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## The performance and control requirements of a REPOINT track switch

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## **Abstract**

This paper concerns the high-level mechanical, electrical, and control requirements for a proposed novel design of railway track switch. The track switch is being designed as part of the Repoint project, with the stated aim of investigating methods of increasing railway capacity and improving network delay performance through the application of technologies common to other industries. The basic mechanical design of the novel switch is discussed. The mechanical considerations are discussed in the context of the electrical and control system requirements, which are then investigated and justified. For the electrical and control design, the requirements focus on the functional performance, sustainability, fault tolerance and fault diagnostics. The requirements presented in this paper are being used to inform the design of a lab scale technology demonstrator, which will be completed by August 2014.

**Keywords:** Track Switch, Fault Tolerance, Redundancy, Reliability, Capacity, Train Control, System Requirements

## **1 Introduction**

Railway track switching provides necessary flexibility to a rail network, allowing vehicles many different routes. However, track switches represent single points of failure, and even when operational can represent a network capacity constraint due to the design of physical track components alongside the associated systems of control and operation. Switches are expensive and complex designs when compared to equivalent plain line, as can be seen in industrial design and maintenance manuals [1, 2]. Their population is therefore generally optimised at design time alongside a known timetable in order to minimise initial outlay and substantial ongoing maintenance costs. This can compound the negative effects upon network performance during asset failures or

other timetable perturbation incidents.

Referring specifically to the United Kingdom, open-access statistics [3] show passenger counts are at their highest level since re-privatisation (1995-6), with some lines now running at or near operational vehicular capacity. This fact, when coupled with cross-industry initiatives such as the '24/7 Railway'[4], 'On-time Railway', and increasing overnight freight utilisation as suggested in the recent 'Rail Freight Report'[5], is much reducing the portion of time available to take maintenance possessions of infrastructure. Importantly, it is often not the physical maintenance act itself which is expensive monetary terms, but instead the time the asset is out of use - whether this be a planned possession or an unpredicted failure. The monetary cost is associated to a capacity cost. With the move towards cab-signalling, the only remaining lineside active assets will be switches and level crossings, and these will thus contribute an ever increasing portion of attributable delay without significant further work to improve performance.

In recent years, much research has been conducted into what has been termed RCM<sup>2</sup> (Remote Condition Monitoring and Reliability Centred Maintenance) of fixed rail assets to boost availability, and several projects have achieved notable success in this area. Points condition monitoring in particular has attracted much academic research, for instance [6, 7]. RCM<sup>2</sup> has been used for some years in other industries, most notably aviation, achieving similar positive results. However, the RCM<sup>2</sup> approach has two main issues when utilised without the level of subsystem redundancy typically present in aircraft, and these issues are thoroughly studied in literature, particularly [8]. Firstly, greater knowledge of asset condition does not implicitly improve asset availability or reduce cost, it merely changes the window within which repairs can be conducted - the subsystem must generally still be taken out of service to facilitate repair. Secondly, since detection, diagnosis or prognosis can never be 100% accurate, there is still an ever-present risk of an incipient fault directly causing an asset failure in service.

For a step change in performance, such as that seen in aircraft engine availability over the last fifty years, it would be necessary to reconsider some mechanical design aspects of track switches alongside novel condition monitoring systems. This was recognised in 2010 by the United Kingdoms RSSB (Rail Safety and Standards Board) as part of a call for proposals titled: 'Railway Capacity: overcoming the constraints caused by nodes (stations and junctions) on the rail network'. REPOINT was one response to that call, and was a two-year project inspired by other industries, particularly aerospace, to examine whether the redundancy concepts which are readily accepted in other safety critical environments could be used beneficially for track switching on railway networks. The project sought to answer the research question:

Could a fundamental re-think of railway track switching ease some of the current route-setting constraints to provide higher capacity, and

provide a significant reduction in operational unreliability arising from points failures?

REPOINT proposed that nodes require some built in redundancy to faults - fundamentally changing the nature of a junction and leading to higher reliability of the asset and improved capacity. The capacity improvement comes partly from the reliability improvement and partly due to changes in the operating rules that become possible when the switches are redesigned to be intrinsically safe. The significant capacity benefits of re-engineering switches have been previously published by the authors, for instance in [9, 10]. However, another significant output of this project referred to hereinafter was a proposal on how this re-engineering could be achieved in practical engineering terms, directly leading to novel actuation mechanism. A detailed design of this proposal is available in more detail within the associated patent documents at [11, 12], and in a forthcoming journal paper. The concept design utilises four principles novel to track switching design, some inspired by the aerospace and nuclear industries: the LRU (Line-replaceable unit, formally defined in [13]), mission-critical subsystem redundancy, fault tolerant control, and model-based condition monitoring. These have been combined with an idea fundamental to the rail sphere: Fail-safe operation.

There currently exists a knowledge-gap regarding the practical implementation and operational aspects of this novel design, and it is this gap which this paper begins to answer by proposing an engineering and control specification for a high-availability switch installation. Firstly, the paper provides a brief overview as to the proposed design and mode of operation of a REPOINT switch in section 2. The mechanical performance requirements, including lifecycle costs and maintenance, are covered in section 3. The electrical and control performance requirements are discussed in section 4, along with potential control strategies to optimise particular cost variables. Section 5 covers the potential to combine condition monitoring from the ground up, allowing the full benefits of subsystem redundancy to be delivered, as discussed above. Section 6 concludes the paper and discusses future work.

## **2 The REPOINT switch**

### **2.1 General Layout**

Figure 1 shows the general layout of what is referred to herein as a ‘traditional’ switch arrangement. It will be noted that the design consists of a single actuator with a combined blade locking function. The type shown has a lineside actuator, but other designs variously place the actuating mechanism between the running rails, alternatively mounted between or within the supporting bearers. The actuator unit moves two switch rails between two positions, locking each rail in place when movement is

complete in either position. This general arrangement has several drawbacks from an availability point of view. Firstly, that the single actuation unit means that the switch necessarily must be taken out of use for any maintenance act upon the mechanism. Secondly, that the locking of the blades in either position - a safety requirement in most jurisdictions - is provided by a single mechanism within the actuator unit. Therefore any failure of that unit manifesting as a 'loss of detection' must be investigated by a maintenance team before traffic can pass the switch.

Figure 2 shows a proposed REPOINT installation. This takes the general arrangement of a stub switch. Multiple, parallel-channel actuation mechanisms are mounted within bearers. The locking function is isolated from the actuation function, and each actuator-bearer has an instance of each. Thus there is now provision for multi-channel operation of the switch. The mechanical arrangement of each actuator/bearer unit means that a single unit can be isolated from the moving switch rails; maintenance can be carried out whilst traffic still flows over the switch, and crucially, when the switch is still capable of changing position using the remaining in-service actuator-bearers. The arrangement is designed to be fail-safe in that the actuator places enough energy into the switch rails - in the form of stored spring energy by bending the rails - that in the event of any failure of power supply during the switch motion cycle, the switch rails will return to one of the safe states for the passage of traffic.

In order to allow these properties, a novel mechanical arrangement as shown in Fig. 3 is proposed. A motor and gearhead is mounted in the end of the bearer, accessible for maintenance from the lineside. Motion is transferred through an actuation rod, with teeth cut on the underside, driving two pinions. Each pinion features a cam arm, with a protrusion upon the end of the cam which engages in matching cut-outs on the underside of a component referred to as the 'hopper'. The top face of the hopper is open to the elements and provides a mounting surface for the switch rails. Locking in either position is provided by the same cut-out on the underside of the hopper engaging with a stationary protrusion mounted to the base of the actuator-bearer housing. Thus to move between positions, the rails must first be lifted out of this locking 'groove', before traversing a semi-circular path to be dropped in the second position. This accurately aligns the track in each position.

### **3 Mechanical Performance Considerations**

This section summarises the high-level mechanical considerations of a track switch design. In order to generate a design which will deliver the stated benefits in a real-world scenario, it is important to fully understand the operating conditions and environment of the switch, from design to disposal. The requirements have been broken down into Life-Cycle, Maintenance, Operating Environment and Safety.

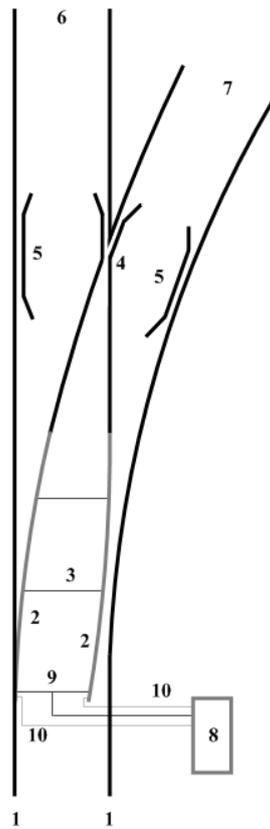


Figure 1: Typical ‘traditional’ switch arrangement, reproduced from [10]. (Black, Bold) *Stock Rails*; 2 (Grey, Bold) *Moveable Switch Rails*; 3 *Stretcher Bars*; 4 *Common Crossing*; 5 *Check Rails*; 6 *Straight Route (herein, ‘Normal’ Route)*; 7 *Turnout Route (herein, ‘Reverse’ Route)*; 8 *POE (Points Operating Equipment), lineside type shown*; 9 (Black) *Drive Bar and Drive Stretcher* ; 10 *Detection Rods*

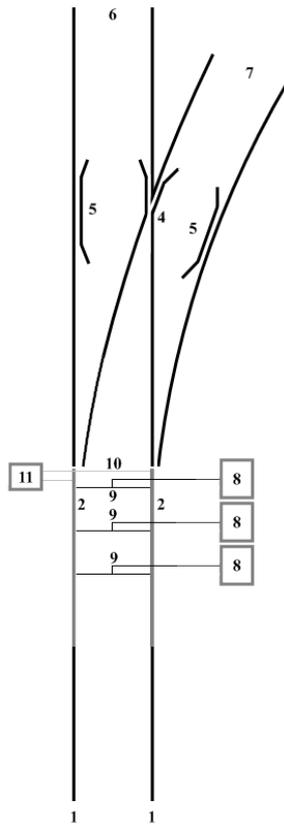


Figure 2: Proposed REPOINT high-availability stub-switch concept with redundant actuation and locking paths. 1 (Black, Bold) *Stock Rails*; 2 (Grey, Bold) *Moveable Switch Rails*; 4 *Common Crossing*; 5 *Check Rails*; 6 *Straight Route (herein, 'Normal' Route)*; 7 *Turnout Route (herein, 'Reverse' Route)*; 8 *Redundant Multi-channel Actuators*; 9 (Black) *Drive Rod and Linkages* ; 10 *Detection Rods* ; 11 *Blade Position Detection and Feedback Unit*. Reproduced from [10]

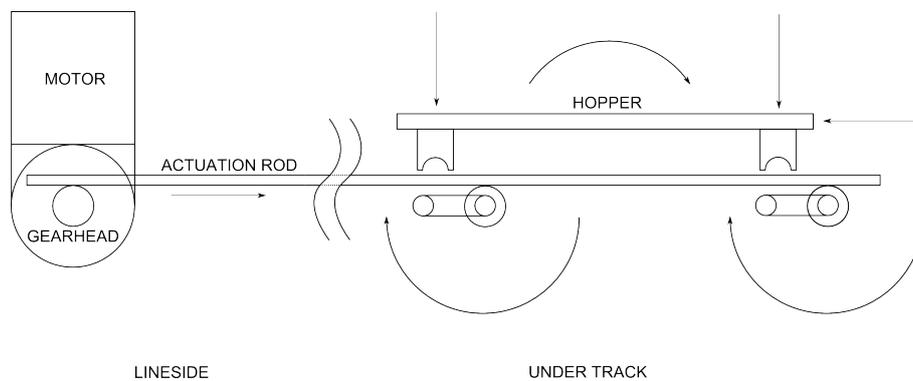


Figure 3: Mechanical Arrangement of the actuation mechanism within a single actuator-bearer

### **3.1 Life-Cycle**

The life-cycle of rail assets is typically much longer than other industries. Existing switches are designed for a life of around 30 years, though this is frequently extended. Initial fitment and end-of-life replacement generally involve extended blockages of the line. Recently there has been a drive to reduce the fitment time of switches to a single evening possession, as part of a programme called 'Modular SC'. This approach pre-assembles the switch in a yard nearby, and uses specially designed tilting wagons to deliver and install the track components of the switch. If possible, the Repoint design should adopt this approach. The design is particularly suited to exceeding the fitment times achieved by this method, as the actuation components are combined inside the bearers, meaning a switch could potentially be delivered entirely plug and play.

Accepting that there will always be unique installation scenarios, whole life costs across a network can be further reduced by the adoption of a standardised component set across all switches. Currently, each switch is adapted to a particular installation, for instance by planing the switch blades in a particular manner. The instances of this type of operation should be minimised such that replacement components for any installation can be held in stock. As many of these components as possible should be COTS, with open specification, in order to further reduce costs. At renewal, the switch should be as easy to lift and dispose as to initially fit. Again the repoint design lends itself to this operation since the actuation components are mounted entirely within the bearers.

### **3.2 Maintenance**

Currently, switches are subject to a time-based inspection and maintenance schedule. Faults are both investigated and fixed line-side, and most machines are not designed for rapid component replacement.

Figure 4 shows the classification of maintenance operations which may be performed upon a Repoint switch between asset deployment and end-of-life. Critical to reducing the lifecycle costs discussed above are three factors:

- Firstly, that the volume of unplanned maintenance is reduced to an absolute minimum. Unplanned maintenance is the most costly form of maintenance, in terms of network operations and the physical act itself.
- Secondly, that planned maintenance is kept to a minimal level. For instance, unplanned maintenance could be reduced by replacing the entire switch mechanism every week, but this would be unreasonable.
- Thirdly, that as much of the planned maintenance as possible from inspection to planned overhauls can, in order of preference, be automated, be conducted away from line-side, or conducted with the line open to regular traffic. The last point requires personnel access to critical equipment which is outside the specified boundaries stipulated by the network operator. For Network Rail this

distance is 1.4m from the nearest running rail for <100mph lines, and 2m for lines rated for 100+mph running.

The benefits of migration of maintenance type work from unplanned to planned is much discussed in literature, and is primarily enabled by the fitment of an effective condition monitoring system and self-diagnosis as described in section 5. A modular mechanical arrangement and parallel functional channels enables the second and third points to be achieved. Automatic inspection is already well advanced for plain line, with track recording cars monitoring every line on the British network each month. However, this is less so for switch installations, due to the unique nature of each. Making critical components of the switch visible to the inspection cameras on these cars is one way to monitor components which would otherwise require human attendance. For instance, any visible nuts could be affixed with loosening indicators, and standard track clips used for the switch rails. Conducting maintenance away from line-side is congruent with the adoption of the universal LRU and a reduced, modular, component count. For a predicted motor failure, for instance, the maintenance technician can take new motor/gearbox unit from the shelf, swap the unit at line-side, and then return to the depot to investigate the fault within the removed component. The act of swapping units should take of the order of seconds, leaving the technical investigation as to the nature of the fault, and any potential fixes, an unlimited amount of time in more suitable surroundings.

### **3.3 Operating Environment**

The operating environment at trackside is recognised as being very tough. Outdoor temperatures range from -30C to +40C. Tracks are often flooded or frozen over in winter, and the rail temperature in summer can reach upwards of 70C. There are numerous sources of contaminants, not least abrasive coal dust falling from wagons, fuel oil and ballast fragments. In some places human faeces is dropped directly onto the track. Traditionally, mechanisms have been left open to the elements with the belief that it is better to be able to view over-engineered components are in good working order than try to protect them. However, should the critical components be of redundant channels, their life may be extended by enclosing them in a protective casing and allowing for condition monitoring, or withdrawal for inspection. The negative effects of ice and snow is currently combated with points heaters, long strips which clip to the rail foot and try to prevent the flange gap becoming jammed. In the repaint design, there is no flange gap to grow or shrink, so this is less of a concern, though some effort must be made to prevent the mechanism itself freezing up.

Typical vibrations at the railhead from passing traffic are of the order of 100g. Any sensing equipment attached directly to the rail would therefore have a limited service life. This should especially be considered with any position detection sensors, which are crucial to feeding back the switch position to the interlocking. It is also of concern when choosing anti-loosening measures upon all critical fasteners.

There is also the consideration of criminal human intervention, for instance vandals

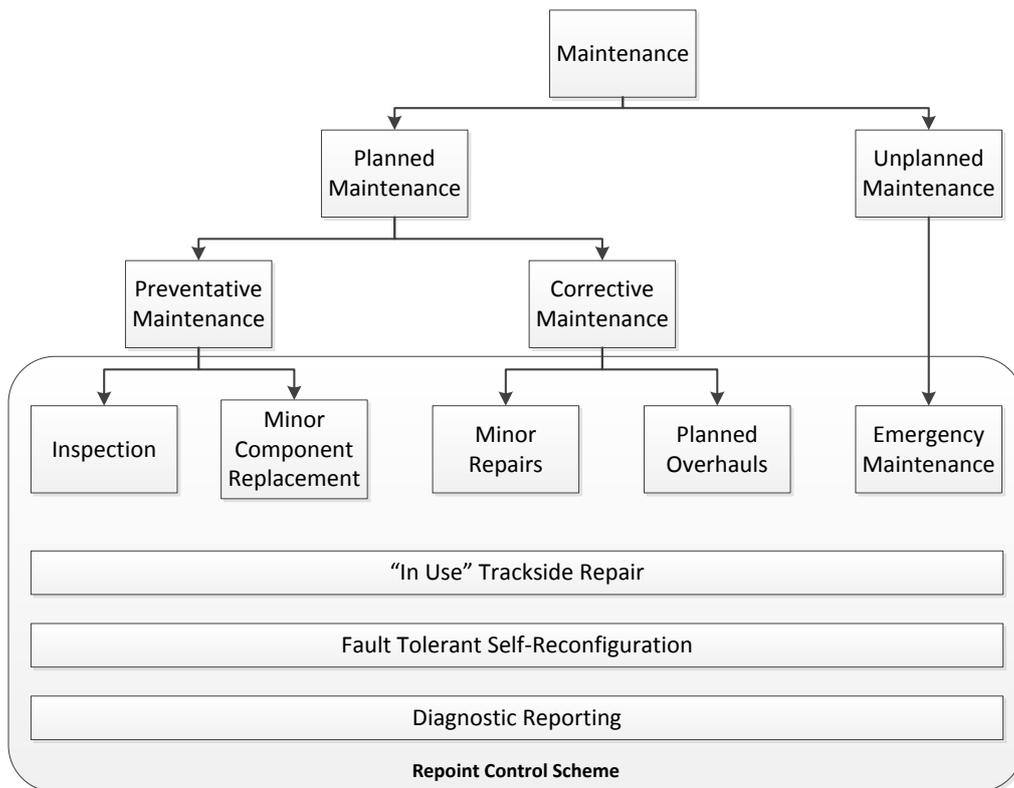


Figure 4: Typical maintenance activities and supporting Reprint functions

or terrorists. Whilst this must be a concern to the final design, there is no reason to believe the Repoint design will be more susceptible than any existing design.

The operating environment is unlikely to change, so for the purposes of design decisions, must instead be protected against.

### **3.4 Safety**

A switch is a safety critical system, and no drop in relative safety would be accepted for a new design. Any design error or undetected failure can directly lead to a derailment and fatalities. Thus any new design must go through an extended safety analysis and process of due diligence. The rail industry has an extensive system of type approval for this purpose. There are two main differences between the layout proposed in section 2 and a 'traditional' track switch.

Firstly, all locking in the new design is dependent upon the rails being forced into their locking groove; that is, the rail ends are essentially floating, and position assurance in the vertical plane is sacrificed to enable the multi-channel actuation. Existing locking mechanisms require a lateral force in the order of several tonnes to break the lock. From a safety justification point of view, therefore, there should be a force of several tonnes required in the vertical direction in order to unlock the Repoint design. In reality, forces of this magnitude would be hard to achieve as the load from a wheel set is almost exclusively in the opposite direction - directly downwards.

Secondly, stretcher bars have been eliminated from the design, the rail gauge is instead maintained at every sleeper through the use of industry standard plates and track clips. Stretcher bars have long been a weak link in existing designs, coupled with the fact that incipient faults or out-of-tolerance incidents are not always detectable through the signalling system. The revised design should therefore offer a safety improvement, however a full design analysis would need to be performed in due course to demonstrate this.

All failure modes which may directly render the switch in an unsafe state must be easily detectable and identifiable, either by a passing track measurement car or any in-built condition monitoring system which is discussed later in section 5.1.

## **4 Electrical and Control Performance Requirements**

The electrical and control requirements for a Repoint switch fall into one of two classes: those that ensure the acceptable functional performance of the switch, and those that ensure this performance is sustainable over the long term within a pre-existing technical and economic framework.

## 4.1 Requirements

All of the electrical and control requirements are summarised below. These requirements were identified by examining the performance of existing UK points machines and by an engineering analysis the proposed Repoint design. The key objectives driving these requirements are that the Repoint design should be more reliable, easier to maintain and display an improved performance over the currently available solutions.

### 4.1.1 Functional Performance

There are three functional performance requirements.

*Electrical interface:* A Repoint machine should be backwards compatible with the pre-existing signalling infrastructure. As such, the electrical and communication interface between the switch and the track-side equipment should comply with the existing standards [14]. That is, the machine should operate at 110V and work with the standard UK S&C relay configuration [15]. A Repoint switch should not need any additional interface to safely and correctly operate, although the optional facility to pass additional information back to the signal box is desirable.

*Actuation time:* A reduced actuation time compared to the switches currently in use on the UK rail network is desirable. A reduced actuation time at a given junction can result in an increase in the overall capacity of its parent network, as described in [16]. In the UK, the current maximum operation time allowed for a point machine is around eight seconds. In practice, the operation time is typically two to four seconds [17]. As such, a Repoint switch should have an operation time of under two seconds.

*Robustness and fault tolerance:* Owing to parameter drift, non-linearities, manufacturing differences, variable environmental conditions, and a number of other factors, there will be a degree of variability in the operation of an actuator bearer over time. These differences can be generally classed as disturbances or uncertainty. The Repoint control system must take this into account at the design stage. For a classical frequency domain control design, typical guidance is to design a 45 degree phase margin in the system's closed loop response (See [18] for more detail). Alternatively, assuming a potential 20% parameter variation in all physical components at the design stage allows for a conservative control design. In addition to successfully dealing with disturbances and uncertainty, an important characteristic of a Repoint switch control system is fault tolerance. That is, the ability to compensate for faults in such a way that they do not lead to system failure [8]. Given the importance of this characteristic, it is discussed separately in 5.

### 4.1.2 Operational Sustainability

There are three sustainability requirements.

*Maximising operational lifespan:* The complexity and expense of track-side maintenance work make it desirable to maximise the operational lifespan of a Repoint

switch. An early stage reliability analysis of the Repoint design highlighted that an important factor affecting the operational lifespan is the relative balance of wear across each of the three actuator bearers. Contributing factors to wear on an actuator bearer will include the motor/gearhead thermal load, the torque load, and various environmental factors such as the ambient temperature, humidity, and exposure to contaminants. The wear itself can be expected to take the form of seal degradation, pitting/spalling in the gearhead surfaces, bending, torsion, and Hertzian fatigue, corrosion, and so on. Several of these factors cannot be directly controlled (rather, they are mitigated by the mechanical design - see section 2, and by appropriate component selection), but the thermal and torque load on each bearer can be controlled. Further analysis is required to determine the optimal thermal and torque balance for each bearer. Ensuring an even balance across all three would maximise the lifespan on each, but increases the likelihood of concurrent failures towards the end of their life. Alternatively an uneven load would decrease the likelihood of concurrent failures, but this potentially would come at the expense of a reduced average lifespan. An appropriate balance must be found. Traditionally, most points machines have used single phase DC brush motors, however the Repoint design will use electronically commutated brushless motors to eliminate the need for brush replacement and maintenance.

*Minimise infrastructure load:* It is anticipated that Repoint switches could be used across an entire line/network. As such, it is prudent to consider their wider systematic impact on their host network infrastructure. A route based switching regime, as commonly used in the UK, typically requires many switches to actuate simultaneously. Presently, the impact of this on the network infrastructure is the relatively large electrical current draw when a new route is set, owing to the inrush current of multiple motors turning on within a short space of time. The electrical network infrastructure has to be rated accordingly. The Repoint electrical and control scheme, therefore, should be designed to minimise both the motor inrush current and steady state current. This can be achieved through efficient motor commutation and effective motor current control.

*Simplified installation and maintenance:* As discussed in 3, ease of installation and maintenance is an important design consideration. The role of the Repoint control scheme in this regard is to provide a “single button” interface to turn on and off each actuator bearer individually. The aim is that each bearer can be removed, maintained and reinstalled individually without disrupting the normal operation of the switch. To this end, the control scheme should self-reconfigure for an arbitrary number of actuator bearers. In addition to this, when the switch is first powered on, it should self-configure and not require any input from track-side personnel, other than turning on each actuator bearer.

## 4.2 Structure

Figure 5 represents a top level schematic illustration of the candidate Repoint control scheme, in this case with three actuator bearers.

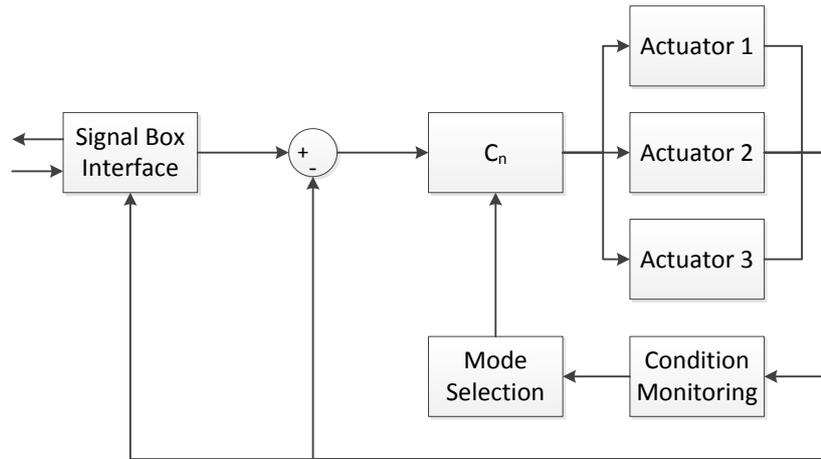


Figure 5: A schematic illustration of a possible Repoint control system

On the right of the illustration are the three actuator bearers. The input to each bearer will be a (commutated) voltage across the motor. Feedback from each bearer will include the motor position encoder signal, the hall device signals (assuming a BLDC motor is used), the motor thermocouple signal, two end-stop switch signals, and a motor current sensor signal. All of these feedback signals will be passed back to a Programmable Logic Controller (PLC) unit located in the signal box. The end stop switches will additionally be used in conjunction with the existing signal relays to provide backwards compatibility with the legacy infrastructure. Both the condition monitoring scheme and the control scheme software will be executed upon the PLC.

The control scheme should have several operating modes to allow individual actuator bearers to be turned on or off, either by track-side personnel, or automatically according to the condition of the switch. The condition monitoring scheme is discussed in detail below, but from the perspective of the control scheme, its main function is to determine which actuator bearers should be active. Assuming each actuator bearer has two operational modes (i.e. on or off) the number of distinct operating modes for the switch as a whole will be equal to the square of the number of actuator bearers; in this example case, nine.

The motor current and torque in each actuator bearer will be controlled by an inner loop PI controller. PI controllers are a widely used, tried and tested tool for motor torque/current control. The main control design task is, therefore, the selection of an outer loop controller to determine the torque command set-point for each actuator bearer. Again, PI(D) control could be used here, however given the competing performance and current draw requirements, an  $H_2$  or  $H_\infty$  are an attractive alternative because they could provide a performance trade-off explicitly defined by a cost function. Model predictive control (MPC) is currently a popular tool in control research, but for this application the technique is unlikely to offer a significant performance improvement over those already mentioned.

## 5 Diagnostics and Fault Detection

### 5.1 Condition Monitoring and Prognostics

A condition monitoring scheme is a tool which recognises abnormal behaviour in a process, plant or system. This process is also known as Fault Diagnosis and Isolation (FDI), where specific information on the nature of the fault is generated. The techniques used in the development of these tools have roots in several areas, including control engineering, statistics and machine intelligence.

Condition monitoring and FDI schemes use knowledge of a plant or process, frequently determined *a priori*, to ascertain the dynamics and/or specific features of the plant in a fault free state, or under predefined fault conditions. The plant is checked for consistency with these dynamics or features and the outcome is used to form the basis of a diagnosis. Typically the objective is to determine if a fault has occurred, or is likely to occur in the future (prognostics).

In 2003, Venkatasubramanian wrote three papers reviewing the most common FDI techniques [19, 20, 21]. The FDI techniques were classified according to their method of knowledge representation, with three main categories of techniques being identified: Quantitative model based, qualitative model based and process history based.

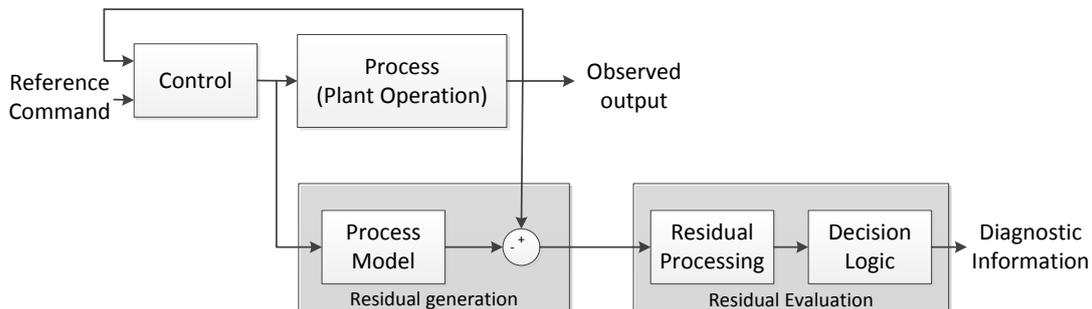


Figure 6: A schematic illustration of a generic quantitative FDI scheme

These reviews show that, where the dynamics of a plant can be mathematically described, quantitative model based condition monitoring schemes can provide accurate and timely diagnostic information. Applications for the rail industry have included low adhesion estimation [22], suspension parameter estimation [23], and extensive work condition-monitoring existing points mechanisms, for instance in [24]. Outside the rail industry there have been numerous applications in fields as diverse as nuclear fusion [25] to wind turbine engineering [26]. The availability of detailed design information for Repoint, and the historical success of quantitative model based condition monitoring, indicate that this class of technique could be used successfully in the Re-point project.

Figure 6 is a schematic illustration of a generic quantitative FDI scheme. The scheme has three main components: the plant, the residual generator, and the residual evaluator. The residual generator comprises primarily of a real-time mathematical pre-

dicator/estimator. This estimates or infers the current state, output, or parameters of the plant, based on previous process variable measurements and the *a priori* knowledge of the plant captured by a mathematical model. The estimate is checked for consistency with the plant, in real-time, using process data. The difference between the measured and estimated state of the plant is represented numerically, and is typically referred to as the residual.

The residual is passed from the residual generator to the residual evaluator. A residual with a high magnitude indicates that there is a discrepancy between the mathematical model and the plant. Sometimes this can be attributed to some transient condition, measurement noise, or unmodelled dynamic. Alternatively, it could be a sign of a plant fault. The purpose of the residual evaluator is to discriminate between these situations and to provide useful diagnostic information. For example, the diagnostic information might identify if a fault has occurred, its type, and its location, or it might provide information to support maintenance activities.

## **5.2 Detection, Reconfiguration and Reporting**

As previously stated, an important feature of the Repoint design is fault detection and fault tolerance. The role of (quantitative) model based condition monitoring in this is, firstly, to carry out fault detection and, secondly, to provide diagnostic information that can be used for automatic self-reconfiguration and by maintenance personnel.

### **5.2.1 Detection Range**

The first step of the condition monitoring scheme design is to determine what types of faults are to be detected. Several reliability analysis tools are available for investigating failure modes, but for Repoint the most suitable, in the first instance, is a Failure Mode Effects and Criticality Analysis (FMECA). A full description of the FMECA procedure is given in IEC 60812 and BS 5760-5. A FMECA is a systematic analysis of a design which explores the potential failure modes of each design component and their potential impact. The purpose is to identify, at the design stage, areas which can be redesigned to reduce the likelihood of failures, and where potential failures are unavoidable, take steps to mitigate their impact. Condition monitoring, fault tolerance and control reconfiguration are the main mitigation strategies for Repoint. The types of faults taken into consideration will include, but are not limited to, motor faults, gearhead faults, mechanical drive faults, locking faults, electrical faults, and sensor faults. At the very minimum, the fault detection scheme should detect any faults that prevent or impair the normal performance of the switch. Ideally, it should also detect those that do not have an immediate performance impact, but will require a preventative maintenance intervention. In [27], Rausand and Høyland describe an FMECA process that includes building a risk matrix to classify faults. The severity of each examined fault is classified using the commonly adopted scale suggested by Hammer [28]:

*Catastrophic:* Any failure that could result in deaths or injuries or prevent performance of the intended mission.

*Critical:* Any failure that will degrade the system beyond acceptable limits and create a safety hazard (i.e. cause death or injury if corrective action isn't immediately taken).

*Major:* Any failure that will degrade the system beyond acceptable limits but can be adequately counteracted or controlled by alternate means.

*Minor:* Any failure that does not degrade the overall performance beyond acceptable limits - one of the nuisance variety.

Using this scale during the FMECA procedure for Repoint will help to identify what faults should be detected.

### **5.2.2 Fault Detection Time**

In section 4, it was noted that a single actuation movement should take no longer than two seconds. Faults affecting the movement or locking phase of a single bearer will be most easily detected during this time, therefore it follows that the total time required for a fault to be detected should also be under two seconds. More generally, the fault detection scheme should, for any Repoint operation, be able to detect faults prior to the completion of that operation. This is to ensure that the control scheme can be reconfigured before the operation is repeated.

### **5.2.3 Reconfiguration**

As described in section 2, a Repoint switch is designed so that it can operate with only one functional actuator bearer in order to provide some degree of physical redundancy. The condition monitoring and control scheme should support this by providing a facility for self-reconfiguration in the field. For Repoint, reconfiguration will primarily take the form of turning on and off individual actuator bearers, although there is additional scope to change the control parameters for each bearer, should that later be deemed desirable. For a switch with three actuator bearers, a minimum of nine operating modes would be required; one for each possible combination of active and inactive bearers.

Decisions on how to reconfigure a Repoint switch should be made automatically unless otherwise specified (e.g. during a maintenance activity). Three decision criteria could be used to assess when and if a switch should self-reconfigure: the ability of the switch to complete the current and subsequent position changes, the ability of the switch to meet its regular performance criteria, and the ability of the switch to mitigate potential future damage. The objective guiding the selection of these criteria is that the switch should have a guaranteed consistent performance, even when faults occur, in order to reduce the systematic difficulties currently associated with points machine failures.

#### **5.2.4 Reporting**

The final requirement of the Repoint condition monitoring scheme is the inclusion of a reporting facility. One of the objectives of the Repoint design was to simplify maintenance activities, reducing time and expense. A straightforward method of achieving this is to present the data already collected by the control and condition monitoring scheme in a manner that maintenance personnel would find useful. In the case of planned maintenance, the switch should estimate and report back parameters that don't meet the design specification (e.g. excessive friction in the mechanical assembly, irregular motor thermal performance etc.). In the case of unplanned maintenance where a fault is to be corrected, the switch should aim to report back enough information to both guide the repair and to guide the entry of the fault into the Fault Management System (FMS) Database or equivalent.

## **6 Conclusion and Future Work**

This paper has discussed the mechanical, electrical, and control requirements for a Repoint track switch. These requirements will inform the design of a lab scale demonstration device that will be commissioned by August 2014 at Loughborough University.

To summarise, the main mechanical requirements can be broken down into Life-Cycle, Maintenance, Operating Environment and Safety. No sacrifice of safety for additional performance would be acceptable to the industry, and the operating environment is a constant. This means performance change must be enabled through revised life-cycle and maintenance practice. Changes to both of these factors can be enabled by revising the control and fault detection aspects of the design, the focus of the rest of the paper.

The electrical and control requirements were selected to maximise both the functional performance and operational sustainability of the switch. The electrical interface should be compatible with the current signalling infrastructure, the actuation time should, at a minimum, match the actuation time of a contemporary UK switch, and it should exhibit a high degree of fault tolerance through automatically reconfigurable controls. The switch should also have a long operational lifespan, should minimise the impact on network electrical infrastructure, and should allow for simplified installation and maintenance.

Finally, suitable fault detection and diagnostic schemes were investigated. It was suggested that a quantitative model based condition monitoring scheme be included in the design. A FMECA based method for choosing which faults to detect was recommended. The detection time should be quicker than the time period for one actuation movement and the diagnosis (where a fault is detected) should be used to guide an automatic control reconfiguration. In addition to this, the switch should have some reporting capacity, to provide diagnostic information to maintenance personnel, to enable reduced maintenance and life-cycle costs.

The next phase of the Repoint project is the design and construction of a lab scale demonstrator to showcase the design concept. The design procedure is currently underway, and the requirements presented in this paper are being used to guide this process. It is expected that the demonstrator will be completed by August 2014.

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