RESISTANCE	16	1.17%	63.5%
206	BLADE LOCK	350	*OUT OF ADJUSTMENT/GAUGE	14	1.02%	64.5%
155	ROD DRIVE	360	*LOOSE/INSECURE/LEAKING	13	0.95%	65.4%
155	ROD DRIVE	361	LOOSE	12	0.88%	66.3%
178	DETECTION ASSEMBLY	351	OUT OF ADJUSTMENT	11	0.80%	67.1%
000	....	200	ERROR/NEGLIGENCE	10	0.73%	67.8%
000	....	380	POOR LUBRICATION	10	0.73%	68.6%
178	DETECTION ASSEMBLY	411	HIGH RESISTANCE	10	0.73%	69.3%
000	....	110	T.O.K. S/R WHILE TESTING	9	0.66%	70.0%
000	....	Z40	NON-FAIL (MAINTENANCE)	9	0.66%	70.6%
012	STRETCHER	310	*FRACTURED/BROKEN	8	0.58%	71.2%
173	CLUTCH FRICTION	351	OUT OF ADJUSTMENT	8	0.58%	71.8%
173	CLUTCH FRICTION	900	DEFECTIVE	8	0.58%	72.4%

Table 4 - Top 25 faults for the M series switch actuator

Sub assembly code	Subassembly text	Defect code	Defect text	Count of fail nr	%	Cum. %
000		130	T.O.K. RIGHT ON ARRIVAL	666	17.02%	17.0%
154	ROD DETECTOR	351	OUT OF ADJUSTMENT	356	9.10%	26.1%
155	ROD DRIVE	351	OUT OF ADJUSTMENT	348	8.89%	35.0%
156	FACING POINT LOCK	351	OUT OF ADJUSTMENT	245	6.26%	41.3%
155	ROD DRIVE	350	*OUT OF ADJUSTMENT/GAUGE	196	5.01%	46.3%
154	ROD DETECTOR	350	*OUT OF ADJUSTMENT/GAUGE	148	3.78%	50.1%
Null		Null		139	3.55%	53.6%
156	FACING POINT LOCK	350	*OUT OF ADJUSTMENT/GAUGE	101	2.58%	56.2%
172	MOTOR	900	DEFECTIVE	88	2.25%	58.4%
000	....	200	ERROR/NEGLIGENCE	47	1.20%	59.6%
012	STRETCHER	310	*FRACTURED/BROKEN	45	1.15%	60.8%
172	MOTOR	340	WORN/DET/OUT OF TOLERANCE	45	1.15%	61.9%
177	CUTOUT RESET	200	ERROR/NEGLIGENCE	44	1.12%	63.1%
172	MOTOR	411	HIGH RESISTANCE	42	1.07%	64.1%
155	ROD DRIVE	361	LOOSE	37	0.95%	65.1%
175	SNUBBING GEAR	900	DEFECTIVE	34	0.87%	65.9%
178	DETECTION ASSEMBLY	411	HIGH RESISTANCE	34	0.87%	66.8%
000	....	900	DEFECTIVE	33	0.84%	67.7%
155	ROD DRIVE	360	*LOOSE/INSECURE/LEAKING	26	0.66%	68.3%
000	....	Z40	NON-FAIL (MAINTENANCE)	24	0.61%	68.9%
000	....	110	T.O.K. S/R WHILE TESTING	23	0.59%	69.5%
000	....	411	HIGH RESISTANCE	21	0.54%	70.1%
179	CIRCUIT CONTROLLER	411	HIGH RESISTANCE	21	0.54%	70.6%
172	MOTOR	400	ELECTRIC FAILURE	18	0.46%	71.1%
178	DETECTION ASSEMBLY	350	*OUT OF ADJUSTMENT/GAUGE	17	0.43%	71.5%

Table 5 - Top 25 faults for the HW switch actuator

Clamp Lock code	**No.**	**M Series code**	**No.**	**HW Series code**	**No.**
Tested OK (TOK) right on arrival	**935**	**TOK right on arrival**	**258**	**TOK right on arrival**	**666**
No/Diff Norm or Rev – no cause [found]	491	No/Diff Norm or Rev – no cause [found]	134	No/Diff Norm or Rev – no cause [found]	347
Chair	61	Lost detection/indication	27	Lost detection/indication	27
Lubrication	54	Slow - no cause [found]	13	Out of correspondence (OOC) - no cause [found]	33
OOC - no cause [found]	34	Flicking – no fault found (NFF)	9	Flicking - NFF	30
Slow - no cause [found]	34	Heat	7	Slow - no cause [found]	19
Flicking - NFF	33	OOC - no cause [found]	7	Uncertain cause	18
Lost detection/indication	31	Lubrication	6	Fire	12
Fire	22	Obstruction	6	Heater	12
Ballast	17	Gearbox water ingress	5	Motor	6
Rubbish	17	Misreport	5	Springs	6
Points out of adjustment (OOA)	15	Miscellaneous (<5 each)	39	Chair	5
Relay	12			Contact	5
Heater	10			Misreport	5
Backdrive OOA	8			Rubbish	5
Maintenance error	8			Miscellaneous (<5 each)	64
Misreport	8				
Miscellaneous (<8 each)	80				

Table 6 - Breakdown of causes for most frequent fault on Clamp Lock, M63 and HW switch actuators

Clamp Lock code	**No.**	**M Series code**	**No.**	**HW Series code**	**No.**
Cam, adjustable OOA	**292**	**Rod, detector OOA (inc. out of gauge)**	**154**	**Rod, detector OOA (inc. out of gauge)**	**356**
Detection OOA	161	Detection OOA	69	Detection OOA	258
Tappets	60	Detection OOA	42	Points OOA	11
Cam	16	Detection spring	7	Springs	8
Points OOA	16	Tight lock	6	Detection & lock OOA	7
Tight lock	8	Heat	5	Tight lock	7
Loose fastener	6	Lock & detection OOA	5	Lock OOA	6
Backdrive OOA	5	Miscellaneous (<5 each)	20	Contact	5
Uncertain cause	4			Detection & drive OOA	5
Miscellaneous (<5 each)	16			Heat	5
				Miscellaneous (<5 each)	44

Table 7 - Breakdown of causes for second most frequent fault in Clamp Lock, M63 and HW switch actuators

Clamp Lock code	**No.**	**M Series code**	**No.**	**HW Series code**	**No.**
Rod, drive O.O.A.	**171**	**Rod, drive O.O.A.**	**91**	**Rod, drive O.O.A.**	**544**
Backdrive O.O.A.	133	Drive O.O.A.	51	Drive O.O.A.	340
Drive O.O.A.	9	Lock O.O.A.	6	Drive nut	49
Chair & drive O.O.A.	6	Drive nut	5	Tight lock	28
Miscellaneous (<5 each)	23	Heat	4	Lock O.O.A.	13
		Loose fasteners	4	Loose fasteners	13
		Points adjusted/lubed	4	Bouncing	11
Detection assy. defective	**229**	Tight lock	4	Drive & lock O.O.A.	11
Microswitch	195	Miscellaneous (<4 each)	13	Points O.O.A.	8
Limit switch	8			Detection & drive O.O.A.	7
Detection O.O.A.	7			Detection O.O.A.	7
Miscellaneous (<5 each)	19			Drive overrun	7
				Miscellaneous (<7 each)	50
Lock arm poor lubrication	**147**	**Facing point lock O.O.A.**	**103**	**Facing point lock O.O.A.**	**245**
Lube	112	Lock O.O.A.	44	Lock O.O.A.	107
Hook	15	Tight lock	39	Tight lock	79
Ballast	13	Heat	12	Heat	17
Tight lock	5	Miscellaneous (<5 each)	8	FPL O.O.A.	10
Miscellaneous (<5 each)	2			Points O.O.A.	7
				Loose fasteners	5
				Miscellaneous (<5 each)	20
Total	**1774**	**Total**	**606**	**Total**	**1811**

Table 8 - Breakdown of causes for faults 3-5 (Clamp Lock), faults 3 and 4 (HW and M63) in the ranking of most frequent faults

Appendix C Vossloh DLD components

Vossloh Cogifer's Signalling Department has developed a complete range of electro hydraulic and electromechanical switch mechanisms wedged or trail able, suitable for national rail networks, urban transport systems (metros, LRT or tramways) and industrial networks.

The point machine MCEM91 is designed to the standard NF F 52-152. It is equipped with two contacts for each switch position.

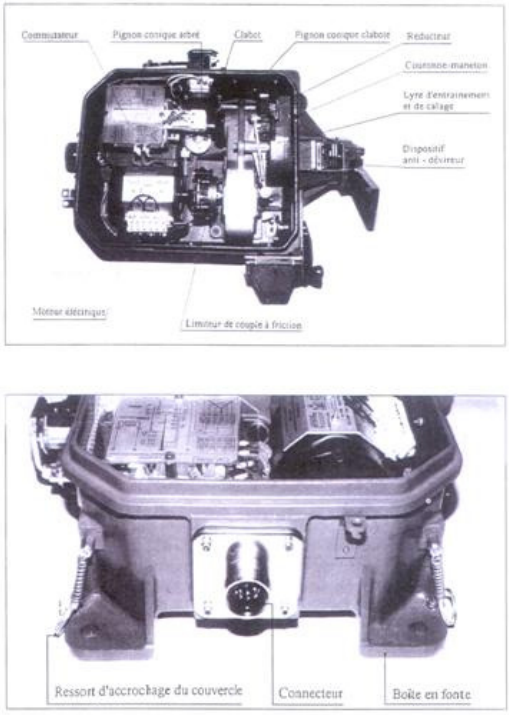


Figure 12 - MCEM91 switch actuator

The Vossloh Paulvé detector monitors the closing and opening of a turnout at the point, the heel or of the heel of the nose.

Paulvé detectors are fitted at the heel of the turnout and their quantity depends on the turnout configuration. Generally there is a couple of Paulvé detectors at each "back drive" of the turnout. A "back drive" which allows a second "Attack point" in the rear of the switch blades, and so ensures that the heel opening is granted if complete movement is performed at the extremities of the blades.

Figure 13 - (left) Vossloh Paulvé detector; (right) Vossloh VCC locking device

The VCC clamp lock is a positive locking device for turnouts; its operation is linked to that of the switch. It is installed at the location of the slide chair of the switch.

A pair of VCC locking devices comprises the body fitted on the stock rail and their C Arm connected to the movable blade. The VCC devices (body + C Arm) ensure the locking of the closed blade, as well as the impossibility for the opened blade to be closed unless there is a movement initiated by the point machine. This also guarantees that the C Arm cannot move (and so unlock the switch) due for example to vibrations, as they are immobilised by the point machine.

Each VCC is equipped with a detector, which has:

- 2 closing contacts if the blade is in closed position AND if the C Arm is in the relevant locked position,
- 2 opening contacts if the blade is removed from the closed position.

The Vossloh Moveable Frog is produced for High Speed systems. It enables crossing at speeds greater than 320 km/h in a straight line, and 230 km/h in reverse. Other different applications may be envisaged in this domain, for example, cast manganese frogs with mobile points for switch gear designed for heavy loads.

Appendix D Siemens point machines

D.1 S700K point machine

Features:

- Suitable for points on main line and mass transit railways, derailers and movable frogs
- MTBF around 550,000 hours
- Overhaul interval of 1 million operations
- DC or AC motors
- Ball spindle drive
- Integrated detection

Figure 14 - Siemens S700K point machine

D.2 S700V in-sleeper point machine

This actuator is a compact version of the S700K which is installed within a hollow “trough” sleeper. This enables tamping operations to be carried out over switches and crossings because there is no interference with the equipment. Like the S700K, this actuator can be used with several different types of motor. It is designed to be low-maintenance, with the possibility for pre-installation of certain parts, reducing possession time. For long switches, several actuators are installed and work together to throw the switch. Notably, this actuator system throws the switch rails one after the other, rather than at the same time.

Figure 15 - A mark II ICE passes over a switch driven by 3 S700V point machines

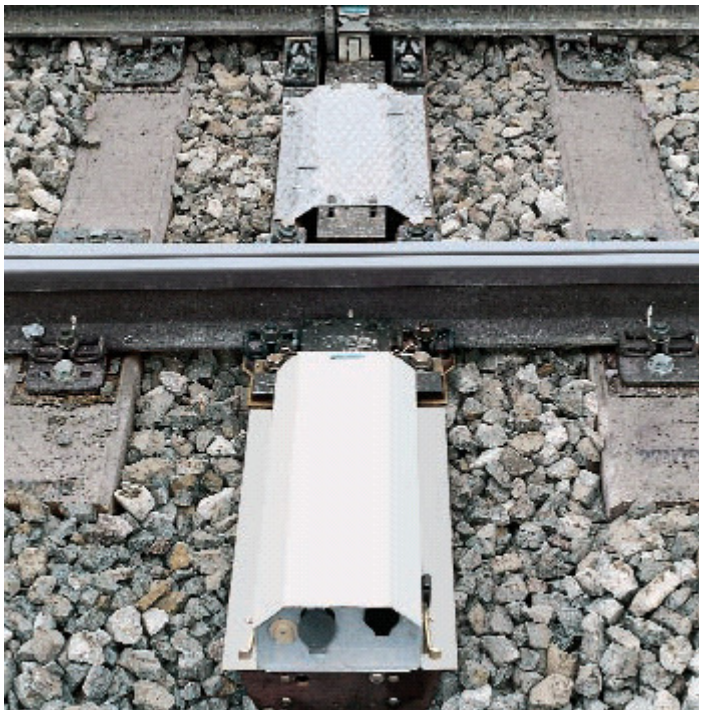


Figure 16 - Close-up of the S700V point machine

Appendix E Clamp Lock point machines

For a hydraulic clamp lock point machine the drive is provided by pumping oil through a hydraulic circuit, as shown in Figure 17. The stages of the throw are shown below:

1) In an initial de-energised state one of the front hydraulic actuators is extended in order to hold one of the switch rails closed and locked. The control valve spool rests in the central position, blocking off the oil feed and return lines, which hydraulically locks the extended actuator. Requesting the points to throw from normal to reverse energises the pump motor and the reverse valve solenoid simultaneously.
2) The valve spool moves to open the actuator feed/return lines and oil under pressure is fed in to the reverse actuator.
3) The reverse actuator extends and the normal actuator retracts by the action of the tie bar between the drive lock slides. The oil from the retracting actuator returns to the tank.
4) At the end of the throw and when detection of the points in completed, the detection relay opens the point control circuit to de-energise the motor and the solenoid control valve.
5) When the power pack solenoids are de-energised, the control valve spool returns to the central position once more to lock the actuators hydraulically.

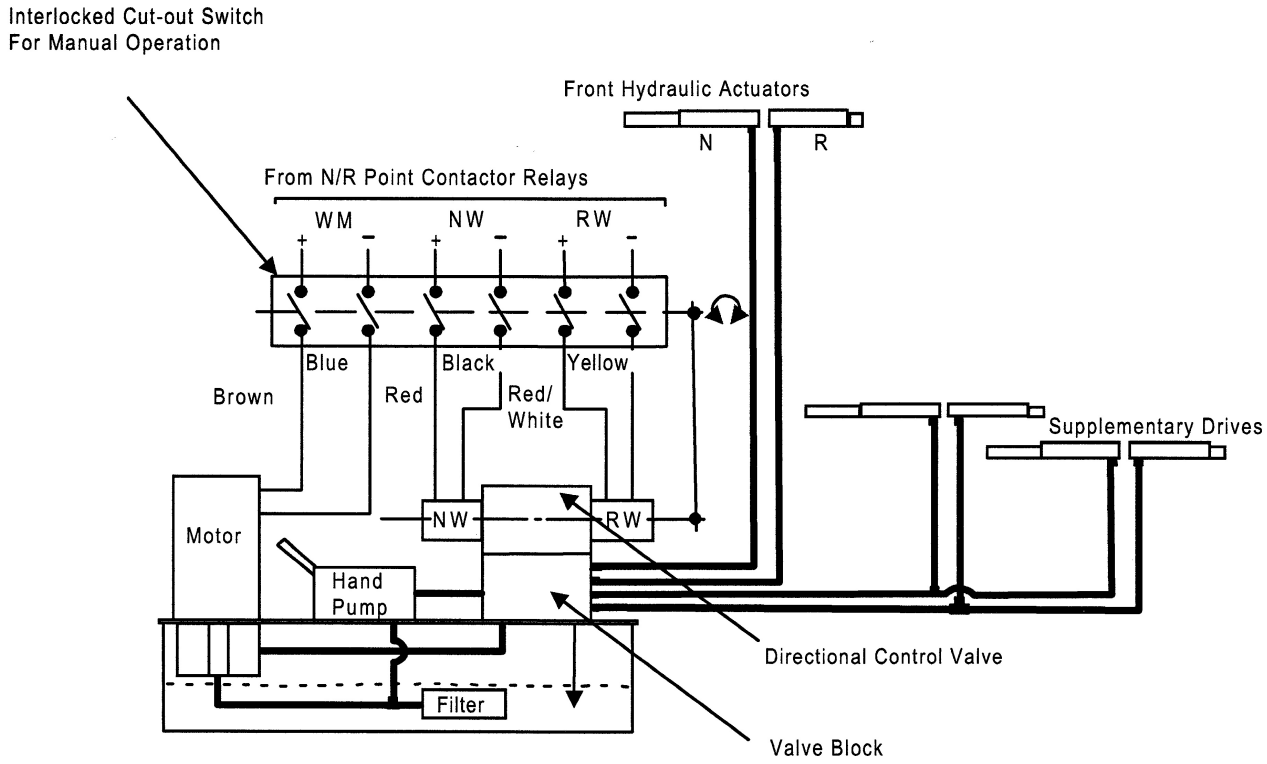


Figure 17 - Hydraulic circuit of a SPX Clamp Lock switch actuator

Appendix F Electro-pneumatic point machine

Electro-pneumatic point machines were chosen by London Underground because at the time (late 19th century) they were capable of throwing points approximately twice as fast as contemporary hydraulic or electric actuators. They suffer from reliability problems, however, especially in extremes of weather. Because of restricted space in tunnels, these actuators are installed in the four-foot (area between the rails) and are therefore known generally as 'four-foot point machines'.

Appendix G HW and M63 point machines

The Westinghouse M63 and Alstom HW point machines contain a DC electric actuator which drives the points through a magnetic clutch, a mechanical locking system and a set of electrical detection contacts. The M63 machine uses a belt drive to link the motor to the actuator drive; the HW uses a set of reduction gears. These machines are found throughout the UK, but the M63 is now being superseded by new designs.

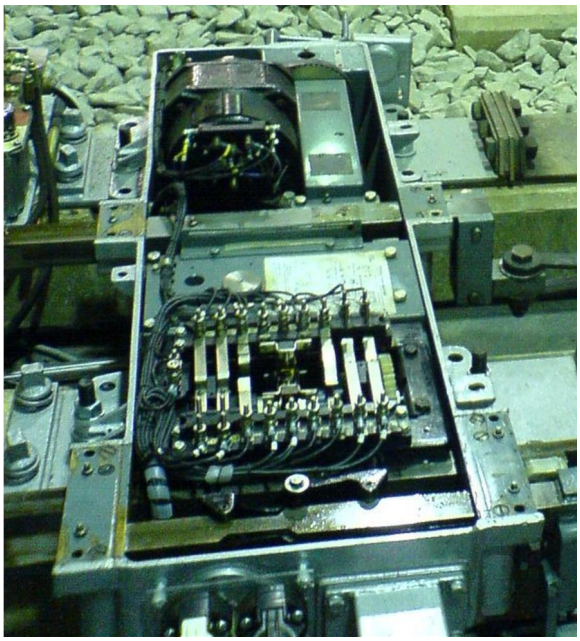


Figure 18 - Westinghouse M63 point machine