Redundantly Engineered Points (REPOINT) for Enhanced Reliability and Capacity of Railway Track Switching

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Abstract— Points on railway networks enable different routes through the network to be achieved, thereby allowing rail-transport links between many different destinations. However, they are critical parts of the network as a points failure often leads to delays, re-routing and cancellations. Even when fully operational they represent an important capacity constraint because route setting makes assumptions about what would happen in the event of points failure(s) in order to ensure safety. The REPOINT project is investigating the potential of completely redesigning points and incorporating redundancy approaches that are used in other safety critical situations (like aircraft). This fundamentally changes the nature of a junction so that it will have some built in redundancy to faults – leading to higher reliability of the junction and improved capacity. The capacity improvement comes partly from the reliability improvement and partly due to changes in the operating rules of the railway that become possible when the points are redesigned to be more reliable. This paper summarises work to date on the project.

Keywords— Availability, Capacity, Maintainability, Reliability, Track Switching

I. INTRODUCTION

Rail networks operating more than a single vehicle upon a single line are dependent upon the ability to provide multiple routes for traffic. Switches (UK: Points) serve this purpose, allowing the permanent way to merge and diverge, providing different routes. The standard design, in use throughout the world, consists of two ‘switch blades’ upon a suitable supporting structure, which are able to slide laterally between two ‘stock rails’ [1, 2].

Whilst switch actuation has evolved (from man-powered rods and levers to more modern electrical or electro-hydraulic designs) the basic mechanical arrangement of switches has remained identical since the very first rail networks were envisioned.

For all the operational flexibility switches provide, they also represent a single-point-of-failure. Switch failures can rapidly cripple operations. In some jurisdictions, due to control rules around the location and locking of adjacent switches, single switch failures can sometimes prevent use of an entire junction or station throat [2].

Infrastructure operators have long recognised this fact, and switches are subject to careful inspection and maintenance regimes to reduce failures. There is a current trend in the rail industry towards condition monitoring and condition based maintenance, which promises to reduce failures [4,5]. However, these strategies can only reduce - not eradicate – asset failures, and at certain key locations in any network, this may not be enough. It will also not provide sufficient performance improvement to justify the relaxation of the rules of junction control in order to increase capacity – to enable this, a step change in performance would be required.

Other industries with safety-critical systems have long utilized redundancy and passive safety as a method of achieving fault-tolerant, high-availability operation [6]. Redundant systems have seen some use in the rail infrastructure sphere, a successful and widely-adopted example being the architecture of Solid State Interlocking [7]. However, as of 2010, there are no examples of redundancy approaches in the actuation, pathway provision, or feedback systems (detection) of single switch designs.

Recognising these facts, the 2-year REPOINT programme was formed to investigate novel concepts for track switching and to quantify their potential effects upon operational unreliability and capacity. REPOINT seeks 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 failures in switches?”

This paper will summarise the REPOINT project, then will focus: firstly, on the benefits and limitations of building redundancy into existing switch designs; secondly upon the potential capacity and reliability gains from re-writing the rules of junction control coupled with novel designs, including a case study upon the proposed HS2 High-speed line; and thirdly discussing novel-concepts for track switching that have been developed over the course of the project. The conclusions highlight the predicted benefits and consider the steps needed in future to take the project forward.

II. EXISTING INSTALLATIONS

A single turnout consists of two stock rails, two switch rails and a common crossing, fastened by clips, bolts and/or chairs to supporting bearers of wood or concrete, themselves supported upon a bed of ballast. Some installations are of slab track, that is, the rails are directly supported by a concrete raft with no ballast. The stock rails are securely

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fixed to prevent movement, whilst the free ends of the switch rails are free to slide upon supporting cast iron chairs, their movement restricted by the attached stretcher bars and the lock and drive arrangement provided by the points operating equipment (POE). There are several different designs of POE which are located variously in between the running rails, at the line side, or a combination of both.

Higher line speeds require shallower divergence angles, which in turn require longer switches. This leads to a difference in track arrangement between a typical station throat installation, and high-speed mainline installation - short, small clearances with many overlapping features in the former, and long, spaced out designs in the latter. Longer designs require multiple actuation points upon the switch blades. This is provided either by a power take-off from the main actuator, or additional actuators along the length of the moving switch blades [1]. Fig 1. shows the general component arrangement of a typical UK switch.

III. ADDING REDUNDANCY TO EXISTING DESIGNS

The simplest method of introducing redundancy into existing installations is to take existing components and duplicate them. This would be similar to the approach taken to actuate control surfaces in modern aircraft designs. Many different arrangements exist. In order to judge whether this approach could deliver value-for-money reliability improvements, a benchmarking exercise was undertaken. Firstly, a switch design was broken down into 3 subsystems, Actuation, P-way and Detection. Typical asset costs for each were established from industry supplier data on a new-for-old basis. Failure data was obtained from an infrastructure operator, which was analysed to assign failures to one of the three categories:

- **Actuation**: Those caused by failure within the actuation subsystem. The actuation subsystem is defined as being responsible for the actuation of the switch rails, linkages providing transmission of drive to the switch rails and the locking system.
- **P-Way**: Those caused by failure within the P-way subsystem. The P-way subsystem is defined as the switch rails, stock rails, associated slide chairs and sleepers/bearers.
- **Detection**: Those caused by failure within the detection subsystem. The detection subsystem is defined as being those components which detect the position of the switch rails and facing points lock and transmit thus back to the interlocking.

A range of possible design options was then generated, each featuring a different combination of redundant subsystems of each class. Note that redundancy of the P-way subsystem necessitates multiple routes through the switch, essentially meaning replacing a single switch with three, and necessitating a subsequent multiplication of the actuation and detection elements. Differing asset utilisation in these examples will lead to differing of route availabilities for normal and reverse. Multiplication of detection elements was carried out only on a two-out-of-three voting basis due to the safety critical nature of the information provided by the subsystem.
TABLE I
RELIABILITY AND COST OF REDUNDANT OPTIONS DEVELOPED FROM EXISTING DESIGN BASELINE.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Cost (x1000GBP 2011)</th>
<th>( R^* ) (13week survivor function)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>140</td>
<td>0.52</td>
</tr>
<tr>
<td>A</td>
<td>178</td>
<td>0.62</td>
</tr>
<tr>
<td>B</td>
<td>196</td>
<td>0.62</td>
</tr>
<tr>
<td>C</td>
<td>163</td>
<td>0.54</td>
</tr>
<tr>
<td>D</td>
<td>426</td>
<td>0.27 (0.50)</td>
</tr>
<tr>
<td>E</td>
<td>201</td>
<td>0.65</td>
</tr>
<tr>
<td>F</td>
<td>219</td>
<td>0.65</td>
</tr>
<tr>
<td>G</td>
<td>567</td>
<td>0.42 (0.95)</td>
</tr>
</tbody>
</table>

\( ^a \) Reverse route value in brackets where applicable.

The potential reliability improvement of each concept has been evaluated using a block diagram style approach as shown in Fig. 2. Predicted cost was evaluated by multiplying the known cost of each subsystem along with some assumed allowances for line-side integration of multiple, redundant subsystems.

Table I shows the estimated cost and reliability of a range of design options, and Fig. 3 illustrates the calculated increase in asset reliability, measured by 13-week survivor function, plotted against the estimated cost of that concept. \( R^* \) Represents the fraction of an asset population which would still be functioning after 13 weeks continuous use at a level equivalent to morning rush hour.

The results of this benchmarking study are mixed. Firstly, and positively, a large increase in route availability can be achieved through the design and installation of a high-redundancy asset utilising existing practice as a baseline, especially through concept G. However, the large gain in primary route availability comes at the price of a small loss combining redundant switches to form redundant networks in order to reduce the effects of this loss [8], the results of which are also mixed but beyond the scope of this paper.

Taking a holistic view, the cost increase necessary to achieve the predicted gain in availability, even with redundant networks, may be better invested in additional maintenance. This is difficult to quantify and is the subject of on-going work\(^1\).

Crucially, the expected reliability gain from this approach is not enough to enable a change in junction control from the traditional 'assume dangerous until proven safe' to an 'assume safe until proven dangerous', with the associated relaxation of junction control rules. The discussed approach, therefore, cannot bring about the step-change impact upon network capacity which REPOINT seeks. To achieve this mode of operation, it will be necessary to radically rethink the design of S&C to incorporate redundancy and fail-safe modes from the very outset.

IV. REWRITING THE RULES OF JUNCTION CONTROL

The rules of junction control have evolved over time to suit current designs of switch. There are many interlocking rules relating to junction operation which ensure the safety of trains - e.g. flank protection. However, for the sake of this section we will consider only the command-move-lock-detect-clear cycle of a train making a move over a single turnout only – facing, unless specified trailing.

A. Current British Practice

Specifically, British practice is to have absolute position detection of the blades in the closed position only\(^2\). An associated interlocking arrangement prevents trains crossing a switch in an unsafe (or sometimes safe but incorrectly-set ) state, by preventing the clearing of signals on approach, thereby withholding movement permission for approaching trains.

This arrangement of protection applies in similar form whatever type of signalling is utilised. It is necessary for the safe operation of the railway with current switch technology. Switch failures - leaving the switch in an unsafe state - can be expected, and traffic needs to be protected against their occurrence.

B. Junction Margins

In the signalling field, the switch is said to be 'Normal', 'Reverse' or 'Out of Correspondence' [9]. The latter indicates that the switch is in any position but locked and detected in one of the two passable positions for traffic, yet in this state, the interlocking prevents any signals showing clear. This introduces necessary margins between vehicles at junctions above and beyond what is termed the 'plain line signalling headway' [10]. It is these additional margins – junction allowances - which, more often than not, define the operational parameters and therefore capacity of a transport network, even though the plain-line headway is a more oft-quoted figure.

Various methods of reducing junction margins have proved successful. Flighting trains is one example, where trains to the same destination closely follow one another

\(^1\) Whole-life analysis is beyond the scope of this paper due to the unique nature of operations/maintenance of each junction upon a network, and is instead the subject of on-going work within REPOINT as part of case study sections.

\(^2\) It is true both blades are detected, yet the open blade is detected as 'not closed' only - its actual position is unknown, and ensured through the use of 'Stretcher Bars' – See Fig. 1.
meaning less time is lost changing the switch to a new position between every train. Sometimes, for reasons of economy, plain line is signalled to a lower capacity than its design would otherwise allow because it was well known at design time that the associated junctions would limit network capacity in any case.

However, the only way a junction could achieve the specified plain-line headway of adjoining lines is to remove all associated junction margins – that is, for the control system to operate the switch as though there was no switch present at all. To achieve this requires a radical rethink of junction control.

C. Ensuring Safety

What is proposed is a change of paradigm, not a reduction in safety. Currently, safety is ensured by having signals protecting an unsafe junction. This has the drawback whereby if a train were to SPAD\(^2\), it could still be derailed, or encroach upon the path of another, as the junction may be in an unsafe state.

If the physical switch components were designed in a passively safe state, it would not lead to derailment if the train encroached the junction against the authority of the signalling system. An equivalent safety level could be delivered via the hardware on the ground, rather than by the controlling system. This may enable relaxing the rules of the control system which specifically limit junction capacity.

D. Eradicating Margins to Increase Capacity

Junction margins are broadly split into 3 categories:-

- An allowance for the braking time of an approaching train in order to take a lower-speed turnout route. This shall be referred to as a ‘Braking margin’.
- An allowance for the movement, locking and detection of the switch, interlocking arrangement and transmission of state – Referred to as an ‘Infrastructure margin’.
- An allowance built into the timetable to enable ‘catch-up’ running after a delay (perhaps, but not exclusively an asset failure), and for the perturbed time distribution of trains arriving at the junction for a trailing move needing to share the same section of track beyond the switch - the ‘Operational margin’.

Braking Margins have the simplest conceptual eradication. For optimal capacity, the switch must be designed to have a turnout route speed as high as the main line speed. With traditional designs, however, this becomes increasingly difficult as line speed increases. Firstly, due to the dynamic forces on the switch. Secondly, due to the increasingly fine crossing angle requiring active crossings, the best known of which being the ‘swing nose’.

Redesigning the switch arrangement with turnout speed as a primary consideration is possible, and has been a fundamental part of the REPOINT work. Conceptual designs now exist which could allow up to 360kph (225mph) turnout speed, eradicating braking/accelerating margin entirely.

To eradicate infrastructure margins, a mixture of modified rules and modified infrastructure is necessary. Faster actuating switches is the first requirement. Currently around 7 seconds is allowed \[^9\]. Secondly, transmitting a command for movement should be done ahead of the time the switch is required to move, rather than when required. This means the time allowed for command transmission and confirmation can be overlaid upon the headway of the preceding train, rather than appending to it.

To recoup the very last part of the infrastructure margin, it is suggested that switch state should be relayed to the train locally rather than via a centralised command and control centre. This does not save a large amount of time under colour-light signalling, but with the advent of in-cab signalling, each command-confirmation transmission cycle can have an allowance of up to 5 seconds. The technology to do this already exists - as examples, an AWS\(^5\) magnet could be adapted for purpose, or a MA (Movement Authority) could be issued in separate parts for ‘track’ and ‘switch’.

To eradicate operational margins is a somewhat different challenge. Slightly perturbed arrival times during regular running are completely normal, yet are a concern for reliable, high-capacity junction utilisation. This is a concern of trailing junctions only, as perturbed times from two arrival paths merge to one. This can be overcome to a large part by the fitment of full ATO\(^3\) with the ability to communicate across merging routes. Many projects are ongoing in this field, and this is beyond the scope of REPOINT. Suffice to say their positive results will be necessary for the successful capacity utilisation of some junctions, and the industry is well aware of this fact.

The fraction of operational margin allocated for ‘catch-up’ running after an incident is directly correlated to the reliability of the infrastructure. UIC406 \[^{11}\] provides a comprehensive discussion of ‘capacity consumption’ and CUI (Capacity Utilisation Index) – the portion of signalled capacity which can be utilised upon a network in an operational scenario. This portion increases with homogeneity of traffic and infrastructure reliability. REPOINT can therefore assist in eradicating some of this margin by providing more reliable assets.

V. EVALUATING POTENTIAL CAPACITY AND RELIABILITY GAINS - A CASE STUDY ON HS2

As stated in section III, every junction upon the British rail infrastructure is unique in terms of physical layout, signalling, maintenance, timetabled traffic and operations. Therefore it is not possible to state the benefits of the REPOINT approach as a blanket figure. Instead a ‘case study’ approach will be used at a particular junction in order to judge potential capacity gains.

\[^{2}\] Signal Passed at Danger, an industry term for a vehicle passing beyond the end of its movement authority.

\[^{3}\] Automatic Warning System – a system which alerts drivers to restrictive signal aspects, and automatically applies emergency braking if the warnings are ignored.

\[^{5}\] Automatic Train Operation/Automatic Train Control – systems which can combine to keep a train within a predefined margin of the running timetable.
A. HS2 – The proposed High-speed line

HS2 is a proposed high-speed rail link between Birmingham and London in the United Kingdom [12]. It is unique in rail services/proposals in that it is proposed to run a metro-class service frequency at high-speed rail speeds – the line has a design speed of 400kph (though an initial in-service speed of 360kph is suggested). This means the performance – and more specifically the capacity - of the line is absolutely constrained by the parameters of the switches, as discussed in section IV part B.

The proposed specification of the new line can be found in [12, 13, 14]. It is clear that the most likely in-service capacity of the line is limited by converging junctions, reducing capacity by 2 to 4 trains per hour, depending on specification, though this capacity in itself is constrained as the designers have assumed the junctions will limit capacity in this way, and have specified plain line signalling thus.

B. HS2 with the REPOINT Approach

In design documents [12], it is surmised that the line will be signalled at ETCS-Level 2 (European Train Control System) only, and the deployment of ETCS-Level 3 would bring cost savings but not improve capacity at junctions. However, following the REPOINT approach, it is possible that moving block signalling could be applied through junctions by utilising split MA’s. This means that the capacity gains are now threefold:

- Junction margins have been eradicated or overlaid upon already necessary plain line headway allowances, meaning the capacity of the junction can match the capacity of adjoining plain line6.
- Full moving block ETCS Level 3 can be deployed on the adjoining plain line, further increasing the network capacity. This is possible without the REPOINT approach, but would not yield any network capacity gains due to the junctions still existing as pinch points.
- High availability infrastructure coupled with removal of differential braking/acceleration allowance (from full line speed turnout routes) enables a higher CUI to be achieved without incurring additional delay [11, 14].

A summary of the respective capacities of the HS2 proposal, in terms of headway and operational paths per hour, is shown in table II. HS2 specifications are taken directly from the HS2 Ltd Document [12], and the potential REPOINT capacity calculated using the same methodology. There is a single figure for REPOINT, due to the fact that the concepts allow the junction to be signalled at the same capacity as plain line, thus no differential in capacities is present.

Note the REPOINT figure relies upon a successful deployment of ATC/ATO in order to regulate the arrival times of trains at a converging junction with precision. It is unfair to say, therefore, that this saving is entirely due to

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6 In some instances, junction capacity can be shown to exceed that of adjoining plain line, a desirable situation during perturbed running. This can be achieved by reducing the train detection granularity within given margins of a junction.

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VI. NOVEL CONCEPTS:- ERADICATING UNSAFE SWITCH FAILURE MODES

The initial studies show that we can improve reliability by increasing the redundancy of conventional switches. This section looks at the redesign of switches to reduce the need for redundancy.

When generating novel switching concepts, the strategy is first to design out unnecessary features, then design out failure modes, and finally apply functional redundancy only to those subsystems which remain. As an extra concern, the switch should be passively safe to reap the full benefits listed in sections IV and V.

Table III shows a summary of data provided by a UK infrastructure operator, classifying total failures over a single route by cause. It should be noted that not all designs feature all components listed, therefore the percentages can give an indication of which failure types to design out first.

Locking faults – including the Clamplock mechanism - make up 20% of attributed failures. The Clamplock mechanism is herein classed as a locking fault as the design exists to lock rails in place – without the locking function, the mechanism could consist solely of a hydraulic ram. REPOINT has been investigating designs for passive locking which would eliminate this failure category without introducing new.7 Inspiration is taken from the Nuclear Power industry where such design principles are common.

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7 As of September 2012, the REPOINT team is involved in filing patents in several areas related to railway track switching and associated control, and are unfortunately therefore not in a position to reveal, in this paper, the exact nature of solutions to be employed.
Switch blade blockages are not listed in table III as they are not currently considered a switch failure and therefore not recorded, yet they should be considered a system failure. Reducing blockages requires eradicating the flange gap (which changes in size with actuation) between the stock and switch rails. The REPOINT design solution for this issue also means stretcher bars can be eradicated, which are the second highest defined failure cause at 12% (Somewhat expected, as multiple stretcher bars are mandated in every current UK Design).

An approach based around multiple redundancy of actuation with a novel, simplified mechanism and self-contained bearing surfaces should reduce, by several orders of magnitude, actuator, transmission and friction based faults (21% of total faults from back-drive mechanism, Drive rod Assy. and Point Motor). The proposed approach also means that, should a failure of these subsystems occur, it would not lead to a derailment in any case.

Other benefits of the proposed approach are also worth noting:

- Multiple routes are possible from a single switching unit – initial design calculations suggest up to 4 turnout routes could be provided from a single switch.
- Switch designs possible with up to 225mph turnout speed by providing a positively located, correct alignment and curvature in all positions
- Highly modular component set reduces costs and eases maintenance – e.g. no planing of unique switch blades.
- Maintenance in traffic – multiple actuators mean that a single, failed unit can be removed and replaced whilst the switch still provides full functionality.

VII. CONCLUSION

This paper has provided a broad overview of the work of the REPOINT project, which was tasked with carrying out a fundamental rethink of railway track switching technology. The aim is to improve the behaviour and reliability of track switching technology to a level where network capacity can be significantly increased. This capacity increase can be maximised if the redesigned switches allow the rules of junction control to be altered.

Section III evaluates the addition of redundancy to existing designs. Key sub-systems have been defined and redundancy has been introduced in each to create seven new concept switch systems with improved performance characteristics. These have been evaluated for use in a simple single-turnout node and the appropriate reliability figures and costs have been estimated. The results demonstrate that it is possible to significantly increase switch and network availability through the varying use of subsystem redundancy. However, it is clear that there is a significant additional cost associated with doing so, and novel designs with passive safety features may be a better option.

Section IV discusses changes which may be possible in order to eradicate the junction margins which currently limit stated network capacity. Some of these changes come from infrastructure changes, whilst others come from the rule changes possible when the infrastructure is designed under a different paradigm. Section V demonstrates what these changes would mean in an operational scenario, utilising the proposed HS2 line as a case study. The results show a significant capacity increase is possible with this combined approach.

Finally, section VI gives an overview of the failure modes of existing designs, and touches upon some of the technology currently under investigation by REPOINT in order to enable the changes discussed in the previous sections. It should be noted that minimal details are provided due to the currently unprotected status of the IP generated over the course of REPOINT.

Future research will include assessment of capacities and estimates of impact of REPOINT upon selected case study nodes.

REFERENCES


