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Rethinking Rail Track Switches for Fault Tolerance and Enhanced Performance

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Abstract: Railway track switches, commonly referred to as ‘turnouts’ or ‘points’, are a necessary element of any rail network. However, they often prove to be performance limiting elements of networks. A novel concept for rail track switching has been developed as part of a UK research project with substantial industrial input. The novel design meets the set of functional requirements for track switching solutions, in addition to offering several features that current designs are unable to, in particular to enable multi-channel actuation and rail locking, and provide a degree of fault tolerance. This paper describes the design and operation of this switching concept, from requirements capture and solution generation through to the construction of the laboratory demonstrator. The novel concept is contrasted with the design and operation of the ‘traditional’ switch design. Conclusions to the work show that the novel concept meets all functional requirements whilst exceeding the capabilities of existing designs in most non-functional requirement areas.

Keywords: Track Switch; Capacity; Reliability; Multi-channel Redundancy; Fault Tolerance.

1. INTRODUCTION

A novel concept for rail track switching has been developed as part of a UK research project with substantial industrial input. The concept is currently at the demonstrator phase, with a scale (384mm) gauge unit currently operational in a laboratory - as depicted in Figure 1, and two published patents by Bemment et al. (2015a, b) The design meets the set of functional requirements for track switching solutions, in addition to enabling multi-channel actuation and rail locking, to provide a degree of fault tolerance.

Track switches (‘turnouts’ or ‘points’) are a necessary element of any rail network. Switches enable vehicles to take many different routes through the network. Waterloo station throat, one of the most complex pieces of track work in the UK, is responsible for the safe arrival of just under 108 million passengers per year and features 80 switches within just 500 linear metres of route (Source: ORR Online Data Portal (2013)). Figure 2 shows the simplest junction element - a single turnout arrangement.

Track switches represent single points of failure, and their failures can prevent use of extensive sections of the network. It is for this reason that rail network performance is negatively affected by switch failures to a greater degree than any other asset ORR Online Data Portal (2013).

Morgan (2009) states that existing track switch systems are the result of the evolution of a single design solution dating

to early mining railways in the 1700s. The operating parameters of a modern railway system are much changed from those early days. Other elements of rail systems have undergone step changes as disruptive technologies have made an impact. Notable examples are the moves from steam to diesel and electric traction, the widespread adoption of reinforced concrete for viaducts and tunnels, and the move to SSI (Solid State Interlocking). However, apart from small incremental changes, for instance to actuation methods, a modern track switch is of the same design and operation as those early days - despite the requirements having changed significantly.

This paper considers the design and operation of track switches with a view to improving their negative impact upon network performance. Performance, in this instance, is considered as maintainability, system capacity, reliability and cost, though it is accepted other measures could be utilised. Existing systems, their limitations and impact upon performance are considered in under the Existing Systems Section. A requirements capture exercise follows in the Requirements Analysis Section, which sets out the minimum functional set required of a track switching solution. A series of solutions were generated and evaluated leading to the reduction of these options to the most appropriate. The paper then presents more detail on what has been termed ‘The Repoint Solution’, including its general arrangement, feasibility, and the qualitative benefits and drawbacks. Conclusions to the Repoint study are then presented alongside possible future work

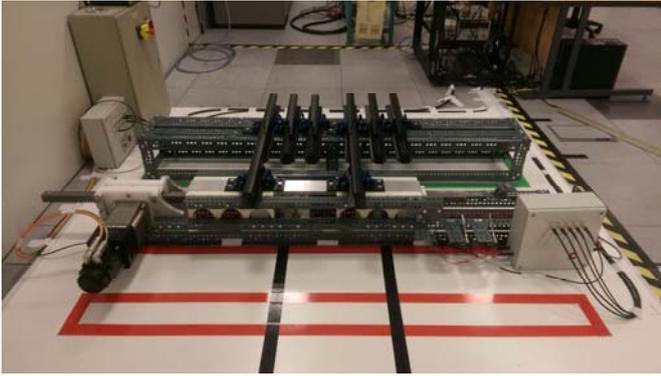


Fig. 1. The general arrangement of the novel track switching demonstrator in the laboratory at Loughborough University, at 384mm gauge.

2. EXISTING SYSTEMS

2.1 Mechanical Design

There are many methods of achieving a solution to the conflicting issues posed by track switching. However, all major railway systems throughout the world utilising the 'traditional' arrangement of twin steel running rails and flanged wheels have adopted a broadly similar mechanical arrangement, extensively detailed in both industry publications, e.g. Morgan (2009) and in academic literature; Eker et al. (2011) and Silmon and Roberts (2010). This arrangement is shown in Fig. 2.

Switch arrangements consist of three distinct elements, or panels; namely 'switches', 'crossings', and 'closure panels'. The switch would generally be bracketed on all routes by sections of plain line, but in more complex junctions -

especially those where footprint is restricted - switches may be adjacent or even overlap.

The switch panel comprises a pair of longitudinally extending switch rails are free to bend or pivot beyond a given point, and slide upon supporting plates or chairs, between two fixed 'stock' or 'running' rails. A mechanical linkage from the power source links the two switch rails, operating so as to open one rail and close the other. Actuation power and transmission is variously provided by humans and mechanical lever arrangements, pneumatics, hydraulics, or electro-mechanics.

The closure panel provides the diverging routes and bridges the gap between the switch and crossing panels. At the point where the outer rails of the two diverging routes cross, provision must be made for the wheel flanges to pass through unhindered. In common use are built-up and cast crossings, which have a gap in both running rails to allow this.

2.2 Signalling and Operational Rules

Switches remain in position and locked until commanded to move via the signalling system. The position of the blades, and the integrity of the position lock, is continually fed back to the interlocking via a subsystem known as 'detection'. When changing position, traditional switch designs move through a state which can be considered dangerous due to the inherent derailment risk, when the moveable blades are between the two set positions. Trains can be issued a movement authority to pass the switch only once the movement process is complete. This process normally takes several seconds; around 8 seconds is allowed in British signalling practice. A more detailed discussion of the British practice of switch control and operation is provided in 'Principles of power point control and detection' by Hadaway (1950).

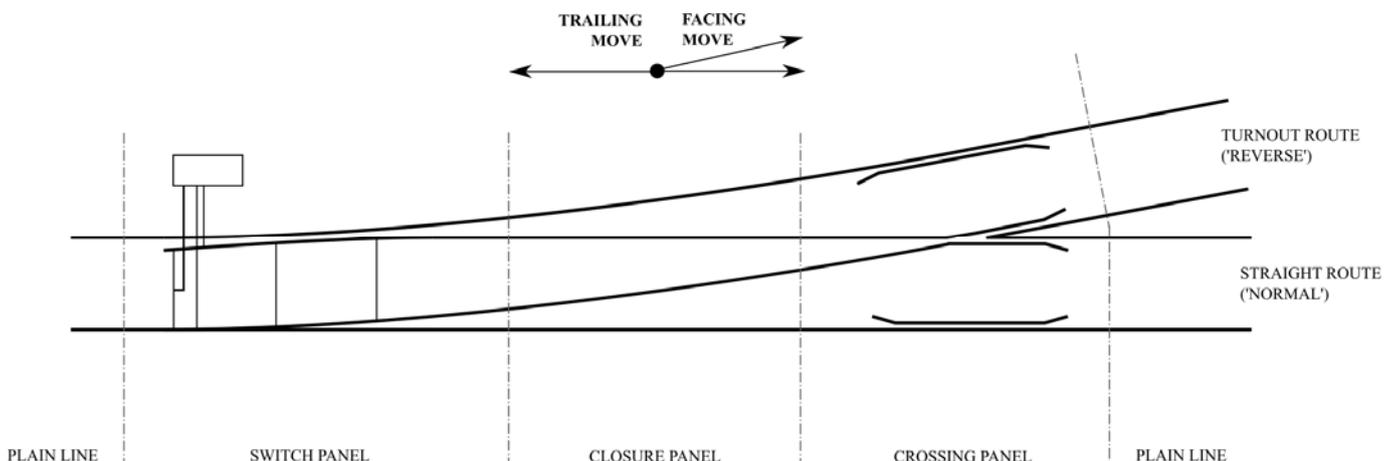


Fig. 2. Typical traditional switch layout, with sleepers/bearers omitted for clarity.

2.3 Capacity

These restrictions upon movement lead to a reduction in the theoretical maximum capacity of a junction below what could be expected from an equivalent section of plain line. Additional capacity is lost in installations where the turnout route has a speed restriction below that of the straight route; in these cases some braking or acceleration must take place upon the mainline. It is not possible to define capacity as an absolute value, thus it is not possible to calculate, in the general sense, what this capacity restriction equates to. Capacity consumption is the method utilised by the industry, as detailed in literature: Abril et al. (2008), Nash et al. (2004) & Parkinson et al. (1996); and further explored in standard UIC406, UIC(2004). Previously published work has explored and subsequently modelled these capacity constraints and methods to alleviate, both from the authors of this paper, Bemment et al. (2013a & b) and others, for example Liu et al. (2013). The application of moving block signalling schemes will not necessarily alleviate capacity constraints at junctions, as the fixed obstruction provided by a switch causes the signalling operation to revert to fixed block at this point.

2.4 Reliability

There are 21,602 switches upon the UK network, as of 2012. With a mean of 5,917 failures per year amongst this population, equating to an MTBSAF (Mean Time Between Service Affecting Failure) of 3.65 years network-wide. It is important to note that the impact of failures is compounded by the fact that switches are often co-located at junctions or nodes, meaning many individual failures could affect the same node and cause repeated disruption. Switch failures do, however, cause a lower average delay minute count than some other failure types. Despite the nodal location, switches have built-in manual overrides to enable response teams to begin to hand-signal trains past the junction upon arrival, reducing the delay impact. This could not be matched for some other infrastructure failures, examples being rail breaks or bridge failures, both of which have much higher mean delay minute counts.

Data from the Office of Rail Regulation for incident counts and subsequent delay minute counts for asset failures on the UK infrastructure between 2007 and 2012 has been analysed, (Source: ORR Online Data Portal (2013)). For every published year apart from 2013-2014, points failures contribute the highest total of delay incidents. However, points failure incidents, and subsequent delay minutes incurred, have fallen significantly over the same period. This is due, in part, to Network Rail's Intelligent Infrastructure programme, more details of which are provided by Silmon and Roberts (2010).

2.5 Human Factors

Considering the whole life-cycle of switches and crossings, there are several cases where humans come into contact with

the system. Design, installation and commissioning, and end of life decommissioning are of consideration. Choices regarding the type of machine and location, and the practicalities and practices at installation are known to have a significant effect upon the performance of the switch. These will not be discussed further in this paper as the issues would affect all designs and there is much ongoing research into this field presented in COMSA (2014). The primary human contact through the working life of the switch installation is via signallers, who operate (but may be remote from) the switch, and the maintainers, who visit regularly to perform inspections, maintenance and adjustments, but are generally unable to operate the switch locally.

The signaller: Irrespective of the method of switch operation, be that mechanical or through levels of electrical interlocking, the signaller is the daily user of the switch, but acts at a level abstracted from its actual operation. The level of abstraction increases the more modern the signalling system, and this can compound issues when there is a switch failure.

The maintainer: Switches are subject to careful inspection and maintenance regimes. UK switches undergo a rigorous and highly prescribed maintenance schedule to ensure all safety critical components are in good order. This involves two independent teams - Signalling and Permanent way Departments - visiting each switch; the latter at a frequency of once per week. It is unlikely that regular inspections can be reduced to zero, due to the design of switches having several safety concerns for which regular inspection is the mitigation. In addition to time-interval maintenance, the maintenance organisation has a rapid response unit which is responsible for attending any asset failures, including switches. Even condition-based switch maintenance requires a possession of the line and human intervention which is not always possible at short notice.

2.6 Considerations for Switch Redesign

For any switch redesign to be successful, concern must be given to maintainability. It would be of specific benefit for any proposed design to:

1. Enable the continued and safe functioning of the switch despite a given number of known faults in subsystems.
2. Communicate known faults to a control centre such that repair work can be managed and scheduled appropriately.
3. Enable as many maintenance operations as possible to be conducted without maintenance possession.
4. Enable as many maintenance operations as possible to be mechanised or conducted off-track to minimise risk to personnel, improve output and reduce costs.
5. Use a minimum, COTS (Commercial off-the-shelf) component set such that spares can be carried without needing adapting to specific switch installations.

3. REQUIREMENTS ANALYSIS

3.1 Essential requirements of a track-switching solution

The requirements of the system reduce to a simple set of key technical requirements which are a combination of those for a track system, those for a safety-critical asset, and those for a mission-critical asset. The track system function is to support and guide vehicles. The active element has two functions: to direct vehicles along the correct path; and to confirm the route to the interlocking, or provide information that the switch is unsafe. This operation must be performed within a given timeframe. Traditionally these have been the only requirements of a switching solution. However, given the high performance standards of a modern railway and the criticality of switch availability, another necessary requirement could be included; namely to communicate back to maintenance resources the current ability of the switch to perform its task, and the requirement for any immediate intervention. The following requirements set is proposed:

1. The switch shall adequately support and guide all passing vehicles (From relevant track standards: RSSB. (2009)). It shall:
 - a. be strong enough for the required static loading.
 - b. be strong enough for the required dynamic loading.
 - c. guide the wheelsets with maximum deviations as specified for the given track quality.
 - d. manage the wear and degradation of support and guidance elements to allowable levels.
2. The switch shall direct vehicles along the path specified by the interlocking as per Genner (1997) & Hadaway (1950).
 - a. When commanded, and not otherwise, it shall align any movable elements so as to direct the wheelset of a vehicle along the specified route.
 - b. When commanded, it shall align any movable elements for the requested route within a specified timeframe.
 - c. It shall ensure all wheelsets of a passing vehicle are directed along the same route.
3. The switch shall confirm to the interlocking the route vehicles will be directed along, and that all active elements are safe for the vehicle to pass, as per Genner (1997) & Hadaway (1950). It shall:
 - a. provide feedback to the interlocking that the requested route is set.
 - b. provide feedback to the interlocking if the requested route is unable to be set.
 - c. provide feedback to the interlocking on (3a) and (3b) within a given timeframe.
4. The switch system shall provide information to maintenance organisations regarding the future

projected ability to perform requirements (2) and (3). It shall:

- a. monitor wear of wear-susceptible parts and adjustment of adjustable parts.
- b. communicate current state of wear and adjustment to maintenance organisations.
- c. calculate and communicate the remaining time of useful operation of the asset without maintenance intervention.
- d. achieve a given level of reliability commensurate with the operations at the node.
- e. minimise the amount of time the node is unavailable due to maintenance activity, and the amount of time maintainers must spend trackside.

3.1 Non-functional requirements

There are further requirements which need to be established, but can be considered non-functional. Whilst all switching solutions need satisfy the full set of functional requirements, non-functional requirements form a set of trade-offs. Non-functional requirements were considered and the most significant listed: fault tolerance, design adaptability, cost, spare utilisation, energy requirements, ease of manufacture, likelihood of acceptance, switching speed, maintainability and standardisation.

4. THE REPOINT SOLUTION

4.1 Generation, evaluation and down selection of solutions

A cross industry focus group was established to generate candidate track switching solutions. These sessions resulted in over 400 individual ideas related to improvements to switches and crossings, covering their physical design, signalling and operation, and maintenance activities. The first filter for down-selection was to exclude any ideas which were mechanically implausible. Construction/operation of some ideas will not be possible, and these ideas must necessarily be rejected at an early stage. Secondly, any ideas which would require wholesale modification of the entire rolling stock fleet were excluded. These included, for example, the removal of all wheel flanges or steerable bogies. The remaining solutions were scored and ranked based on the degree to which they met the functional and non-functional requirements. A more detailed account of the ranking and evaluation process can be found in Bemment et al. (2016)

4.2 Repoint design overview

The most promising concept, chosen to be taken forward for development is a hopping stub switch, the Repoint solution. The design is based around an arrangement known as a stub switch.

The stub switch reverses the elements in a traditional switch, and replaces the long, planed down switch rails shown in

Figure 2 with short, stub-ends formed of full section rail which are able to move between positions.

Figure 3 shows the general arrangement of a 'Repoint' stub switch, with an optional second turnout route shown dotted.

Numbered elements as follows: (1) In-bearer type electro-mechanical actuators featuring integral passive locking elements with detection system; (2) Bearer featuring integral passive locking elements; (3) Bendable, full-section switch rails; (4) Interlocking rail ends.

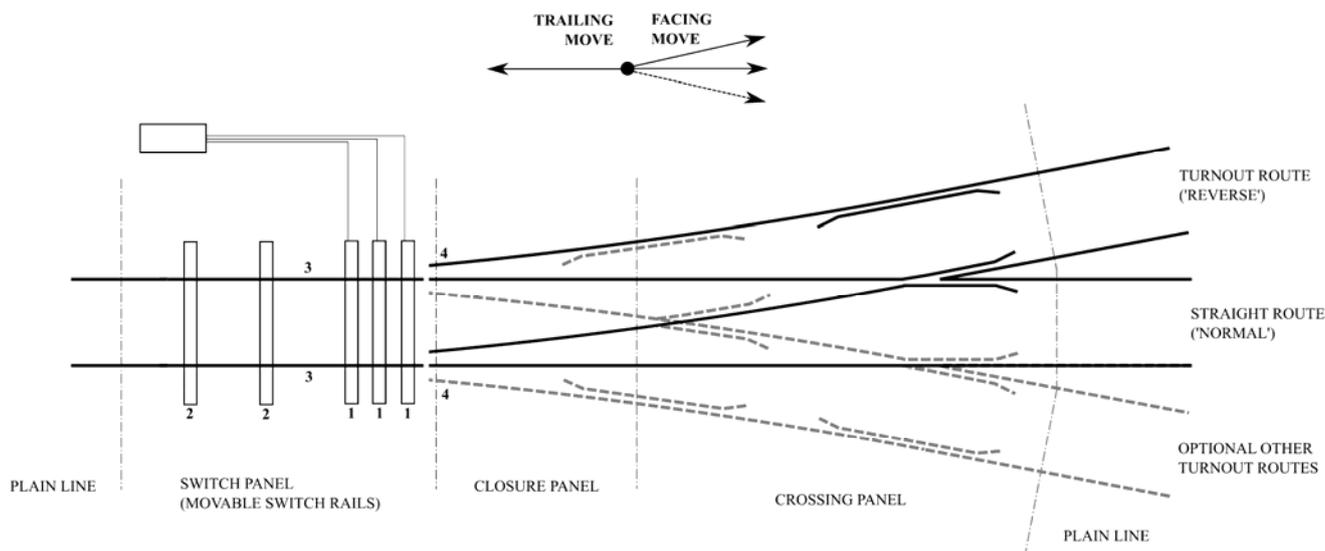


Figure 3. Repoint stub switch general arrangement with electro-mechanical in-bearer type actuators, with most sleepers/bearers omitted for clarity.

4.3 Actuation Concept

A bank of actuators is responsible for moving the full-section switch rails between each position. The actuators bend the rail between each position, from a stationary point, beyond which the track can be considered plain line. There is no hinge. Where the open, moving rail ends interact with the static rails in the track panel, a novel design of interlocking rail end is provided. This is to allow the expansion and contraction (with temperature variation) of all rails in the assembly, whilst still providing support and guidance for wheelsets.

Actuation is provided by a multi-channel actuation bank, with the actuation elements contained within bearers near the movable rail ends. Each actuator is capable of moving the switch alone. Triplex redundancy is shown in Figure 3; however the exact number of actuators required could be tailored to the particular requirements of each location on the basis of an operational reliability figure.

Multi-channel actuation is provided through an arrangement which has been termed 'passive locking'. The theory of passive locking is that when the rail is in one of its stationary, lowered positions, it is unable to move in any direction apart from directly upwards. It is a requirement to lift the interlocking rail ends to disengage them. When the track is lifted, it is free to move laterally, but not longitudinally. Thus the rail hops between adjacent positions. If an actuator is isolated for whatever reason, the adjacent unit(s) can still actuate the switch, as the lifting action will unlock the

isolated unit. It is this feature which enables redundant actuation to be provided as part of the 'Repoint' concept, something not possible with the conventional switch. The general arrangement of the components within each actuator-bearer is shown in figure 4.

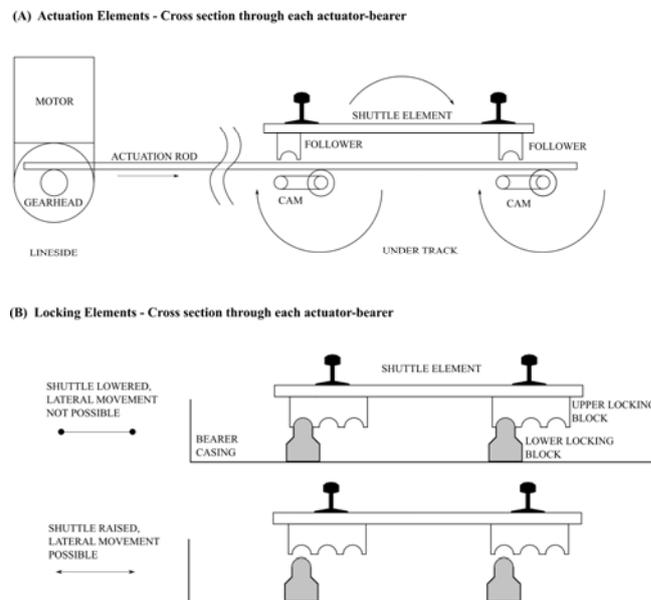


Figure 4. Cross sections of each actuator-bearer. (A) shows internal elements related to the actuation system. (B) shows the associated locking elements, which would be present inside each bearer alongside (A).

4.4 Satisfying the requirements

Referring to the functional requirements specified in the Requirements Analysis (Section 3), we can postulate that the Repoint solution can meet all requirements, and exceed the extent to which existing systems meet the requirements, in particular with regards to providing information to maintenance organisations. In addition, as a clean sheet of paper design, several of the considerations outlined in section 2.6 can be designed in.

4.5 Development of a laboratory-based demonstrator

A scale demonstrator of the concepts has been constructed in a laboratory at Loughborough University (Figure 1). The demonstration actuator/bearer features all components which would be required in a full-size design - controller, motor, gearbox, drive arrangement, roller-cams, and passive locking elements. These components are mounted at the correct spacing in a substantial frame. There are 3 routes - one straight ahead, and two turnout. The demonstrator is at 384mm gauge but all actuation components are sized for CEN-60 type rail, at the most common size of switch upon the UK infrastructure, termed a 'C' switch. Note that extensive associated dynamic modelling work was undertaken in MATLAB/Simulink, in order to demonstrate the viability of the full scale design, presented in Bemment et al. (2013a), Ebinger et al. (2015) & Wright et al. (2014). The demonstrator is a hardware-in-the-loop implementation of a full Repoint track switch. A single, physically constructed active actuator/bearer exists in the laboratory, in parallel with two virtual bearers simulated within a real-time software environment (utilising MATLAB/Simulink and D-Space). As the physical demonstrator is switched between positions, the software model co-simulates this motion for the other two bearers in the alignment.

Critical to the operation of such a proposed switch arrangement is the ability for the three switch machines to operate in unison and in-phase whilst coupled to a traditional interlocking arrangement. By extension, also critical is the ability of two machines to operate in unison should a single machine be isolated when faulty or for maintenance. As only one machine is present, the first step of work towards development of a full-scale installation has been to validate the software models of the actuator bearers in order that a suitable control algorithm, and associated detection logic laws, can be designed to enable this motion. The validation of these models is also important to ensure the viability of the actuation, locking and detection elements of a full-scale design. In the physical implementation, detection is obtained when the shuttle element triggers one of three representative micro-switches when lowered and locked. In the software implementation, position detection is inferred from the co-ordinate position of the shuttle. A representative and validated model is also important for model-based condition monitoring algorithms, which are vital to fulfilling any condition monitoring and reporting requirements.

5. CONCLUSIONS

This paper has presented the background and context to railway track switching, including how track switches can limit the performance of rail networks. These limitations come about as track switch designs have evolved over time to fulfil a particular purpose, meaning they may not be optimised to provide the kind of performance a modern railway network requires. A shortlist of possible design options was generated alongside a non-exhaustive range of design options generated by a cross-industry panel. These options were then reviewed and ranked, with several of the options being combined to create a novel solution to the track switching problem. This novel solution has been termed the 'Repoint' solution, and is described in mechanical detail, including how it satisfies the functional requirements. A scale demonstrator implementation of this solution has been constructed in a laboratory as a first step towards deployment.

5. FUTURE WORK

The design has now been taken to a concept demonstrator phase, therefore the first piece of follow-on work is to build a prototype upon a functioning railway and test - both the operation of the switch, and with the passage of traffic. Suggested, but non-exhaustive, areas of related research are as follows:

- Further modelling of the capacity improvements brought about by a Repoint installation in real-world scenarios.
- Further investigation into, and modelling of, the reliability and maintainability improvements brought about by Repoint installations, singly or across a network.
- A full, formal FTA (Fault Tree Analysis) of any proposed design.
- Investigation into wear and fatigue of the bending rails and part-section rail ends with a range of use cases.
- Investigation into other promising ideas from the concept down-selection phase, including ideas which were rejected for political or standards reasons, such as vehicle based switching.

REFERENCES

- Abril, M., Barber, F., Ingolotti, L., Salido, M.A., Tormos, P. and Lova, A., (2008). An assessment of railway capacity. *Transportation Research Part E: Logistics and Transportation Review*, 44(5), pp.774-806.
- Bemment, S.D., Dixon, R., Goodall, R. and Brown, S., (2013a). *Redundantly engineered track switching for enhanced railway nodal capacity*. In Proc. 1st IFAC ACATTA workshop. Istanbul, Turkey.
- Bemment, S., Dixon, R. and Goodall, R., (2013b). Repoint redundantly engineered points for enhanced reliability and capacity of railway track switching. In Proc. 10th

- World Congress on Railway Research (WCRR). Sydney, Australia.
- Bemment, S.D., Dixon, R., Goodall, R.M. (2015a) *Railway points*. GB Patent no. GB 2516706. Available at <https://www.ipo.gov.uk/p-ipsum.htm>
- Bemment, S.D., Dixon, R., Goodall, R.M. (2015b) *Railway points operating apparatus*. GB Patent no. GB 2516707. Available at <https://www.ipo.gov.uk/p-ipsum.htm>
- Bemment, S.D., Ebinger, E., Goodall, R.M., Ward, C.P. and Dixon, R., (2016). Rethinking rail track switches for fault tolerance and enhanced performance. Proceedings of the IMechE, Part F: *The Journal of Rail and Rapid Transit*, p.0954409716645630.
- COMSA. (2014). Cost-effective improvement of rail transport infrastructure. Deliverable 3.3: *Rail switches and crossings*. EU 7th Framework Programme.
- Hadaway H. (1950). *Principles of power point control and detection (British Practice)*. 'Green Booklet' No.5. The Institution of Railway Signal Engineers, London.
- Ebinger, E and Wright N. (2015) IN PRINT: A Model of a REPOINT Track switch for design optimisation and control. *Control Engineering Practice*; xx(xx): xx–xx.
- Eker, O.F., Camci, F., Guclu, A., Yilboga, H., Sevkli, M. and Baskan, S., (2011). A simple state-based prognostic model for railway turnout systems. *Industrial Electronics, IEEE Transactions on*, 58(5), pp.1718-1726.
- Genner, R. (1997). *Control of points*. Railway Group Standard GK/RT0062. Available at: <http://www.rssb.co.uk/railway-group-standards>
- Liu, R., Whiteing, A. and Koh, A., (2013). Challenging established rules for train control through a fault tolerance approach: applications at a classic railway junction. Proceedings of the IMechE, Part F: *Journal of Rail and Rapid Transit*, 227(6), pp.685-692.
- Morgan, J.C. (2009) *British Railway Track 7th Edition, Volume 1, Design Part 2: Switches and Crossings*. The Permanent Way Institution, Derby, UK.
- Nash, C., Coulthard, S. and Matthews, B., (2004). *Rail track charges in Great Britain—the issue of charging for capacity*. Transport Policy, 11(4), pp.315-327.
- ORR (Office of Rail Regulation) Online Data Portal (2013) *Total journey count reporting*. Available at: dataportal.orr.gov.uk. Accessed: 12th October 2013.
- Parkinson, T. and Fisher, I., (1996). *Rail transit capacity (Vol. 13)*. Transportation Research Board.
- RSSB. (2009) *Track system requirements*. Railway Group Standard GC/RT5021 Issue 4. Available at: <http://www.rssb.co.uk/railway-group-standards>
- Silmon, J., Roberts, C., (2010). Improving switch reliability with innovative condition monitoring techniques. Proceedings of the IMechE, Part F: *The Journal of Rail and Rapid Transit*; 224: pp293–302.
- UIC. (2004) *Capacity*. (English Version, 1st edition). International Union of Railways (UIC), Paris, France.
- Wright, N., Bemment, S.D., Ward, C.P., Dixon, R. and Goodall, R.M., 2014. The performance and control requirements of a REPOINT track switch.