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In2Rail

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Deliverable D2.5

Radical S&C concept: Design concept evaluation study report [TRL2]

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Review Comments

Following the In2Rail midterm review on Tuesday 28th February 2017, this deliverable was requested for revision by the European Commission in the assessment report #Ref. Ares(2017)1734456 - 31/03/2017, In2Rail can confirm that the review comments have been duly considered and this modified report contains revisions to address these specific points.

The below table provides an index to Sections of the revised document that contain the responses to the review comments.

Revision Requested from EC	Revision in document
Ideas most technically feasible should be focused on. It is worth noting that Ch.4 shows an in depth, very specific and well documented and developed dynamic analysis of wheel-rail interactions and principle of guidance at the critical S&C elements, with significant research shown into those concepts, potentially leading to areas of research for the improvement of running behaviours and reduction of contact forces and wear-maintenance. These could be useful and promising areas be focused on for the introduction of innovation ideas.	Section 8.2 describes the pre-assessment process and the final results. All of the ideas were scored in line with the selection criteria using engineering expertise from across the In2Rail WP2 partners. The task-group will further focus on the concepts with high potential and good technical feasibility.
The two shortlisted ideas run the risk of being of very difficult application or not going significantly beyond the state of the art. Should be further elaborated.	The idea of radical concepts is that they are going significantly beyond the state of the art which could mean that there is a risk of difficult application. It is one aim of task 2.3 to localise and describe this risk which will also form part of D2.6.
Ideas selection criteria should be included. The ideas selection and shortlisting process should follow a typical staged feasibility analysis process, with clearly documented methodology.	Section 8.2 now includes the selection criteria. The concepts being taken forward subsequent to this deliverable will undergo a full feasibility study before recommendations to Shift2Rail are made within D2.6.
System integrity needs to be covered.	The system integrity is covered by the selection criteria in section 8.2.
LCC analysis should be added.	A full LCC analysis will be completed during D2.6 in order to make recommendations to Shift2Rail. Further, detailed analysis of the chosen ideas / concepts is necessary to inform the LCC analysis.

Consider collaboration and cross over with the ongoing project S-CODE, in order to avoid duplication of similar works but also to allow the development of new concepts and ideas.	The ongoing S-CODE project was presented, and collaboration with work on D2.6 is taken into account.

Executive Summary

Efficient operation of the railway network is heavily reliant upon the ability to move vehicles from one route to another. Railway switches and crossings (S&C) provide this flexibility through use of moving switch rails and designed 'gaps' within crossing geometries to allow wheel flanges to cross through adjacent rails. S&C designs have evolved over many years but remain fundamentally unchanged with regards to the mechanism of wheel guidance and load transfer.

The overall objective of Task 2.3 is to develop ideas and evaluate concepts for new ways of moving trains from one track to another whilst also improving the RAMS performance and reducing LCC of the S&C system. This deliverable therefore aims to explore alternative, radical solutions to guiding vehicles from one line to another whilst putting aside constraints associated with the existing S&C system (i.e. whole-system design from first principles).

The key objectives of this deliverable document are therefore to present the early stages of the development process, including:

- description of fundamental vehicle guidance principles and associated existing issues;
- a high-level system specification to provide clear boundaries of development;
- radical / novel S&C idea generation and process adopted;
- initial assessment, evaluation and filtering of those ideas;
- initial concept development of selected ideas that presented immediate potential of offering a high value solution.

Chapter 4 discussed the consequences of wheel/rail interaction and associated issues. A key set of fundamental requirements have been established, which includes the assessment of derailment risk, passenger comfort, impact loads, track shifting forces, component fatigue, contact energy for resistance against degradation, wheel/rail contact pressures and peak pressure imparted into the ballast or other supporting track layers.

Following the study of fundamental principles and by extracting knowledge and experience from European Railway Infrastructure Managers, an agreed set for high-level functional and non-functional system requirements have been developed within Chapter 5. These are purposely high-level in order to encourage innovation and creativity and include design and build, safety approval, maintenance, modularity, construction, logistics, environmental and whole-life cost considerations.

A range of alternative S&C ideas have been established through using of a structured idea generation process termed 'OptiKrea'. This process is described in detail within Chapter 6 whilst the outcome is presented within Chapter 7. Three categories of idea have emerged from the OptiKrea workshop:

1. Incremental Design Changes (Existing system modifications to eliminate / reduce common failure modes)
2. Radical Re-design of the S&C System (Totally different mechanism for vehicle guidance)
3. Enabling Technologies (Technology, materials and manufacturing techniques to bring radical solutions to reality)

From these Initial ideas, two concepts emerged that were considered worthy of immediate development in parallel to scoring and ranking of all ideas. One concept focuses on the infrastructure and the removal of the failure prone switch blade, whilst the other adopts a whole system approach and discusses the principles of mechatronic vehicle and the benefits that may be brought to track switching assets.

To ensure that the best value for money is achieved within In2Rail, a structured evaluation process has been established to identify a ranked list of ideas suitable for further conceptual design work. The value analysis process is described within Chapter 8, which is being implemented at the time of writing this deliverable.

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Abbreviations and acronyms

Abbreviation / Acronyms	Description
AEG	Allgemeines Eisenbahngesetz – general railway act
AIRW	Actuated Independently Rotating Wheelset
ASW	Actuated Solid Wheelset
C4R	Capacity4Rail
Capacity4Rail	Increasing Capacity for Rail Networks
CATFERSAN	System name assigned to the modification of the straight stock rail geometry to improve wheel/rail interface
CEN	Comité Européen de Normalisation
CSM	Common Safety Method
CV	UK Switch Size C – Vertical Switch Rails
D	Deliverable
DIRW	Driven Independently Rotating Wheelset
DMU	Diesel Multiple Unit
DoW	Description of work
EBO	Eisenbahn- Bau- und Betriebsordnung – railway construction and operation ordinance
EU	European Union
FAKOP®	Kinematic gauge optimization system for the transition area of a set of switches and movable crossings (frogs).
FBS	Flange-Back Switching
GA	Grant Agreement
GENSYS	Multi-Body Simulation Software
In2Rail	Innovative Intelligent Rail
INNOTRACK	Investigation was about improving present S&C-constructions by optimisation.
KGO	Kinematic Gauge Optimisation
LCC	Life Cycle Cost
MBS	Multi-Body Simulation
MP	Mathematical Intersection Point
NR60	Network Rail Switch Design
OptiKrea	Idea Generation Process
P1	Wheel Profile Type 1
P2	Wheel Profile Type 2
P8	Wheel Profile Type 8
RAMS	Reliability, Availability, Maintainability and Safety
RCF	Rolling Contact Fatigue
RIVAS	Railway Induced Vibration Abatement Solutions
RP	Real Point or Physical Tip of the Switch

Abbreviation / Acronyms	Description
RTRI	Railway Technical Research institute
S&C	Switches & Crossings
S1002	Wheel Profile Type ORE S1002
SIMPACK	Multi-Body Simulation Software
SUSTRAIL	Optimised track and substrate design and component selection to increase sustainable freight traffic as part of mixed traffic operations.
SYC	Secondary Yaw Control
TCP	Theoretical Crossing Point
TRL	Technology Readiness Level
TSI's	Technical Specifications for Interoperability
UIC	International Union of Railways
UIC 716 R	International Union of Railways standard for Maximum Permissible Wear Profiles for Switches
UK	United Kingdom
USP	Under-Sleeper Pad
WITEC	Deutsche Bahn switch type with thicker switch rail
WP	Work Package
WR	Wheel/Rail

1 Background

The present document constitutes the second issue of Deliverable D2.5 “Radical S&C concept: Design concept evaluation study” in the framework of the Project titled “Innovative Intelligent Rail” (Project Acronym: In2Rail; Grant Agreement No 635900).

Almost every modern form of mechanised transport has its steering controlled on board, by a driver or automatic system: in the air, at sea, or on land. There are few equivalents to the railway’s rigidly guided way, with the low rolling resistance of steel wheels on steel rails giving an energy efficiency advantage.

However, in order to allow multiple rail vehicles to share resources at key locations, such as platforms, depots and stabling, as well as share the track between those locations, it is necessary to provide the capability to move, or switch, vehicles between tracks.

Switching, at present, is a purely mechanical concept where the rails move to form a fixed configuration depending on the intended change of direction of the vehicle. The switch rails must mate perfectly with the stock rails while withstanding high impact forces from the vehicle.

A critical examination of designed layout and wheel -rail contact conditions within S&C units reveal that these units are a discontinuity that disrupts the smooth running of the vehicle even under near idealised geometries. The very act of switching direction of the train, particularly at higher speeds, results in higher dynamic forces in both the vertical and lateral directions as demonstrated in Section 4.

This means that the weakest elements of the track are exposed to the highest loads, which makes S&C responsible for a significant and disproportionally high proportion of infrastructure failures.

When these facts are combined with the steady evolution of the switch and crossing concept over at least the last 150 years and ever increasing levels of rail traffic, it becomes apparent that a step change approach to the concept of vehicle switching is required.

2 Objective

The overall objective of In2Rail WP2 is to create solutions for a radical redesign of the S&C system and deliver improvements to the existing S&C system, whilst embracing state-of-the-art technologies.

The focus of Task 2.3 is to focus on the longer-term, next generation solution for S&C by going right back to the fundamental principles of vehicle guidance, discounting existing constraints of the existing system and re-designing the whole system from a set of fundamental system requirements.

The goal of Task 2.3 is therefore to:

"Develop ideas and evaluate concepts for new ways of moving trains from one track to another. This should be achieved whilst also improving the RAMS performance and reducing LCC of the S&C system"

The key objectives of this document (Deliverable D2.5) are therefore to present the early stages of the development process, including:

- description of fundamental vehicle guidance principles and associated existing issues;
- a high-level system specification to provide clear boundaries of development;
- radical / novel S&C idea generation and process adopted;
- initial assessment, evaluation and filtering of those ideas;
- initial concept development of selected ideas that presented immediate potential of offering a high value solution.

3 Scope of Work

3.1 Task Scope

In2Rail Task 2.3 aims to produce radical concepts for how best to move trains between tracks. All ideas will be considered, at least at an initial level, in order to encourage as much creativity and unbounded thinking as possible. The only caveat to this is ideas that vary the operation of the railway such that the necessity to move trains between tracks is redundant. It is determined that although this seems an ideal solution to the problem it also removes all the benefits of being able to move between tracks and is likely to detract from the focus on delivering concepts for an enhanced alternative to the current switch and crossing solution.

Task 2.3 aims to deliver as many concepts as possible to TRL 3, such that Shift2Rail may consider and develop any workable solutions.

3.2 Deliverable Scope

This first deliverable in Task 2.3 will present some initial thoughts on concepts that show the most potential to offer a high value solution to the problem. This includes proposed areas that the Task should continue to work in for the rest of the project.

Detailed project plans and proposals are not within the scope of this deliverable.

4 Wheelset Guidance - Fundamental Principles

To set some defined boundaries to the radical redesign of railway switches and crossings (S&C), understanding the fundamental principles of railway vehicle wheelset guidance is essential. These parameters are those that should be considered universal across all generated concepts (*i.e.* we assume to always maintain a steel wheel running on a steel rail, although the metallurgy and wheel/rail profiles are indeed open to scrutiny).

A thorough understanding of the physical principles of vehicle guidance is essential to open up the door for whole S&C system redesign and optimisation. These then become the starting point for designing a system suitable for its intended purpose of moving a train from one track to another in a safe, reliable, efficient and affordable manner. The optimal solution should also be considered from a whole system perspective, of which the vehicle forms a very important part. To reduce and / or eliminate existing system failure modes and degradation, wheel/rail interaction must be understood.

Chapter 4 discusses the fundamental principles of vehicle guidance and highlights some of the existing issues associated with them.

4.1 Equivalent conicity and steering

Deliverable D2.1 section 7.2.1 provides illustrations and equations explaining the fundamental motion of a railway wheelset on a railway track. Because of the wheel conical shape, the left and right wheels run on different rolling radius (Figure 4.1) and as the rigid axle moves laterally (y-displacement), the outermost wheel runs on a larger radius than the innermost wheel so that it travels the furthest as the axle rolls along the track. This introduces a steering of the axle which then tends to move the axle back towards the track centreline. Because of the axle inertia it overshoots the centreline and a lateral offset appears on the opposite direction so that a kinematic oscillation called Klingel wave ensues (Figure 4.2).

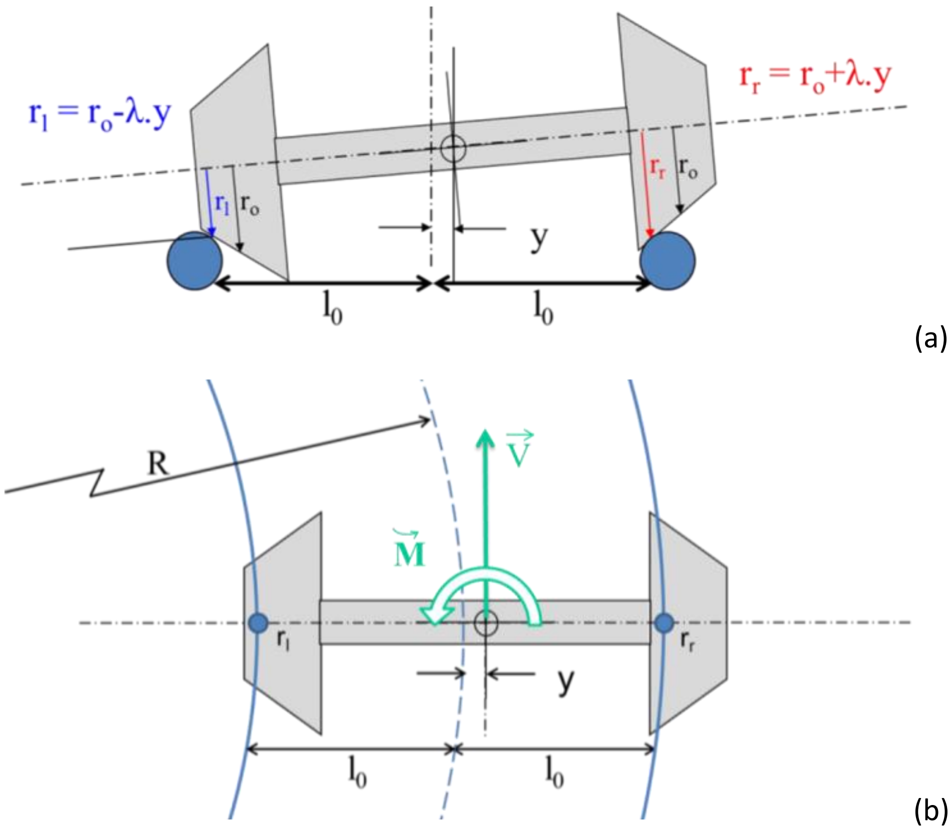


Figure 4.1: Wheelset showing rolling radius difference with lateral offset (y) - front view (a) and top view (b)

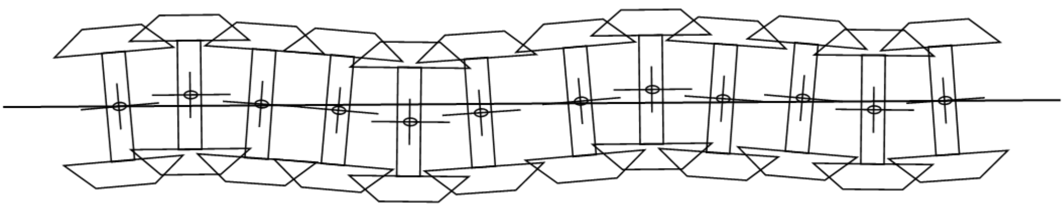


Figure 4.2: Wheelset kinematic motion characterised by Klingel equation

$$L = 2\pi.\sqrt{\frac{r_0.l_0}{\lambda}} \quad (1)$$

This characteristic of the wheelset kinematic motion brings about two fundamental aspects:

- the axle motion is fundamentally unstable above a certain limit speed, which is controlled by appropriate vehicle suspension design and by limiting the equivalent conicity in track (maintenance of rail shape through grinding and periodic re-profiling of wheels through turning);
- wheel conicity is used as the fundamental concept to steer axle through curves. The higher the conicity the easier the axle steers through a curve, as it can develop higher rolling radius difference and therefore steering moment. A railway vehicle therefore passively steers through curves as there exists a natural lateral offset equilibrium position in any curve for which the axle is in pure rolling. In practice the suspension constrains the axle free movement so that an angle of attack develops along with creep forces in the wheel-rail contact.

Because the wheel shape is in effect not purely conical but wears to a non-linear shape, the range of wheelset motion is rather less predictable and tends to oscillate around the centred position within a few millimetres either side, under the action of small perturbation (e.g. track lateral irregularities). Beyond that, high rolling radius and contact angle are generated towards wheel flange contact, which usually appears in the range +/- 7~8mm. This acts as a safety mechanism to prevent derailment and maintain wheels within the track at all times, while imposing large lateral force component on the track.

Assuming an equivalent conicity calculation, the axle lateral offset equilibrium position can be calculated (equation 2) for a certain curve radius. Table 4.1 shows those results for a range of curves representing the range of turnout designs used in the EU (from 6km high speed to 190m slow speed), highlighting necessary lateral offsets which are within the wheel-rail flange clearance ✓, those approaching flange contact ! and those beyond ✗.

$$y = \frac{r_0 . l_0}{\lambda . R} \quad (2)$$

lateral offset y(mm)		Radius (m)						
Conicity	λ	6000	2500	1200	760	500	300	190
very low	0.02	✓3.1	!7.5	✗15.6	✗24.7	✗37.5	✗62.5	✗98.7
low	0.05	✓1.3	✓3.0	!6.3	✗9.9	✗15.0	✗25.0	✗39.5
medium	0.2	✓0.3	✓0.8	✓1.6	✓2.5	✓3.8	!6.3	✗9.9
high	0.4	✓0.2	✓0.4	✓0.8	✓1.2	✓1.9	✓3.1	✓4.9
very high	0.6	✓0.1	✓0.3	✓0.5	✓0.8	✓1.3	✓2.1	✓3.3

Table 4.1: Calculation of wheelset theoretical offset equilibrium position for a range of equivalent conicity and curve radii. Highlighted low and medium conicity are expected design values for typical wheel-rail pairs

From the simple calculation above one can see that high speed turnout negotiation are in principle not a problem, however one might expect low conicity wheels to poorly steer into turnouts with radius as high as 1200-760m which are typical of mixed regional routes and heavy traffic (both volumes and speeds). Short turnout (<300m) can be an issue even for medium conicity wheels. In practice the rolling radius difference rapidly develop as the wheel moves towards the flange, thus reducing the offset calculated here, however the axle also has to fight against the primary suspension stiffness in order to generate the required steering.

4.1.1. Steering through curves – single axle calculation

Using actual wheel and rail profiles (S1002-60E1), further simulations of a single axle (including primary yaw stiffness) running into the curves above at maximum turnout permissible speed show that the lateral force applied onto the high rail increases with tightening radius. From 500m and below the axle reaches saturation in terms of available flangeway clearance (i.e. reaching flange contact), so that its angle of attack builds up rapidly alongside the lateral force necessary to maintain the axle along the direction of the curve.

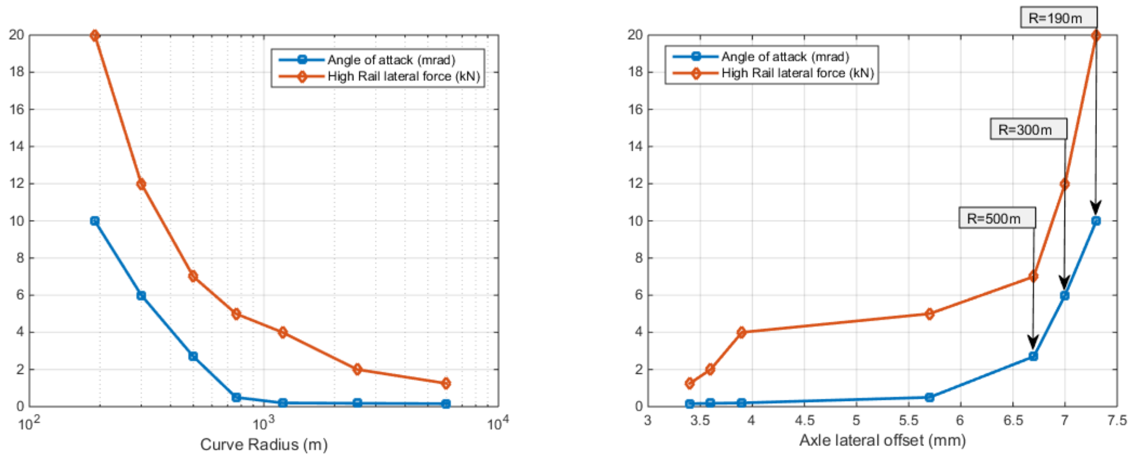


Figure 4.3: Single axle angle of attack and high rail lateral force as a function of curve radius (left) and axle lateral displacement (right)

So far it can therefore be concluded that assuming current wheel and rail profiles with rigid axles, and their tight clearances (flangeway), extreme quasi-static contact conditions (high lateral offset, angle of attack and lateral forces) are necessary to steer a vehicle through turnout curves in the range 500m and below. That is before any non-linearity is introduced, such as varying rail shape in switch and crossing panel, introducing further complexity and dynamic wheel-rail interaction.

In practice there is a tendency to increase gauge in tight curves and to some extent in short turnouts (e.g. from 1432 to 1435mm in the UK and to 1437mm in Sweden) to facilitate curving. This in effect helps increase the rolling radius difference but only marginally. There is effectively a limit on the reduction of rolling radius gained on the low rail. The primary purpose of gauge widening is in fact avoiding 'trapping' of the short wheelbase bogies. The counter effect of this is that allowing more flangeway clearance enables the bogie to rotate more and therefore introduces further angle of attack and lateral steering forces at the leading axle.

The only effective way of reducing lateral forces in short turnout from a radical design point of view is to introduce some sort of self-steering ability of the vehicle; this topic is explored in more detail in Section 9.2. A track based system would need to adopt different strategy for leading and trailing axle and would therefore bring additional complexity. All in all, curving rules in short turnouts are highly compromised with current railway vehicle technology (passively steered rigid axles) and the restraints (e.g. sleepers) on the independent positioning of each rail. The radical design of S&C should take these aspects into account in the design process and where possible, define geometries (layout/gauge) and shapes/dimensions for the supporting rail that improve the status quo on steer-ability of axles and help reduce the rate of wear and rolling contact fatigue damage.

4.1.2. Non-transitioned curving - vehicle dynamics and wheel-rail forces

A full vehicle (UK multiple unit[1]) multibody system model (Figure 4.4 built in VI-Rail ® software) is here used to illustrate further the dynamic behaviour in non-transitioned curves representative of EU turnouts radii (c.f. Table 4.1). Both the dynamic response in entering the curve as well as steady state curving condition are presented. Natural turnout curves are simulated (i.e. no tangential offset) which is the most favourable design.

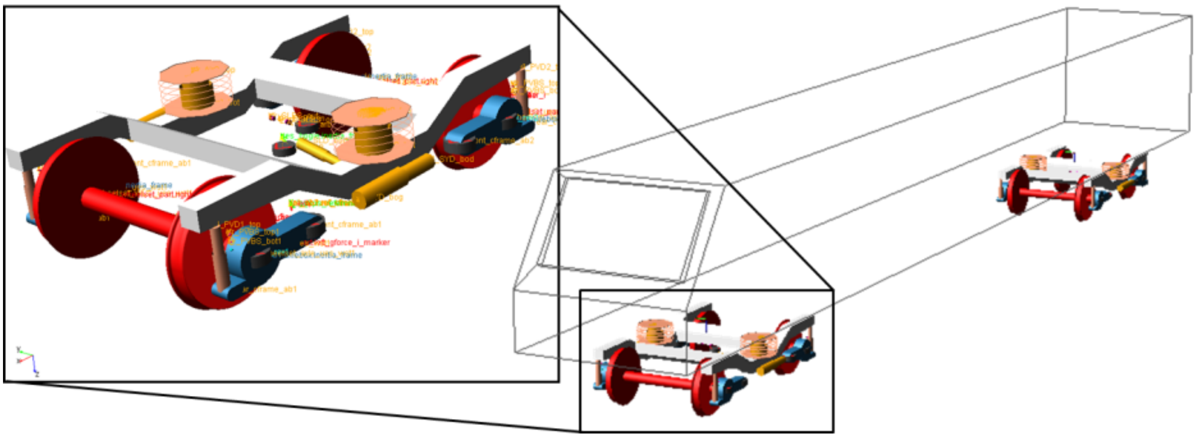


Figure 4.4: UK multiple Unit model (DMU170) used for simulations

Figure 4.5 shows the lateral displacement and angle of attack of the leading and trailing axles of the front bogie (assuming the rear one behaves similarly). As shown before the lateral displacement saturates from R≤500m and the angle of attack then builds up. The movement of the axle starts as soon as the axle enters the curve and builds up very suddenly. This translates into significant acceleration in the car body as shown in Figure 4.6 which is maintained to similar level because of the limit speed in each turnout curve (roughly equivalent to 100mm of cant deficiency in all cases). One important aspect is that the leading and trailing wheelset behave differently and therefore generate different type of effort onto the track and the rails.

[1] Wheel = UK P8, Rail = CEN56 vertical; Gauge = 1435mm, coefficient of friction = 0.35

Figure 4.7 shows the high and low rail forces at leading and trailing axles a function of the turnout case, while Figure 4.8 shows the same results as a function of the wheelset lateral offset. Here again the exponential increase in high (and low) rail lateral force is visible as the radius tightens. Note that the leading axle tends to spread the rails apart as it builds angle of attack and the trailing axle generates track shifting force which is highest in the range 1200m to 500m. It is also important to note that the forces shown here are rather low with respect to those generated from locomotives and freight vehicles with poor steering abilities and generally poorer maintenance states (including wheel shapes).

Associated damage mechanisms are discussed in the following section.

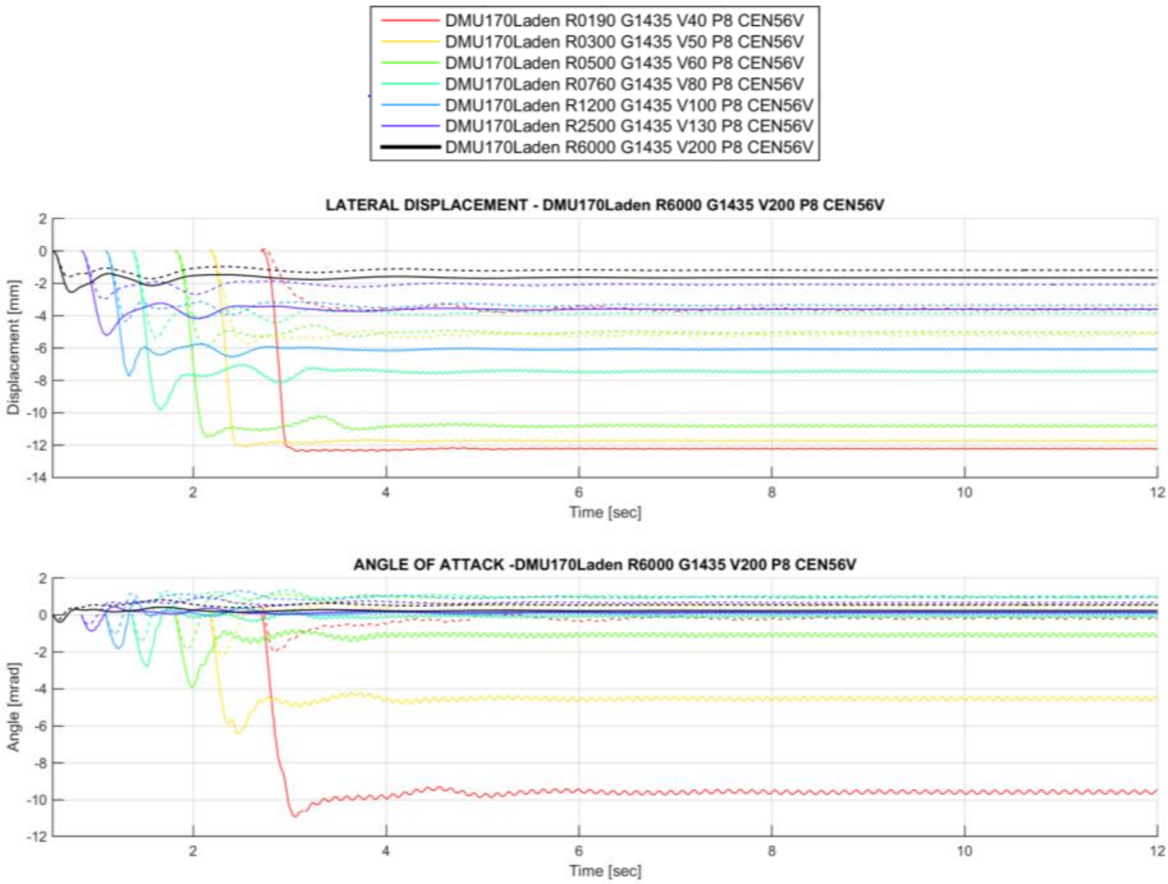


Figure 4.5: Axle lateral displacement (top) and angle of attack (bottom) for leading (solid line) and trailing (dash line) axles of the front bogie

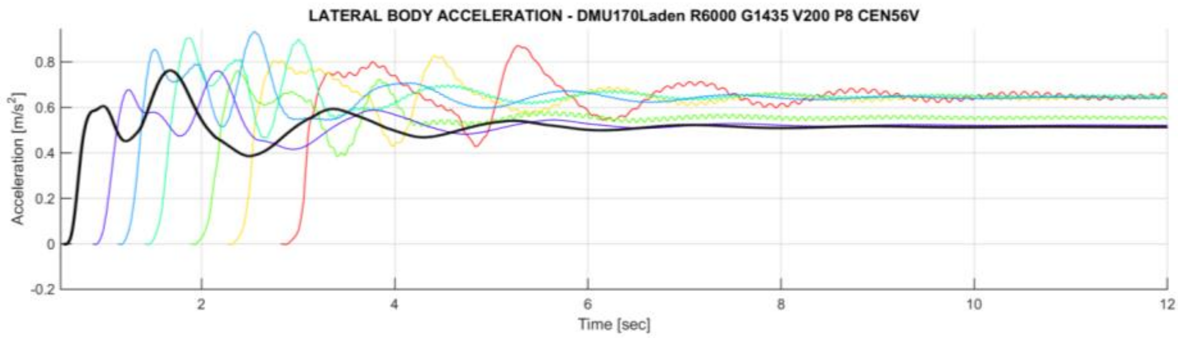


Figure 4.6: Car body lateral acceleration above front bogie centre pivot

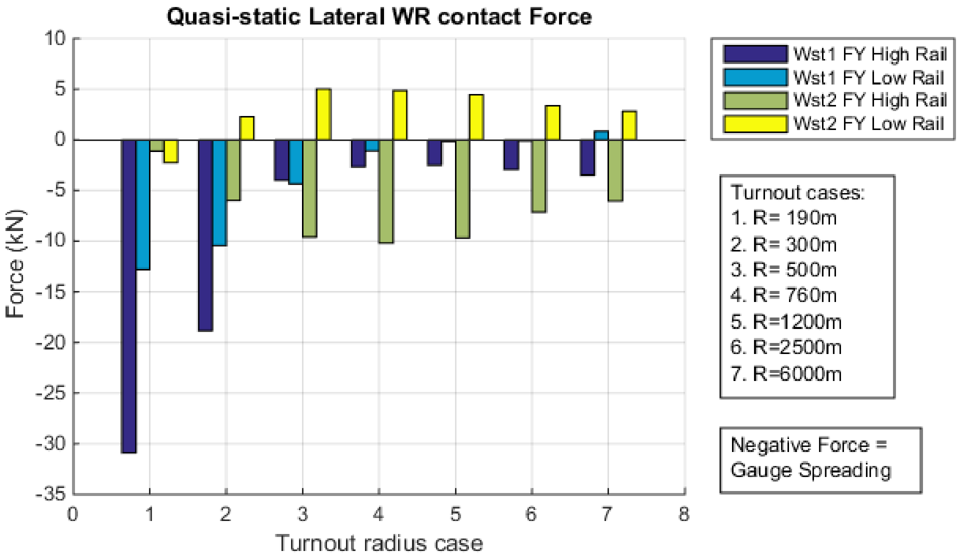


Figure 4.7: Quasi-static curving forces in typical turnout radius curves

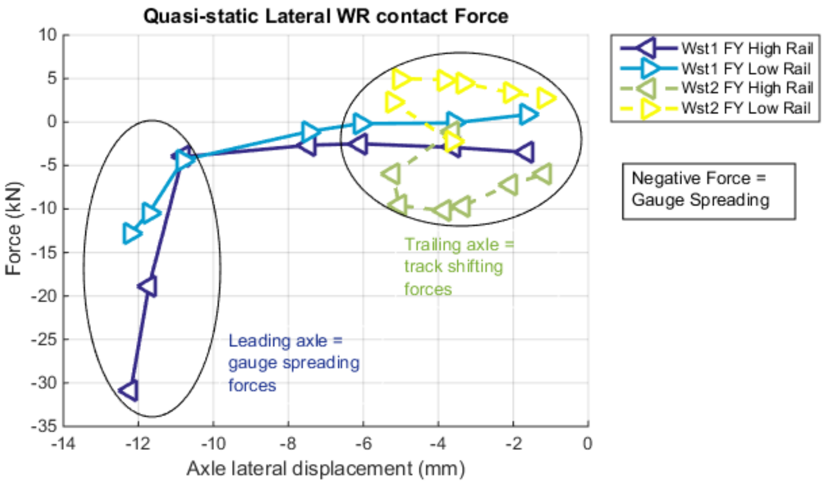


Figure 4.8: Quasi-static curving forces and axle lateral offset in typical turnout radius curves

4.2 Wheelset Interaction Kinematics at Switch Panels

A set of nominal composite rail profiles representing the switch and stock rails in the switch panel is shown in Figure 4.9. Due to the discontinuity at the separation between the deviating stock rail and the straight switch rail as seen in the figure, the rolling radius difference (r-r difference) curve is non-smooth in some areas. This can be observed in Figure 4.10, which shows the rolling radius difference in a contour plot as a function of wheelset position from the front of the turnout and lateral wheelset displacement Δy. The figure is based on the rail geometry in Figure 4.9 with an added nominal rail profile on the opposite side. Before the calculation of rolling radius difference, all cross-sections were positioned to achieve nominal track gauge (lateral rail spacing) for the switch panel. The wheel profile used is a nominal S1002 wheel profile and the rolling radius difference characteristics were calculated using GENSYS (Persson 2015). Note that only lateral wheelset movement towards the switch rail is considered here, but that Figure 4.10 is applicable for traffic in both the through and diverging routes.

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

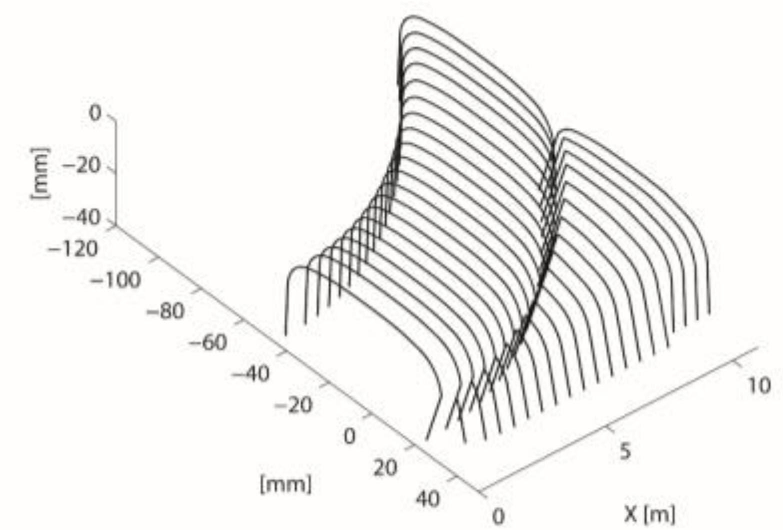


Figure 4.9: Nominal switch rail sections where X is the distance from the front of the turnout

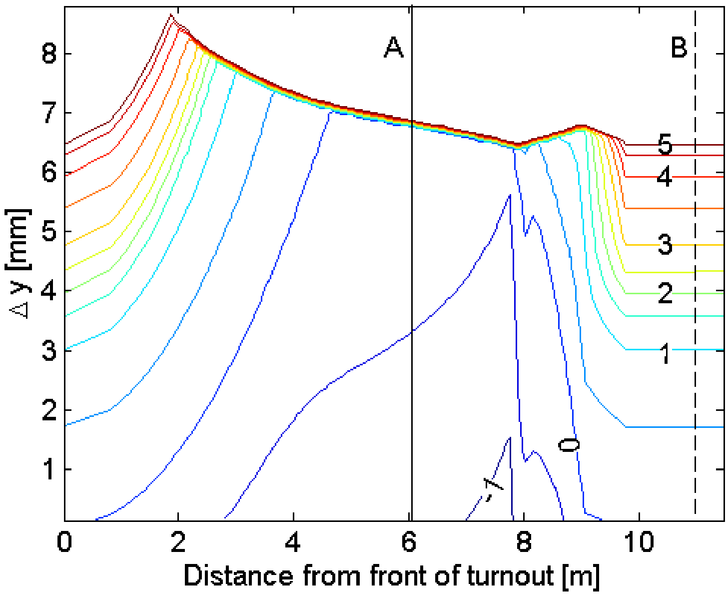


Figure 4.10: Contour plot of rolling radius difference [mm] as a function of lateral wheelset displacement towards the switch rail and position from the front of the turnout. The plot is based on the rail geometry in Figure 4.9 and a nominal S1002 wheel profile

The difference in rolling radius difference characteristics between sections can be studied in more detail in Figure 4.11. Here the rolling radius difference for the two cross-sections A and B in Figure 4.10 are plotted. It can be noted that the rolling radius difference characteristics at cross-section B, where there is a nominal 60E1 profile, is smooth and progressive and goes to zero for zero wheelset lateral displacement. This indicates that the rolling radius difference characteristics are symmetrical as can be expected when the rail profiles are the same on both sides as in Table 4.1. At cross-section A, however, there is a rolling radius difference at $\Delta y = 0$ indicating an asymmetrical rail configuration. Then there is a small linear increase until the wheel flange makes contact with the switch rail leading to an abrupt increase in rolling radius difference. As this situation corresponds to flange climbing, it will typically not appear during normal negotiation of a switch. Instead the wheel will be subjected to a two-point contact situation with one contact point on the switch rail and one on top of the stock rail. The asymmetric rolling radius difference characteristics in the switch panel also make the wheelset steer towards the switch rail even if the track is straight as in the through route, as there is a negative rolling radius difference towards that side due to the deviating curved stock rail.

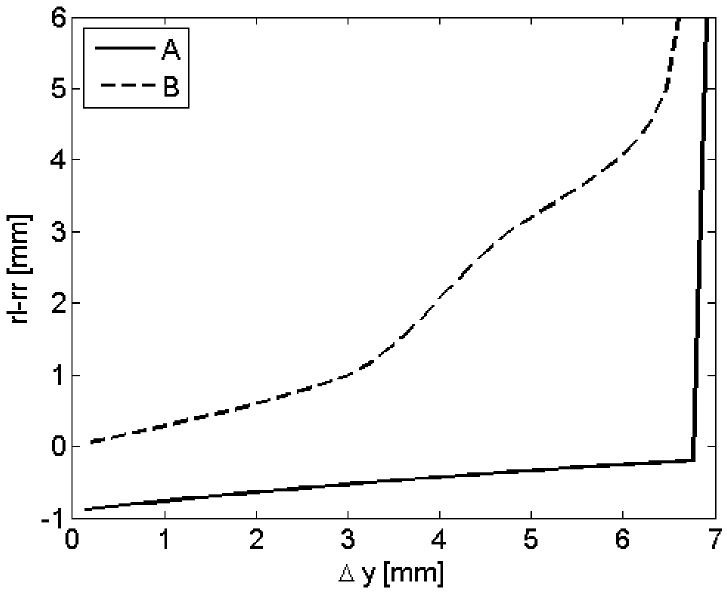


Figure 4.11: Rolling radius difference characteristics for sections A and B of Figure 4.10

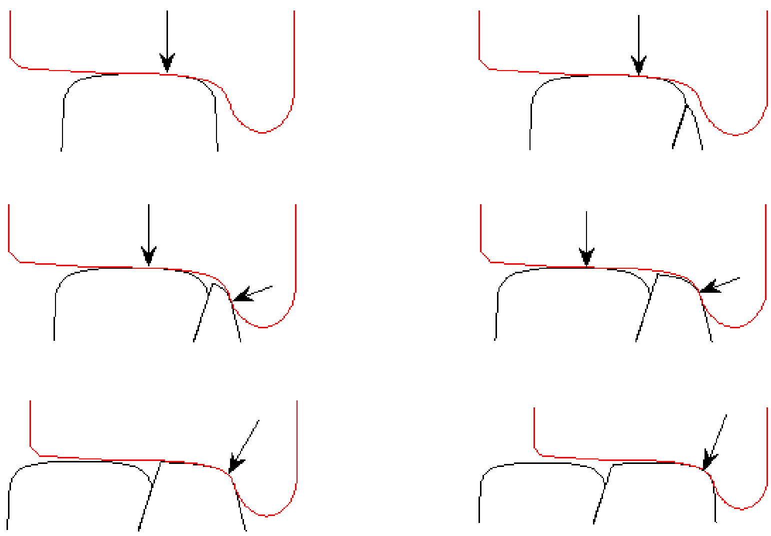


Figure 4.12: Schematic contact conditions and normal wheel–rail contact forces during a switch transition in the diverging route

A schematic presentation of the contact conditions when a wheel passes through the switch in the diverging route is presented in Figure 4.12. As the wheel is travelling on the outside rail of the turn it has to generate a lateral wheel–rail contact force. Due to the poor conicity properties related to the composite switch rail cross-sections, the wheel ends up in the above described two-point contact situation which causes poor steering, high lateral force on the switch rail and significant amounts of wear as the difference in rolling radius between the contact points induces relative motion between wheel and rail in the contact points.

4.2.1 Implications

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

4.3 Crossing panel kinematics

A fixed railway crossing constitutes another kinematic challenge in terms of the wheel–rail contact. The fact that two different rail and wheel paths intersect at one point requires that there exist flangeways which allow for the wheel flanges to pass through the crossing. Therefore the rails are split into a crossing nose and two wing rails. A top-view of a typical crossing layout is presented in Figure 4.13.

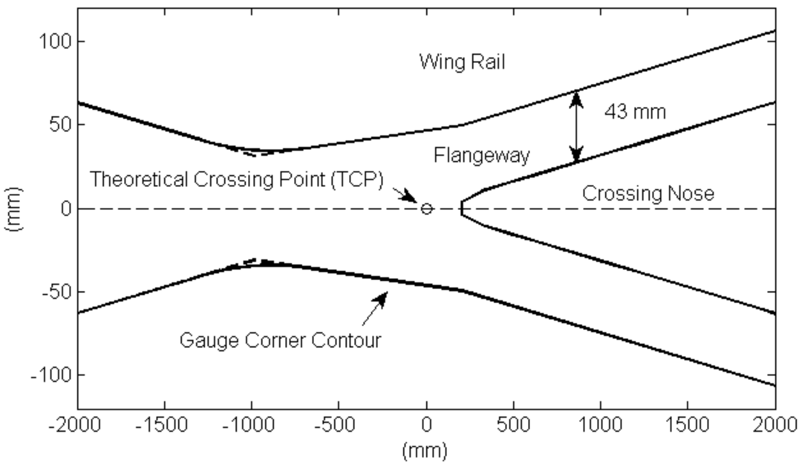


Figure 4.13: Top view of gauge corner contour at crossing

When a wheel passes over the crossing in the facing move (from the switch panel towards the crossing panel) it will first encounter the wing rail. Due to the outwards deviation of the wing rail, the wheel–rail contact point will move towards the outside of the wheel profile. For a typical conical wheel profile, the rolling radius will decrease and the wheel will move downwards unless the wing rail is elevated. The reduced rolling radius on the crossing side will induce a yawing motion of the wheelset towards the crossing. Due to the check rail, the lateral motion of the wheelset is restrained and wheel flange interference contact with the crossing nose is prevented.

When the wheel reaches and makes contact with the crossing nose, the contact load is quickly transferred from the wing rail to the crossing nose. Using eight cross-sections along the crossing, a schematic illustration of the crossing transition for a single wheel profile is illustrated in Figure 4.14. The vertical wheel positions at the different sections that form the vertical wheel trajectory are shown in Figure 4.15. For a typical conical wheel profile, the rolling radius increases as the new contact point is close to the flange root (as illustrated in row three of Figure 4.14). The two-point contact situation during the transition with contacts at different rolling radii induces relative tangential motion in the contacts that causes wear. The transition typically also results in a significant impact force on the crossing nose (or the wing rail depending on the traffic direction) as the slight downward motion of the vertical wheel trajectory is reversed and the wheel is accelerated upwards by the crossing nose.

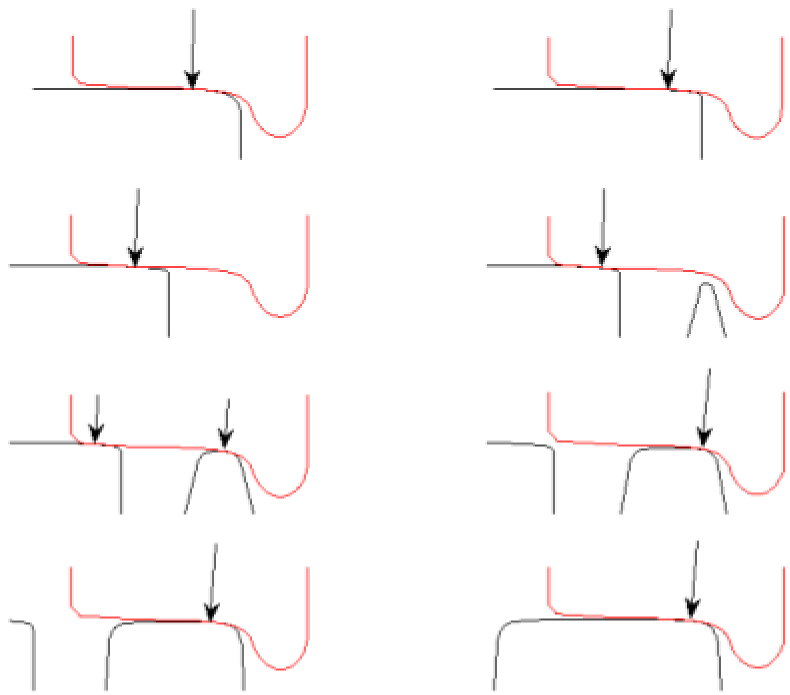


Figure 4.14: Chematic contact conditions and normal wheel–rail contact forces during a crossing transition

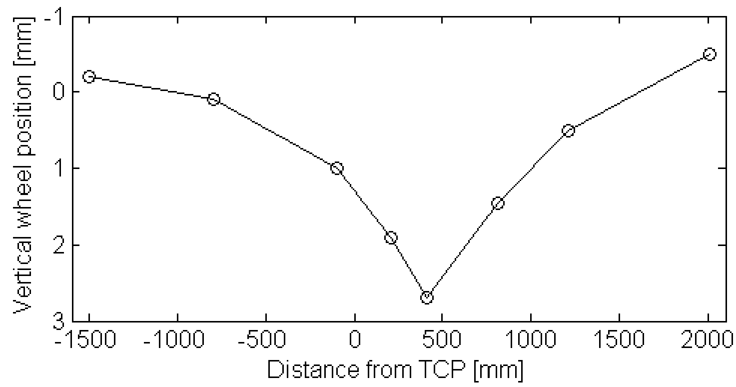


Figure 4.15: Vertical wheel trajectory, based on vertical wheel positions corresponding to the cross-sections of Figure 4.14 as a function of distance from the Theoretical Crossing Point (TCP)

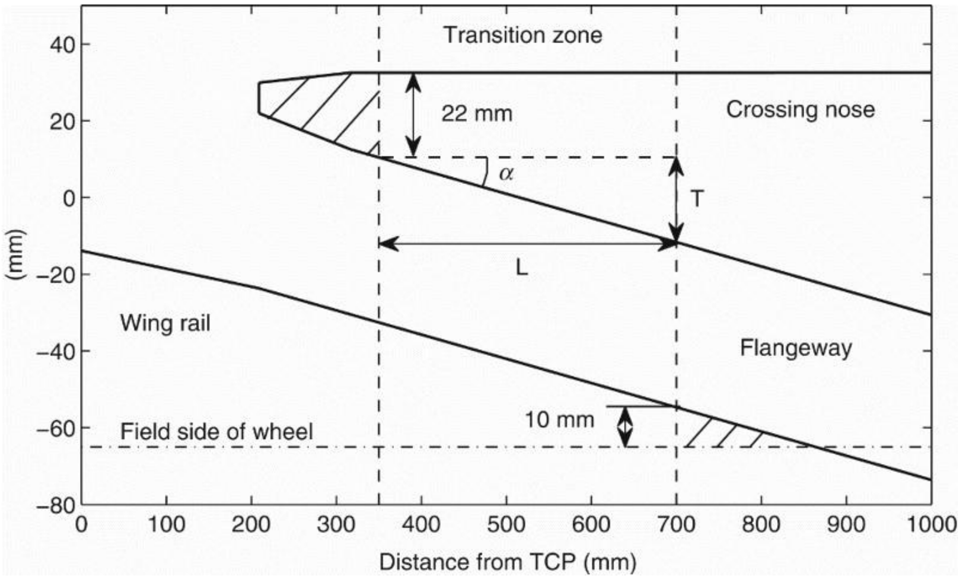


Figure 4.16: Top view of crossing geometry with crossing angle 1:15. TCP = Theoretical Crossing Point

Figure 4.16 shows a schematic cut out top view of a fixed crossing oriented along one of the traffic directions. The vertical dashed lines indicate the beginning and end of the transition zone. The length of the transition zone is denoted L and the change in crossing nose width in the transition zone is denoted T. It can be observed that T is an implicit measure of the transition zone length independent of α as L can be determined from a given T and α using the approximate tangent relation $\alpha \approx T/L$. T also describes the change in overlap between a straight running wheel and the wing rail as the flangeway has a constant width. The exact extension of the transition zone can vary, but it can be concluded that wheels should not make contact with the crossing nose where it is too thin to carry the wheel load, and they should not make contact with the wing rail where the overlap between wheel and wing rail is too small to provide satisfying contact conditions. These areas are marked with stripes in Figure 4.16. Thus, there is a given (short) distance where it is preferred that passing wheels of different shapes make their transition from wing rail to crossing nose or from crossing nose to wing rail. The transition point can be defined as the longitudinal location where a given wheel profile is in simultaneous contact with both the wing rail and the crossing nose.

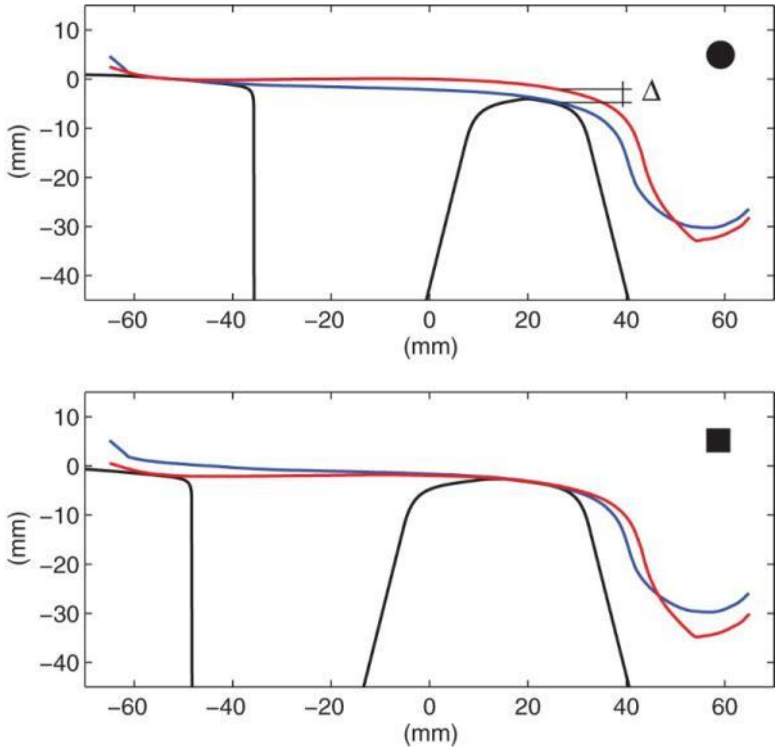


Figure 4.17: Wheel-rail contact for two different wheel profiles at two longitudinal positions in the crossing panel

Figure 4.17 (top) shows the contact situation for two wheel profiles at a given cross-section in the crossing. It can be seen that one wheel profile is in simultaneous contact with the wing rail and the crossing nose, while the other wheel profile is only in contact with the wing rail. In this situation, the first wheel profile is thus in the process of transition from wing rail to crossing nose while the second profile is only supported by the wing rail and has a distance Δ to close before it comes into contact with the crossing nose.

Figure 4.17 (bottom) shows the contact situation for the two wheel profiles at another cross-section further down the crossing. Here the second wheel profile is at its transition point, while the first wheel profile is only supported by the crossing nose. In between these two cross-sections there has been a change in rail profile shape that provides a relative change in support height of the wing rail and crossing nose. Rail profile geometry change along the crossing (transition zone) is thus necessary to accommodate wheel profiles of different shapes, and the magnitude of variation in wheel profile shapes and the length of the transition zone will stipulate the rate of change required for all transitions to take place in the transition zone.

There are however limitations to how the geometrical change can be obtained. The lateral position of the wing rail is determined by the crossing angle α (the angle between the through and diverging routes of the turnout at the crossing, see Figure 4.16) and the flangeway width. Further, the cross-sectional profiles of wing rail and crossing nose should be designed for good contact conditions between wheel and rail. Therefore the tuning of the geometrical rate of change can only be accomplished by the longitudinal height profiles (longitudinal level) of the wing rail and crossing nose. These are also suitable tuning tools as a change in the wing rail or crossing nose height along the crossing will result in a corresponding change of the vertical wheel trajectory when the wheel is in contact with the wing rail and crossing nose respectively.

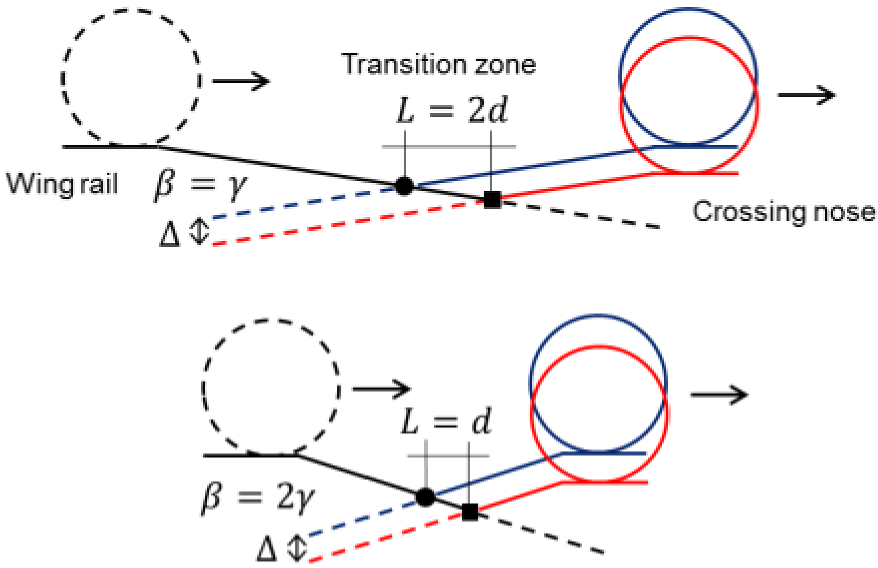


Figure 4.18: Wheel trajectories on wing rail and crossing nose for two different wheel profiles at two different transition zone lengths

The relation between scatter in wheel profile geometry and geometrical crossing properties will now be illustrated by altering the distance between the rail cross-sections of Figure 4.17. Changing the profile spacing corresponds to a change in the crossing angle. Small angles will be assumed in the following discussion such that $\tan(\alpha) \approx \alpha$. First, let the two rail cross-sections be positioned at a distance $L = 2d$ from each other, thus assuming that they represent the beginning and the end of the transition zone. Here d is a fixed but arbitrary length used for reference. The schematic vertical wheel trajectories of the two wheel profiles on the corresponding crossing can be observed in the upper part of Figure 4.18. It is here assumed that the vertical wheel trajectories are piecewise linear and that the resulting impact angle is $\beta = \gamma$ for both wheel profiles. The impact angle β is here defined as the difference in inclination between the vertical wheel trajectories of the wing rail and crossing nose around the wheel trajectory reversal at the transition from wing rail to crossing nose.

If it is assumed that both wheel profiles have the same vertical wheel position on the wing rail, the difference in vertical wheel positions after the transition to the crossing nose is Δ, corresponding to the difference in wheel profile wear depth that causes the difference in transition points as illustrated in Figure 4.17. The “circle” and “square” indicators in Figure 4.17 and Figure 4.18 link cross-section to transition point.

Now let the distance between the two rail sections be halved to become only $L = d$. The new situation can be observed in the bottom of Figure 4.18. As Δ is determined by the rail and wheel profile geometries, it will remain the same. This means that the impact angle will be doubled ($\beta = 2\gamma$) as the same vertical change in crossing geometry should be obtained in half the distance. The same qualitative change in vertical wheel trajectories could be achieved if the longitudinal inclinations of the wing rail and crossing nose were increased, corresponding to relative vertical movement between wing rail and crossing nose in Figure 4.17. The transition points would then be located at other cross-sections than those shown in Figure 4.17.

Studying Figure 4.18 in the transition zones it can be seen that:

$$\Delta = L\frac{\beta}{2} + L\frac{\beta}{2} = L\beta \qquad (3)$$

which can be written as

$$\beta = \frac{\Delta}{L} \qquad (4)$$

Furthermore it can be obtained from Figure 4.16 that:

$$\alpha = \frac{T}{L} \Leftrightarrow L = \frac{T}{\alpha} \qquad (5)$$

Inserting (5) into (4) yields

$$\beta = \frac{\Delta\alpha}{T} \qquad (6)$$

We can thus see that for a given crossing nose width change T within the transition zone, the impact angle is proportional to the spread in wheel profile geometry Δ and crossing angle α. Note that an adjustment of e.g. the crossing nose and wing rail longitudinal inclination is necessary to obtain the required β when Δ or T changes. When α is altered β automatically changes as illustrated using Figure 4.17 and Figure 4.18.

As the spread in wheel profile geometry impose constraints on crossing geometry if all wheel profiles are to perform a smooth transition from wing rail to crossing nose within the transition zone, it is claimed that the scatter in wheel profile shapes in traffic must be accounted for to perform useful optimisations of crossing geometry. If only one wheel profile shape is accounted for, Δ will be zero and it is possible to design a crossing geometry that results in a β close to zero when the wheel rolls over the crossing. The fact that the wheel profile shape will affect damage indicators for traffic in turnouts has previously been demonstrated in (Palsson & Nielsen 2012b).

As can be imagined from the contact conditions pictured in Figure 4.17, the lateral displacement of the wheel profiles will also affect the transition points. As the check rail position and tolerances will determine the range of lateral wheel displacements that are feasible during the crossing passage, it has to be accounted for in the design or optimisation of the crossing geometry.

To give further context to the above discussion, crossing designs are typically defined using a set of reference cross-sections. These sections can then be used to obtain crossings with different crossing angles by altering their spacing, just as in the above example.

4.3.1.1 Alternative derivation of average impact angle

In order to verify the relation in Equation (6), an alternative and more mathematical approach was used within I2R to derive an expression for the average impact angle of a crossing. For a simple wheel-crossing interaction model where the contact point trajectories are described using linear functions and the wheels are assumed to be conical, it was found that

$$\bar{\beta} = \alpha\delta\left(\frac{k}{T} + \frac{1}{2}\right) \qquad (7)$$

Where $\bar{\beta}$ is the average crossing impact angle, δ a range of wheel profile cone angles and k a geometry constant related to the contact positions on the crossing. The crossing angle α and the change in crossing nose width T are the same as in Equation (6). The derivation details can be found in the Appendix A.1.

Comparing Equations (6) and (7) it can be observed that they are qualitatively very similar as both δ and Δ describe the range of wheel profile shapes. There is however more detail in Equation (7) as it also includes the k-parameter. Assuming that the average distance between contact points on the crossing nose and wing rail is 80 mm, the relation between δ and Δ becomes $\Delta = 80\delta$ if δ is measured in radians. Using the parameter values $\alpha = \frac{1}{15}$, $T = $23mm and Δ=3mm, the β-value calculated from (6) becomes 8 mrad. Using the corresponding δ-value and $k = 62$ (based on contact point trajectories presented in Appendix A.1), the $\bar{\beta}$-value calculated from Equation (7) becomes 8.7 mrad. For realistic values of the input parameters there is thus a very small difference in result between Equations (6) and (7).

4.3.2 Implications

The main implication of the derived expressions for the crossing impact angle is that there is a direct relation between the range of wheel profile shapes that are to pass over a crossing and the required dip or impact angle. Good knowledge of the range of wheel profile shapes in traffic is therefore required in order to optimise crossing geometries.

4.4. Current S&C Design Deficiencies

In addition to the fundamental wheelset steering behaviour and the imposed wheel-rail contact forces described thus far, current turnout design add more complications and unfavourable conditions. These result in speed, ride comfort, maintenance, availability and cost issues.

4.4.1. Vertical rail designs

In the UK as well as in the rest of Europe, rails are often installed vertically in a turnout. Twist rails are applied a distance away from the entry of the turnout so that the rail changes from its intended inclination (e.g. 1:20 to 1:40) to vertical over a short distance. This makes the design and installation of the turnout components and fixings more straightforward. However, this has an impact on the steering of the axle as explained previously, as well as potentially changing the contact location and increasing stresses in both wheel and rail. For CEN60 rail and S1002 wheel this does not adversely affect the contact condition, however for CEN56 rail with UK P8 passenger wheel (Figure 4.19), it concentrates the contact band in the gauge corner area, thus increasing the risk for head check to develop. With wear and change in profile this will change but as a starting point, this is not a desired design choice.

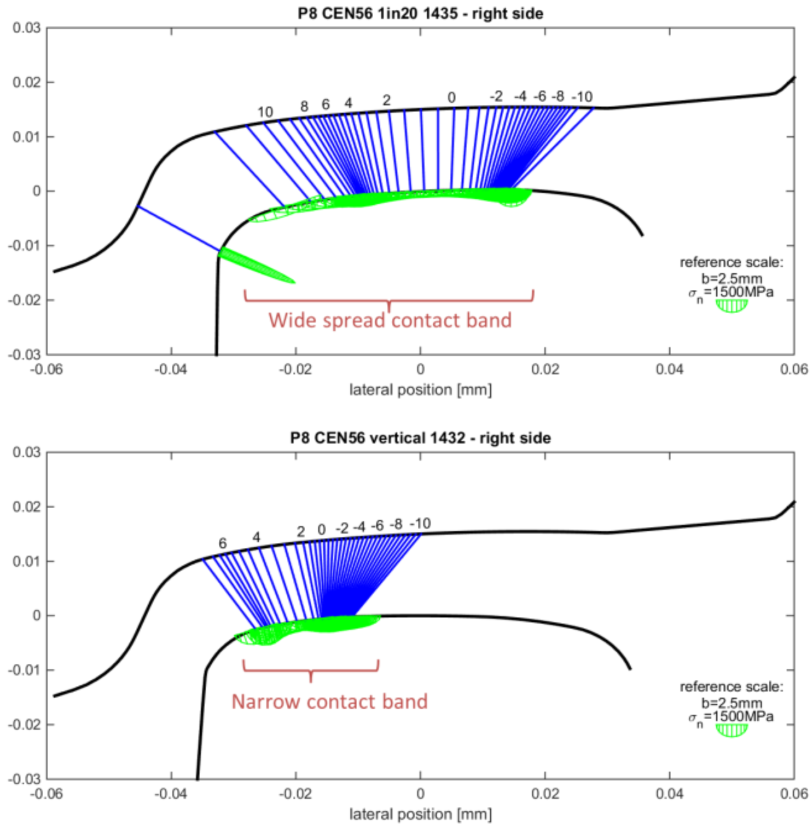


Figure 4.19: contact lines and Hertzian semi-elliptical contact stress for CEN56 rail and UK P8 wheel with inclination 1 in 20 (top) and vertical (bottom) for a range of axle lateral displacement

4.4.2. Switch-Stock rails dynamic effect in diverging route

The switch panel kinematic has already been presented in detail in D2.1 section 7.2.2, illustrating contact conditions in key cross-section of the stock-switch rail pair. Here the results of such contact conditions in terms of rail damage are presented, highlighting the need to improve the kinematic in this area in order to preserve the rails. The results presented here have been prepared as a benchmark against which any new innovative design can be compared. The process and quantities evaluated are explained below in relation to the system performance, and assessment criteria are listed in 4.4.4, 5.3, 6 and 8.2.1.

Simulations include the same vehicle model used previously with a range of 7 wheel profiles with different levels of wear from new P8 (black) to end of life. The turnout is a UK CEN56 vertical C type (R=246m) with a maximum turnout speed of 40km/h. Wheel-rail coefficient of friction is 0.35. Rail shape is as designed.

Figure 4.20 shows the time history for the lateral forces on both high and low rails. As observed before the leading axle pushes both rails outwards (negative force = gauge spreading), while the trailing axle generates low forces. The rise in force is sudden and coincides with the leading axle reaching its maximum lateral displacement and double point contact occurring (flange contact with high lateral component force). In this particular case there are further dynamic oscillations occurring just before 35m when the second axle is moved into contact with the switch rails and this results in a change of contact for the leading axle (bogie realignment).

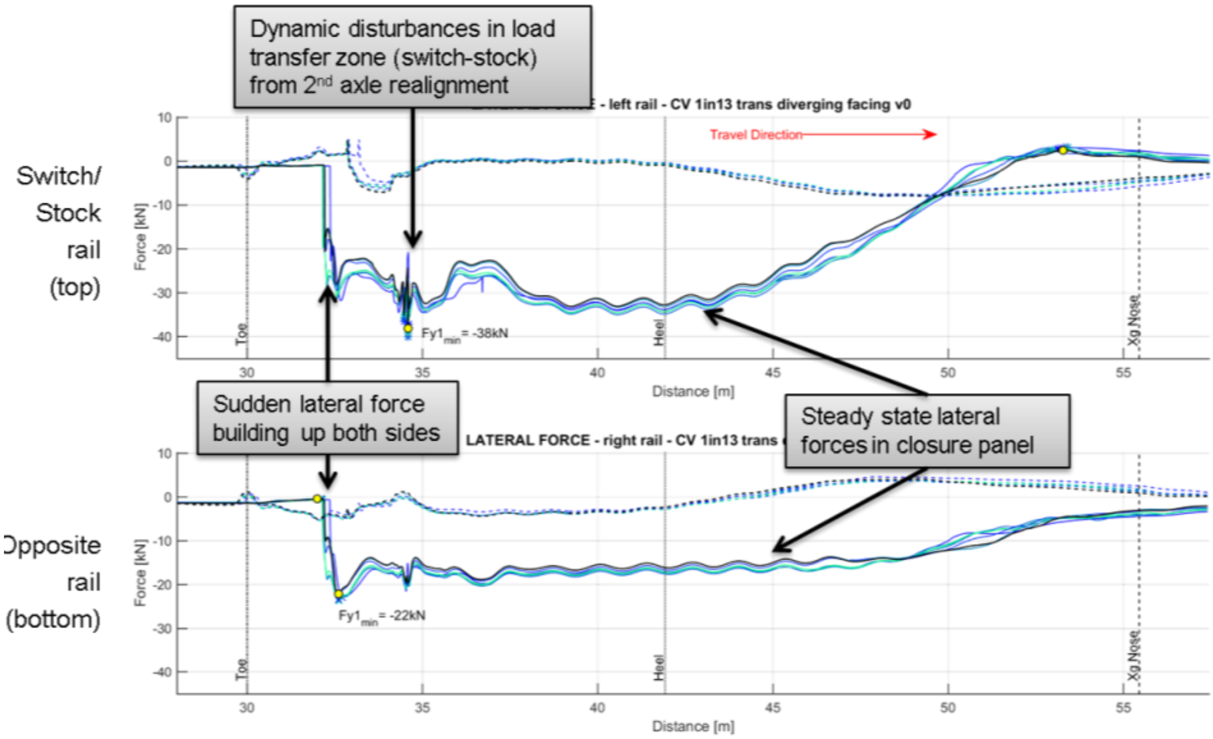


Figure 4.20: Lateral forces on high rail (top) and low rail (bottom) in CEN56V C type turnout for leading (solid line) and trailing axles (dash line)

The change in contact conditions in the transition area (stock to switch rail leads to rapid changes in normal contact stresses as well as tangential contact forces, both leading to potential damages such as plastic deformation/subsurface fatigue and wear/rolling contact fatigue (RCF) respectively.

In Figure 4.21 the point of contact first moves towards the field side as the point of contact tends to follow the stock rail and the axle angle of attack builds up, until the contact with the flange appears (~32.5m). The leading axle is in hard flange contact in the switch rail and then the closure panel (contact band in the range y=-0.025 to -0.036, zero being the rail head centre]). Regime is high wear. The second axle follows the same trend on the stock rail but then contacts the switch/closure rail in the gauge corner (y=-0.01 to -0.018). The regime is low wear/RCF. Both axles generate risk of RCF on the stock rail. On the opposite rail the trailing axle also leads to potential RCF damage in the switch and closure panel.

Figure 4.22 shows the equivalent Hertzian contact pressure (assumes linear elastic material properties). A high variability of pressure is observed. Initial contact with the stock rails gives lower contact pressures, and then pressure increases sharply as contact with the switch rail occurs due to the higher curvature of the geometry in contact. Higher contact pressure is also observed on the closure rails. The jumps in contact conditions on the high rail at distance ~35m also translate in a high peak of contact pressure. Plastic deformation is likely to occur in these predicted conditions. On the low rail the contact pressure is rather constant.

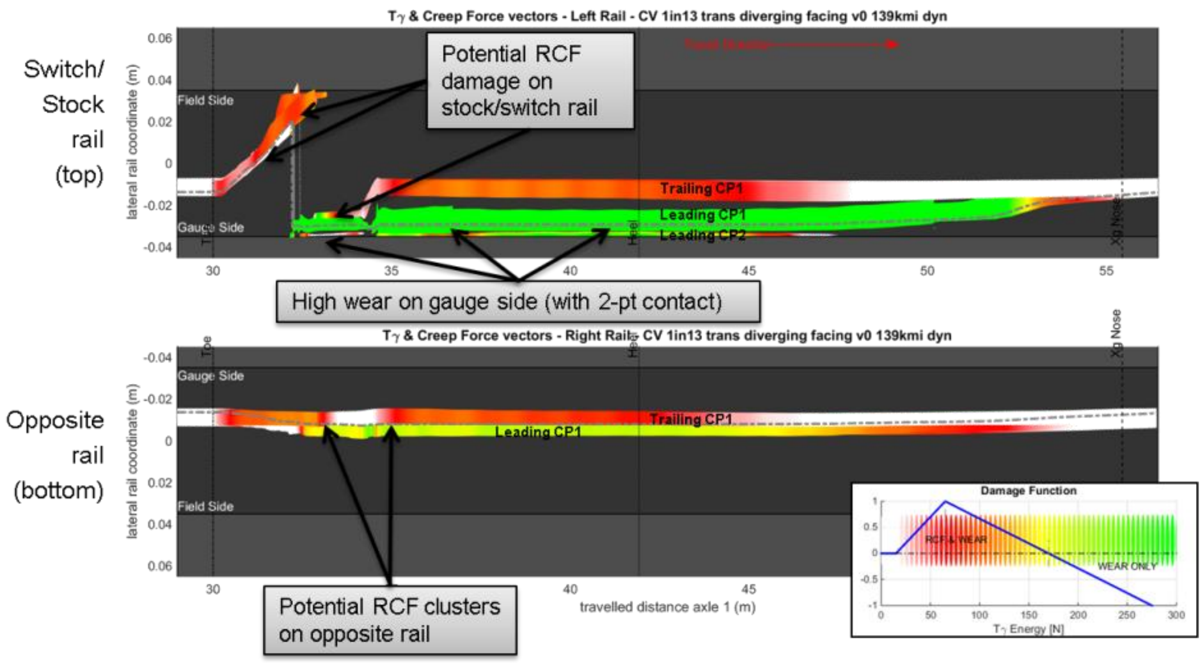


Figure 4.21: Contact band display (view from top) on high rail (top) and low rail (bottom) under the passage of leading and trailing axle. CP1 and CP2 correspond to contact point 1 and 2 (when two point contact occurs on high rail – leading axle). The size of the contact ellipse is representative of output results and the colour code corresponds to the damage function as per the Tγ output[1]: red-orange = RCF, green = wear only

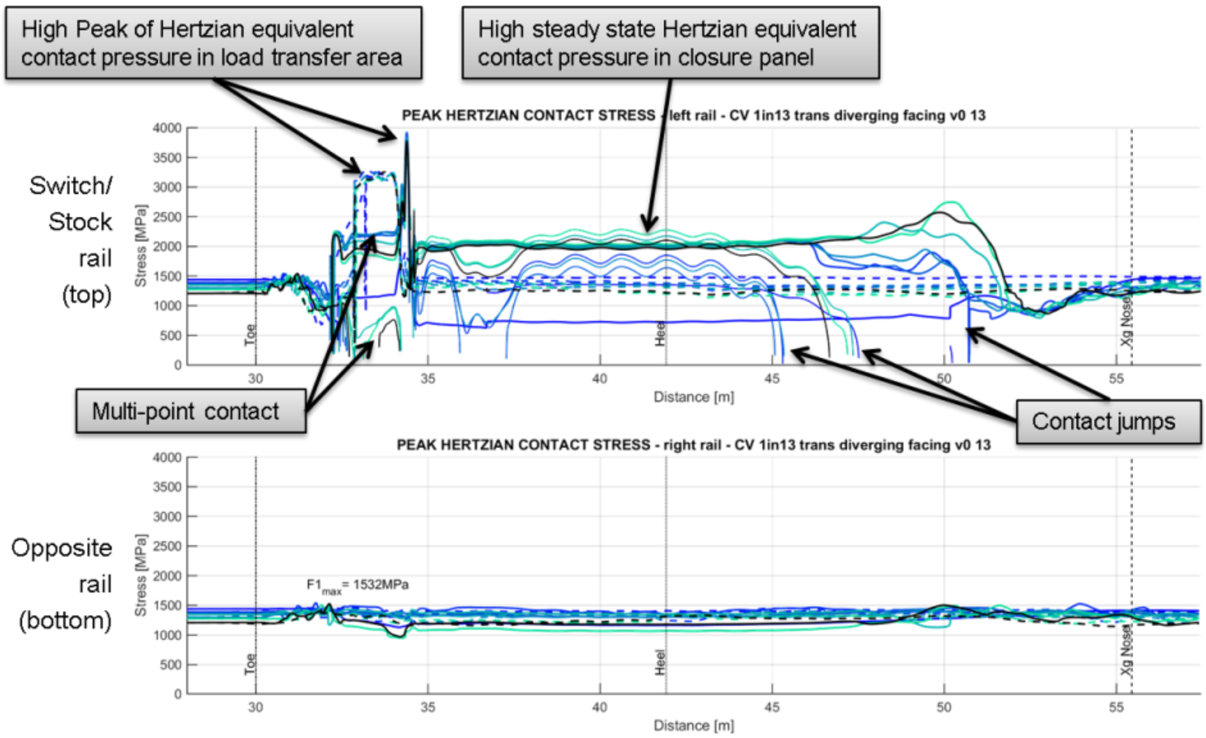


Figure 4.22: Equivalent Hertzian contact stress on high rail (top) and low rail (bottom) under the passage of leading (solid line) and trailing (dash line) axles

4.4.3. Load transfer at crossing panel and vertical impact

In the crossing panel, adverse contact conditions are also present. In addition to the lateral load input, there is a significant vertical dynamic load component due to the transition of contact from the wing rail to the crossing nose and vice versa (facing/trailing directions). Every crossing design and every wheel shapes will affect the way in which the wheel transfer loads onto the crossing and the magnitude and location of the impact. In addition to this, the shape of the wheel, the vehicle speed, the track geometry and move direction affect the attitude of the axle as it approaches the crossing.

To show the relevance of considering the wheel shape in the design process, simulation were carried out on UK crossing designs (CEN56 full cant, CEN56 half cant and NR60) using a freight vehicle model (with Y-series bogie) running at 80km/h and a batch of carefully selected wheel shapes measured on a freight fleet [2]. These results are made available for future comparison of performance against In2Rail innovative designs.

Figure 4.23 shows the vertical motion of the wheel, showing a sudden change in direction as it reaches its lowest position and transfers contact from wing to nose (facing) or nose to wing (trailing). The equivalent so called ‘dip angle’ (2θ) is directly linked to the energy required to force the wheel mass back up and therefore the impact contact force.

Figure 4.24 shows the resulting vertical force, composed of a 1st high frequency impact load (so called P1) and a second lower magnitude – lower frequency load (so called P2). The first one leads to local rail damage (heavy plastic deformation, sub-surface fatigue) and corresponds to the wheel unsprung mass battering the rail. The second one corresponds to the coupled wheel unsprung mass and rail crossing mass crushing the support below (pads/sleeper/ballast), leading to component fatigue (particularly severe for cast crossing) and ballast deterioration. This figure shows that the location and magnitude of impact (and therefore damage) changes with the wheel shapes for both P1 and P2 forces. The hollow wheel (magenta colour) is clearly seen to lead to peculiar load transfer and the highest loads on this particular crossing.

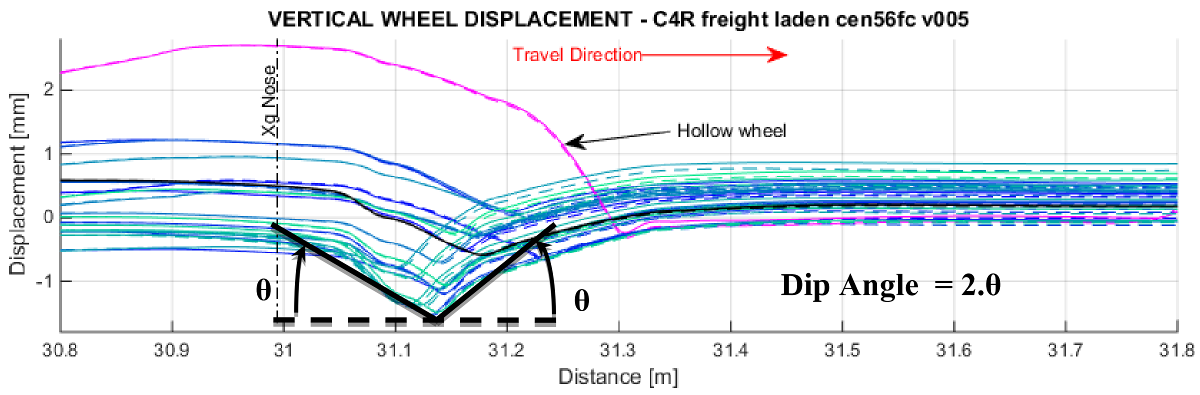


Figure 4.23: Wheel vertical motion (top) for a freight vehicle running over CEN56 full cant crossing in through route facing move for 21 wheels

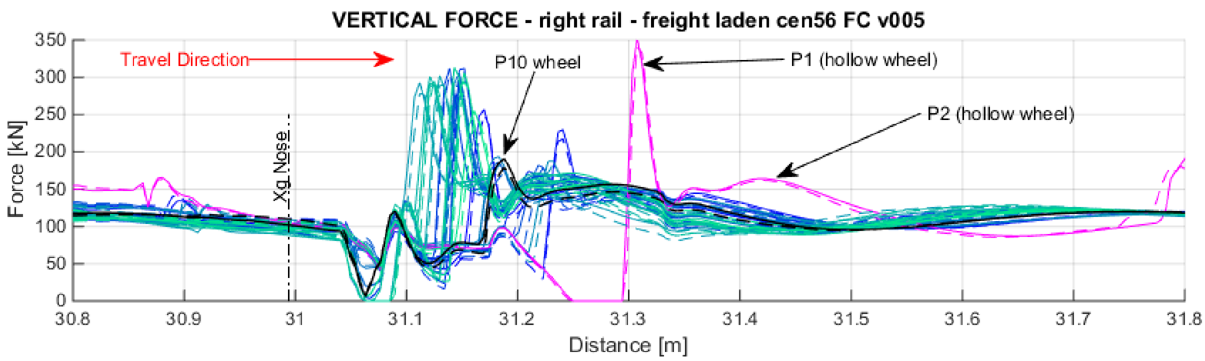


Figure 4.24: Resulting vertical impact force for a freight vehicle running over CEN56 full cant crossing in through route facing move for 21 wheels

Figure 4.25 shows the magnitude of the contact pressure on the crossing geometry (contact patches plotted and view from the top - colour code based on pressure intensity). The wing rail can be seen on the left hand side (wide contact band – mostly white in colour) while the crossing nose is indicated in the centre by a thin contact band (narrow contact band with small radii and high intensity) expanding into a horizontal V-shape (<) that is the crossing vee. Expected damage by plastic deformation and potential for sub-surface fatigue initiation matches site observations: crossing nose and wing rail edge. The hollow wheel can be seen contacting on the field side of the crossing vee (bottom of the plot).

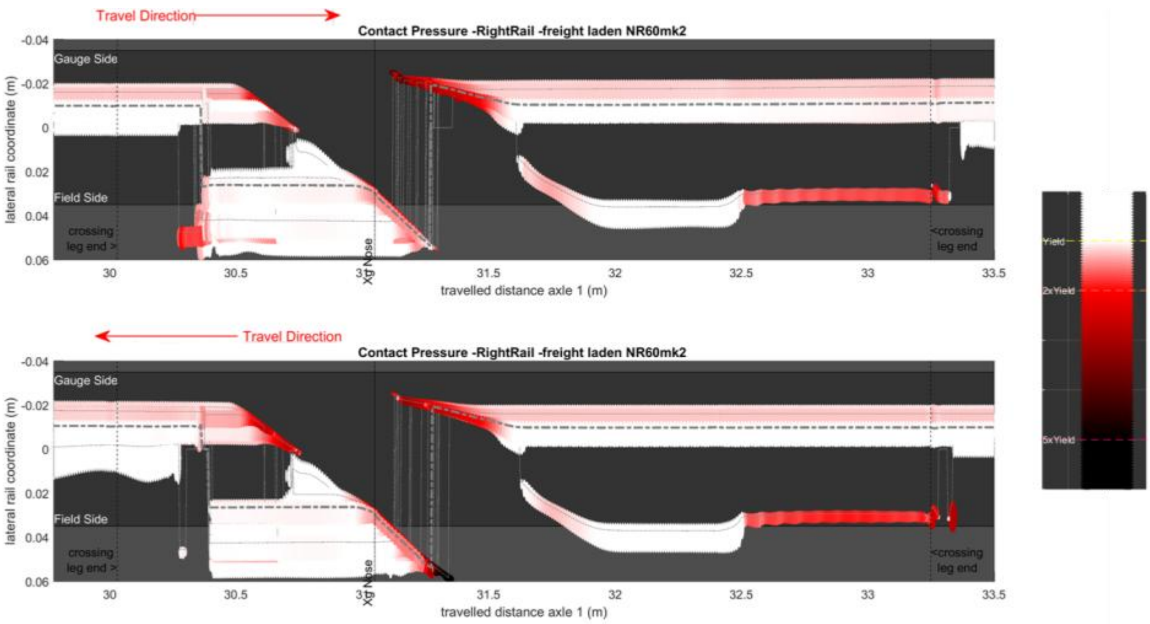


Figure 4.25: Equivalent Hertzian contact pressure for a freight vehicle running over CEN56 full cant crossing in through route facing (top) and trailing (bottom) for 21 different wheels. Colour depends on magnitude

4.4.4. Core Requirements for S&C

From the fundamental principles it is possible to determine the core requirements for the switch and crossing system. The requirements defined below can be used to generate and evaluate possible S&C ideas in a consistent manner.

Safety and Performance indicators to be produced from wheel-rail interaction simulations are:

- Derailment risk Y/Q (for a range of vehicles, wheels and friction coefficients);
- Passenger comfort (vertical, lateral and roll acceleration above leading bogie as well as jerk);
- Vertical impact loads unfiltered and low pass filtered (Q, Q<200Hz) to capture rail/component damage and degradation to support;
- Track shifting forces unfiltered and filtered by 2m sliding mean (ΣY, ΣY2m);
- Rail lateral and resultant forces for component fatigue (Ydyn, Bdyn);
- Contact energy for resistance against wear (Tγ);
- Contact pressure based on Hertzian theory for rail resistance to fatigue (Pdyn);

- Peak pressure on ballast[2] or other supporting track layers (non-ballasted) for resistance to vertical settlement (Pbdyn).

These indicators will be used to firstly benchmark the performance of the existing S&C system and then to evaluate the performance of any radical systems emanating from In2Rail WP2. Example results for the benchmark UK CEN56V switch and crossing are presented from Figure 4.20 to Figure 4.25 and more detailed and direct comparison will be reported in the final deliverable.

[2] Note that this requires a more detailed beam on discrete support for the track model which is not standard in current multibody dynamics simulation software.

5 High-Level Specification for Radical S&C Designs

Following the study of fundamental principles within chapter 4 and extracting knowledge and experience from European Railway Infrastructure Managers, the following functional and non-functional requirements for radical S&C design have emerged. It should be mentioned here that these requirements are purposely very high-level in order to encourage innovation and creativity.

5.1 Functional Requirements

Functional system requirements are those that the system under development must be able to achieve. Due to the nature of this task (*i.e.* concepts for whole S&C system redesign), the system functional requirements reduce down to a single statement:

- Primary Function: The system design shall efficiently direct railway vehicles from one track to another.

Each of the following non-functional requirements can be traded off against each other, so long as the fundamental function of moving the vehicle from one track to another is met. The degree of acceptable risk in relaxing some of the following, non-functional requirements will form part of the risk assessment during conceptual design development.

5.2 Non-Functional Requirements

Non-functional requirements are those that cover additional business, spatial and safety requirements. Unlike the functional requirements, which must all be satisfied by the final system design, the non-functional requirements can be traded off against each other depending on how relevant they are to specific applications of the technology. For instance, in some locations / asset types, space may be a premium (*i.e.* installing a new switch design within a very busy terminal station may present difficulties with regards to the physical space available). In these situations, compromises on the non-functional aspects of the ideal specification may be necessary. The following non-functional requirements have emerged and should be considered during the development of future conceptual designs:

- **Design/Build**: Represents a step change, simple and with limited number of individual components, better robustness, longer lifetime, enables modularity, scalable to accommodate multiple switch lengths and geometries, based on existing technology, entails long transitions for low loads, easy to implement and compatible with existing track and signalling infrastructure;
- **Safety: r**educes the tendency to derail and a reduced risk of rail break. The system shall also be fail-safe (where necessary);
- **Approval/Test/Trial:** proven through validated simulation, proven in tests, proven in track, meets current European standards (TSI), good quality of the wheelset steerage,

good continuity of wheel-rail contact through the 'switch' system, good continuity of wheel-rail contact at the crossing (frog), easy to get approvals;

- **Maintenance/Modularity/Construction Site Logistics:** Reduced inspection frequency, reduce maintenance intervention, enables automatic/remote inspection and maintenance, low wear, low forces on construction, low tendency to corrode, low tendency to generate fault in level, reduced adjustment required, easy to maintain track geometry and support, full tamp-able (if ballasted track), improved electrical isolation, improved cable management, improved installation process, improved commissioning process;
- **Operation:** Enables interoperability, improves track availability, improves through speed, improves turnout speed, increased permissible load, higher reliability, improved track quality retention (rail alignment), low stiffness heterogeneity, low sensitivity to high and low temperatures, low sensitivity to frost and snow;
- **Environmental:** Low noise impact, low vibration impact, low energy consumption during production, low energy consumption during operation;
- **Whole Life Cost:** Whole-life cost of the system related to initial purchase and installation through to additional maintenance and decommissioning costs, estimated using engineering judgement.

Each of these non-functional requirements will be weighted and used to compare, contrast and rank the ideas in order to select suitable candidates for further work within In2Rail. Additional, detailed functional and non-functional requirements, such as those developed within In2Rail Deliverable D2.1, will be included alongside these once any selected ideas are developed into feasible conceptual designs (*i.e.* during the more detailed value analysis for recommending further work within Shift2Rail).

5.3 Key Areas for Consideration

To support the development of any chosen idea, the following set of considerations should be made, which come from known improvement areas within existing S&C design:

- improving steering in curves by introducing vehicle steering and/or track based geometrical improvement to be assessed through a combination of rolling radius difference functions and vehicle dynamics;
- improving transition into the closure panel steady state curve condition in the diverging route;
- validate and improve the rail inclination if it proves to lead to detrimental steering and contact conditions;
- avoid jumps in contact and double point contact on high rail – leading axle in the switch panel;
- where fundamental steering forces cannot be avoided (short turnout), new materials need to be employed that are more appropriate for the predicted contact conditions (high slip velocity and normal stresses) to slow down or eliminate the current damage process;
- contact conditions for any new design should be fully assessed and low contact stresses ensured at all time (situation representative of present switch and closure panels should be avoided).
- The following damage mechanisms should be assessed:
  - track shifting forces (track lateral deterioration),
  - maximum force on high rail (track lateral deterioration and component damage),
  - rail wear and RCF,
  - rail high contact stresses and sub-surface fatigue,
  - vehicle lateral acceleration and jerk (passenger comfort).

There are three key elements of design to consider:

1. Structural integrity of the switch rail: The varying profile of the switch rail along its length is considered a design weakness which is mitigated by the belief that the switch blade is more than adequately supported by the stock rail. Although the increased rate of degradation has always been acknowledged, it has largely been tolerated for the prevailing traffic conditions and vehicle characteristics and emphasis placed on improved maintenance and inspection techniques to mitigate any risks. Attempts have also been made to pass the challenge on to metallurgist to provide more degradation resistant materials for switch blades without any significant increase in costs.
2. Integrity of crossings: Wheel load transfer from wing rail on to the crossing nose results in very high contact stresses and plastic deformation. The industry has looked towards metallurgist to provide explosively hardened austenitic manganese steel crossings or those made of very expensive marageing steels. In addition, the industry has relied upon optimisation of the crossing nose, wheel and the wing rail profiles to minimise the dynamic forces but also recognising the need for materials that can maintain the profiles for longer.
3. Support stiffness: The very nature of S&C layouts demands longer bearer lengths that are also spaced according to the needs of the layout. In addition, the need to accommodate the special rail profiles leads to the deployment of special baseplates. All these factors leads to a variation in support stiffness through the length of the layout, compared to that experienced by the vehicle in plain line. Furthermore, the difficulty in tamping S&C layouts leads to further increases in the variation in support stiffness. The resulting variation is a key factor affecting the wheel-rail contact patch conditions and the resulting rate of degradation.

6 Idea Generation Methodology (OptiKrea)

OptiKrea is a robust, structured idea generation process utilised in the early stages of all WP2 Tasks. The initial elements of this process, Topic Mapping, Goal Setting, Criteria Specification and Criteria Weighting, are also aspects required by the value analysis as described within Chapter 8.

The initial stages of the OptiKrea process were complete during a workshop covering all four WP2 tasks. As a result, Chapter 6 will reiterate the process as already described within WP2 Deliverable D2.1.

6.1. Ideas Generation Process

The process adopted during the ideas generation workshop is called the 'OptiKrea Process' and is summarised within the flowchart illustrated by Figure 6.1, which also highlights the stages completed prior to and during the workshop and those progressed outside of the workshop within Task 2.3.

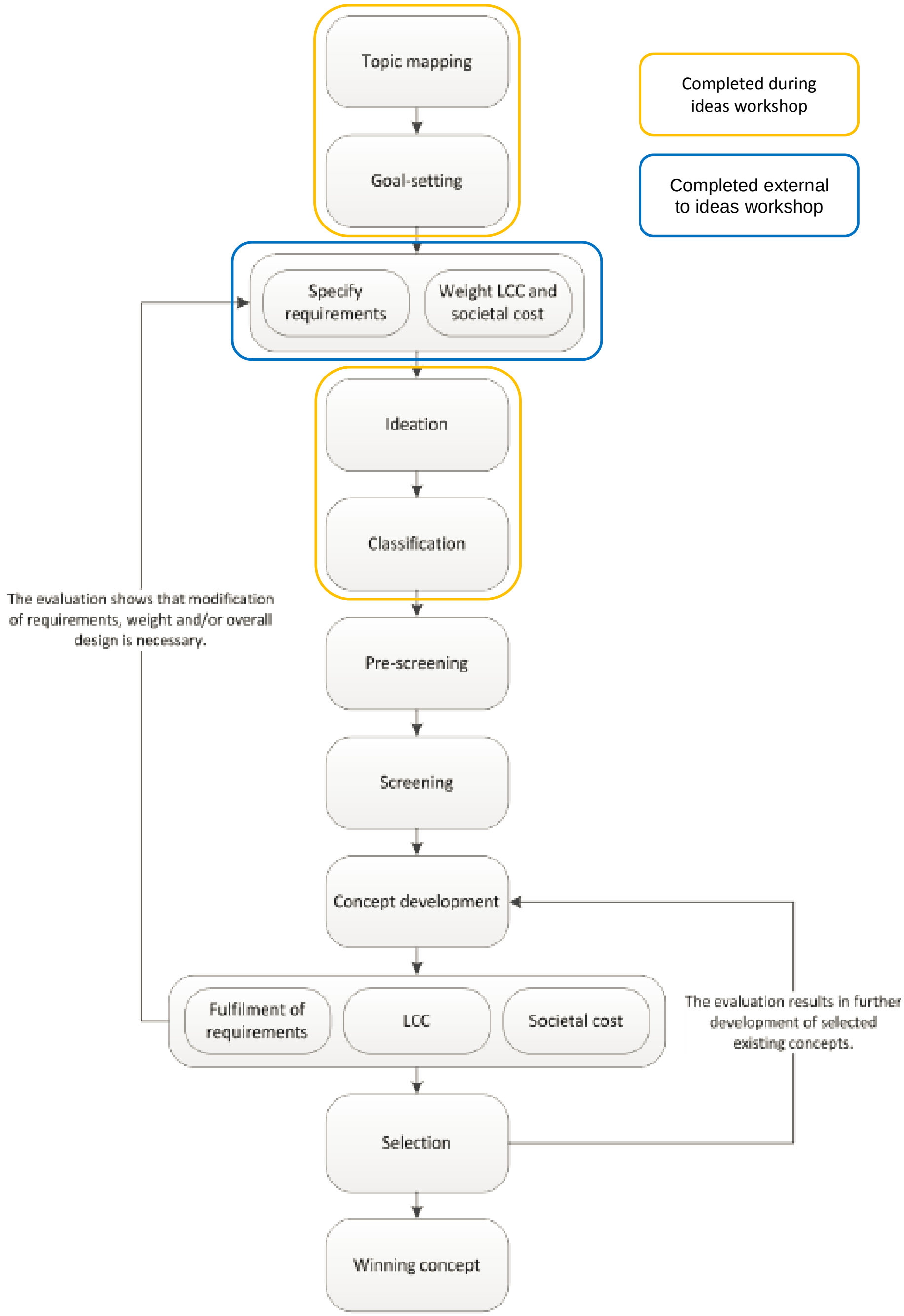


Figure 6.1: OptiKrea Idea / Concept Generation Process Flowchart

6.1.1. Topic Mapping

The first stage included describing the topic area in some detailed based upon a predefined set of topic mapping questions. The answers to each question were discussed during the workshop to help ensure that all those involved in the ideas workshop maintained a common view of what we were trying to achieve. The topic mapping questions and responses can be seen within Table 6.1.

#	Topic Mapping Questions	Task 2.3 (Radical S&C Solutions)
1	**What are the issues with the present product? Why does it need to be exchanged or modified?**	The operating principle has remained unchanged since the original introduction and has a critical dependence on the means of guidance that introduces a tapered section of rail into the space between the running rail gauge face and the wheel flange. These components need to be kept in close tolerance and locked into this position to remain safe. In spite of advances in production processes the costs are currently significant. Main issue with the present product is the susceptibility because of the construction principles and environmental influences. As a result, there are high costs because of inspection, maintenance and production (LCC). Attracting the highest rate of failure of whole railway infrastructure and the highest maintenance and delay cost of the whole rail system. Too complicated (too many parts, too many mechanical functions) and too many different types of S&C configuration. Moving parts are also exposed to environmental conditions whilst 'weak' components are in places with the highest duty conditions (small curvature and point contact in points and crossing noses). S&C's are subject to high dynamics forces under weak support (differential deterioration). Manufacturing techniques also limit design possibilities.
2	**What is the problem really about and wherein lies the greatest need?**	The industry is locked into very decreasing increments of design evolution and has not in recent times explored if there are better ways of achieving the desired system characteristics and performance that can only be achieved by developing new approaches that simultaneously reduce all cost aspects and are capable of providing the desired levels of operational performance. There are some key issues at places of wheel-transitions (switches, crossing nose (frogs), and insulated rail joints) because there are discontinuities in the track - at these places, high dynamic forces occur. Poor and compromised steering of vehicle in the diverging and through routes respectively, leading to high lateral impact loads. Need to improve bearing surface for all or most representative wheels to improve rolling radius difference in both directions. Avoid concentrated high stresses on weak components. Redesign shapes of rails to cope with contact stresses where needed. Improve vertical movement of unsprung mass by eliminating dip angle leading to damaging P1 and P2 forces.

#	Topic Mapping Questions	Task 2.3 (Radical S&C Solutions)
3	**Who wants the problem to be solved and why?**	Infrastructure Managers suffer from financial and reputational losses as a consequence of failure and need to reduce these events by improving Reliability, Availability, Maintainability and Safety performance of S&C.
4	**What are the (root) causes of the problem?**	The supply chain has become entrenched in a single design solution that due to commercial factors and natural independent design evolution has no parts compatibility. The base costs have also grown progressively such that they now represent a significant cost element of the track components. Poor/degrading support on ballasted turnouts, inadequate wheel-rail interface design with conflicting requirements for the through and diverging routes (through: no change of rail shape is desired; diverging: changed rail shape is required to enable allowing better steering).
5	**What functions should the product perform, now and in the future? What tasks should the product be able to solve?**	Enable appropriate steering of rail vehicles at both low and high speed and be applicable over the widest ranges of geometries. To be intrinsically fail safe and to have low risk to all known derailments mechanisms. Moving parts should be isolated from the environment and degradation of the surrounding system.
6	**What properties should the product have/not have?**	Radical new S&C solutions need to be at least as safe as the present designs, suitable for high speed and loads (also low speed), should have reduced Life-Circle-Costs (lower production costs, lower effort in inspection and maintenance, life length of minimum 20 years, more standardisation) and a significant improvement in environment resilience.
7	**What requirements does the environment where the product will be placed bring with it?**	All equipment to be at least IP68 rated in accordance with EN 60529 and take account of the assumption that equipment will be immersion in water due to flooding at some point during its operation. Spatial constraints existing on all rail networks therefore the new system must sit within existing S&C 'footprints'. Interface with existing and new signalling systems must be considered. New solutions should be able to cope with extremes of environmental conditions (i.e. temperature, moisture, vibration, etc…). Assuming existing vehicles, high axle loads and steel wheels may result in high dynamic contact forces (dependant on conceptual design).

#	Topic Mapping Questions	Task 2.3 (Radical S&C Solutions)
8	**What non-obvious wishes, requirements and expectations are present?**	Use of rail sections to form components whilst other parts could be non-metallic. Support types are not limited to a single solution - guidance and support could be separated into bespoke solutions.
9	**What possibilities are open and which are not open in achieving the product?**	To enable radical concepts to emerge, nothing should be excluded at this stage. Possible solutions could include: 1. Wheel flange back steerage 2. Sliding transverse rail panel 3. Rotating longitudinal rail profile cassette. 4. Fixed toe moving heel switch 5. ½ swing nose as front switch system 6. Continuous support (i.e. elimination of individual S&C bearers).
10	**What alternative products exist?**	Principles (wheel guidance, switch rails, closure panels and crossings (frogs)) are common across all countries. Differences only arise within the details of constructions. Existing concepts / solutions include: • Stub rail • Back of wheel guidance • Repoint • Fakop and other kinematic gauge widening (KGO) • Complete rotating panel • Non-intrusive cross-over (raised rail) • Pivoting rails/crossings
11	**What standard requirements exist? What legislation?**	A number of standards exist that control the interaction of the wheel profile and rail during the passage through a switch and this is largely about prevention of derailment mechanisms. Standards include Technical Standards for Interoperability (TSI's), Railway Group Standards (UK), Common Safety Method (CSM), AEG (General Railway Law), EBO (Constructional and operational order for Railway Systems), National Rules, British Standards and
12	**What are the requirements/wishes regarding upgrading?**	The objectives and desired outcomes are as stated in each of the WP tasks and link back to the core operational and cost benefits as identified in the In2Rail DoW submission.

#	Topic Mapping Questions	Task 2.3 (Radical S&C Solutions)
13	**What technical, organizational, environmental and ergonomic trends exist?**	The new designs proposed for evaluation shall also be compliant with emerging environmental policies and be validated against whole life cost and safety criteria. Long-term trends are interoperability in the EU, digitisation, standardisation, noise reduction and protection of the environment. Fully automated inspection and maintenance interventions (drones, robots) and the desire to remove human interventions and hence staff exposure to the live railway. Long-term aspirations of a 24/7 railway.
14	**Are there former projects (or procurements) that are relevant for the present topic?**	INNOTRACK - investigation was about improving present S&C-constructions by optimisation. SUSTRAIL - optimised track and substrate design and component selection to increase sustainable freight traffic as part of mixed traffic operations. Capacity4Rail – Increasing Capacity for Rail Networks RIVAS – Railway Induced Vibration Abatement Solutions
15	**How large is the product volume expected to be?**	The renewal banks for the whole EU infrastructure companies should be considered initially for the next 5 and ten years and then this factored and an impact assessment made on the benefits for each radical S&C design.
16	**Are there other aspects to consider?**	Do non-commercialised existing radical designs exist that could be evaluated immediately. Could more than one track gauge be used for multiple uses (i.e. separate gauges for passenger / freight services?)?

Table 6.1: Topic Mapping for Task 2.3 - Radical S&C Solutions

6.1.2. Goal Setting

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

The goal-setting for WP2 Task 2.3 is to:

"Develop ideas and evaluate concepts for new ways of moving trains from one track to another. This should be achieved whilst also improving the RAMS performance and reducing LCC of the S&C system"

6.1.3. Specify Requirements / Weight LCC and Societal Costs

With In2Rail WP2 Task 2.3 aiming to radically redesign the S&C system and hence the need for innovation and creativity, it was agreed that setting specific system requirements and approximating life-cycle and societal costs would not be beneficial at this very early stage in the development process. These are, however, essential requirements for a more detailed assessment of conceptual designs and will therefore form part of the whole system value analysis to be completed in the latter stages of In2Rail.

6.1.4. Idea Generation and Classification

This OptiKrea idea generation process, as used within this deliverable, is described within Appendix C: OptiKrea Ideation Method. Following the idea generation process, classification and grouping of the ideas was completed with the following three categories emerging:

1. Incremental Design Change (Existing S&C system improvements).
2. Radical redesign of the track changing system.
3. Enabling Technologies (or cross compatible / supportive).

The ideas generated during the idea generation workshop are provided within Chapter 7, where they are sorted and presented within the above categories.

7 Idea Generation

All ideas are captured within a common template. This includes one page for describing the idea and providing a diagram as well as references to any relevant existing knowledge, and a second page for explaining how the idea performs against the core criteria. This provides a consistent format for idea assessment and evaluation.

Ideas that were generated in the first stages of Optikrea but not developed into the Idea Generation sections below are listed in Appendix D:.

7.1 Incremental Design Changes

Ideas in this category are classed as incremental. They involve changes to existing S&C designs to improve performance. Some of the technologies discussed are already under development. These technologies are included in order to capture current developments which may need further work, as they may bring benefits.

Idea 1. Improve Guiding Kinematics

Idea Description

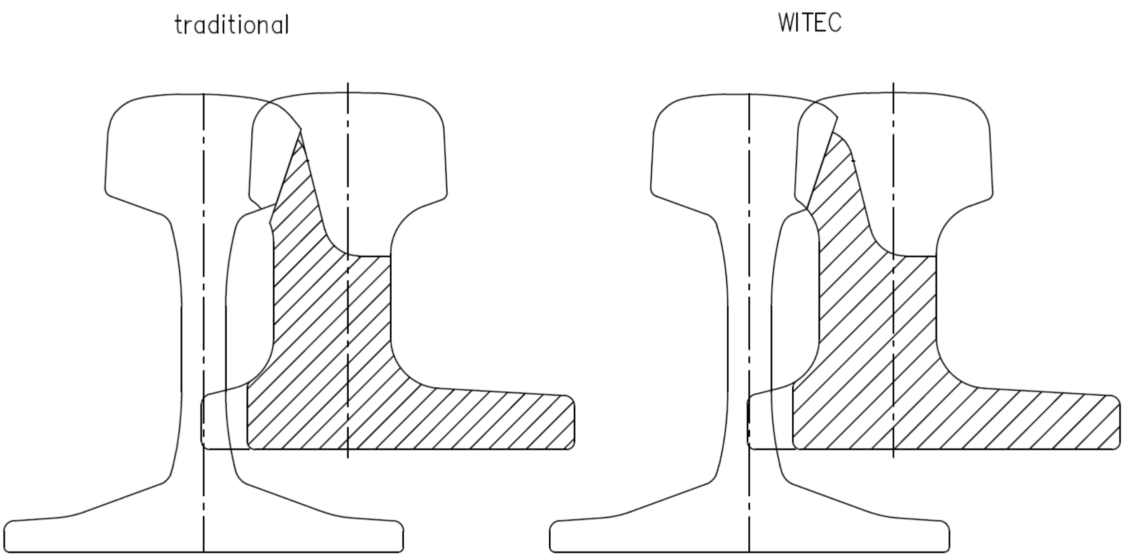
Trafikverket has since 2014 installed S&Cs with thicker switch blades than before. The new design is based on two different milling angles (as the previous just was a straight line). The improvement leads to that the first wheel/rail interaction point occurs where the switch blade is thicker. A second change is that the gauge was changed to 1437 mm instead of 1435 mm. The latter change should give a lower lateral impact on the switch blade at the transition zone.

In its NR60 range (CEN60E1 rails with clothoidal switch geometry), Network Rail has been using S&C since 2002 with switch rails 3mm thicker than before. A new range of S&C with CEN60E1 rails and secant geometry is in development, also with 3mm thickening and possibly 2-slope milling. Some ranges of UK legacy switches has 10mm thickness at the switch toe but these were used for lower speeds.

Deutsche Bahn also have one design on so called WITEC-switches where the switch blade is 5 mm thicker than normal. This effects a gauge widening of 5.2mm at switch tip (2.6mm on each stock rail).

To be innovative this idea needs to go beyond 5 mm more thick switch blade before the normal transition.

Idea Diagram(s)



Existing Knowledge References

See Section B.1.

Idea Key Requirement Information	
Design / Build	The idea is within normal design.
Safety	Can increase safety by reducing the rate of switch toe breaks, a critical derailment enabler.
Approval / Test / Trial	First generation is in use, can be improved further.
Maintenance / Modularity / Construction Site Logistics	Improvement on transition zones. Less wear, less probability for broken tip of switch blade, reduced maintenance requirement.
Operate	Increase in availability.
Environmental	No improvement.
Other	No comment.
WP2 progression capability	Should be discussed as an idea to simulate an improved design.

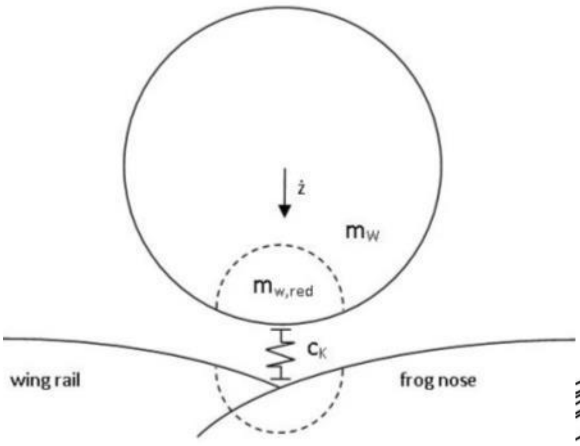
Idea 2. Removable elastically-mounted crossing nose

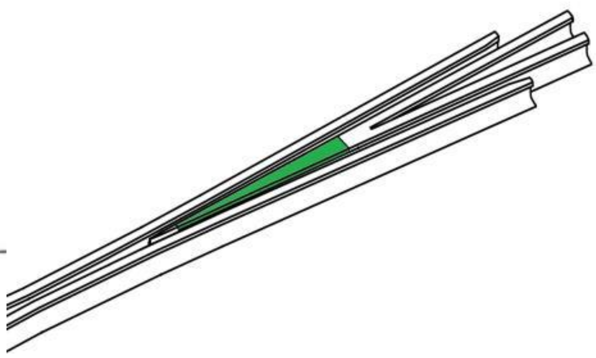
Idea Description

The stiffness of the crossing nose contributes to the impact force experienced during wheel transition. One way to optimise the stiffness of the crossing nose is to make the crossing nose a removable component and modify its mounting mechanism to account for the appropriate stiffness. This would reduce the impact force and the associated damage to the crossing nose.

Furthermore, the replaceable crossing nose could make use of Idea 14, where the crossing nose is manufactured from a suitable high performance material. This would reduce the whole life cost of the crossing by reducing the cost of refurbishment as the damaged element would simply be replaced.

Idea Diagram(s)





Existing Knowledge References

No relevant existing knowledge.

Idea Key Requirement Information	
Design / Build	Not a step change but advancement of an existing principle.
Safety	No improvement for safety.
Approval / Test / Trial	No known work underway or complete.
Maintenance / Modularity / Construction Site Logistics	Could reduce maintenance work and costs by reducing surface welding and grinding tasks. Could increase crossing life, therefore reducing whole life cost. Each crossing type would require a purpose sized removable element. Non destructive testing of material below replaceable nose will become moredifficult.
Operate	Availability could rise.
Environmental	Reduced embodied energy in whole life manufacture of the crossing as it can be more easily refurbished instead of replaced.
Other	-
WP2 progression capability	Simulation work on contact stresses on the variable stiffness component could be explored.

Idea 3. Hopping Switch Actuator

Idea Description

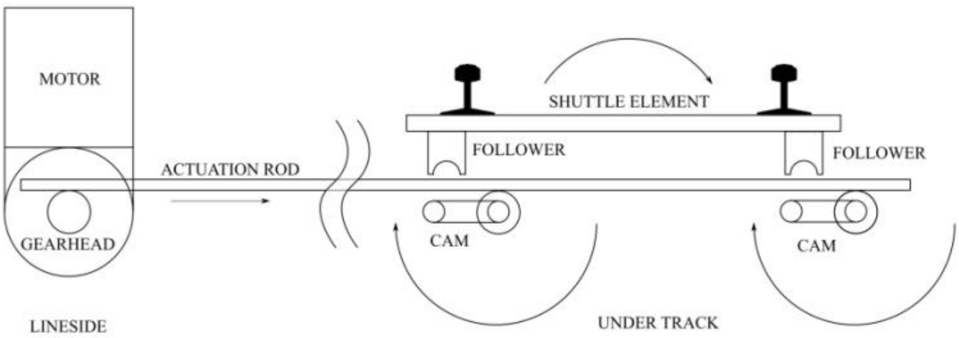
Switch blade actuation is provided by a multi-channel actuation bank, with the actuation elements contained within bearers near the switch blade end.

Multi-channel actuation and locking is possible through an arrangement which has been termed 'passive locking'. 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 necessary to lift the rail ends to disengage the locking devices.

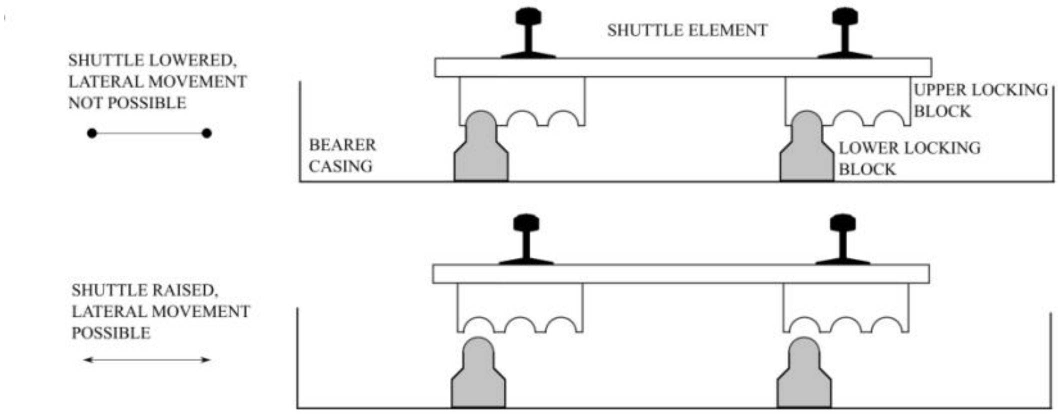
When the track is lifted, it is free to move laterally, but not longitudinally. Thus the rail hops between adjacent positions. If an actuator is isolated, the adjacent unit(s) can still actuate the switch, as the lifting action will unlock the isolated unit. It is this feature which enables redundant actuation to be provided, something not possible with a conventional switch.

Idea Diagram(s)

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



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



Existing Knowledge References

See Section B.5.

Idea Key Requirement Information	
Design / Build	Design and manufacture are considered similar to existing point operating equipment. An electronic control system is required to control the parallel and redundant actuators and to mimic the locking system of existing equipment. Such equipment may require novel approval methodology.
Safety	Safety aspects similar to existing point operating equipment. Trailing moves would not be possible.
Approval / Test / Trial	Minimum change from existing switch panel geometry. An electronic control system is required to control the parallel and redundant actuators and to mimic the locking system of existing equipment. Such equipment may require novel approval methodology.
Maintenance / Modularity / Construction Site Logistics	Would make current locking system redundant.
Operate	No significant difference to today's technology.
Environmental	No significant difference to today's technology.
Other	-
WP2 progression capability	Virtual modelling is the likely limit within the timeframe of In2Rail. Further progress will involve significant capital and design investment in test equipment and facilities.

7.2 Radical Re-design of S&C System

Ideas in this category are radical and present more fundamental changes to the way that system functions. Some of the ideas relate to just the switching or the crossing functionality. It is accepted that some of these ideas are very radical, with the technology to deliver them not yet in existence. These ideas are included for completeness, describing the participant's thoughts.

Idea 4. Diverging Bridge

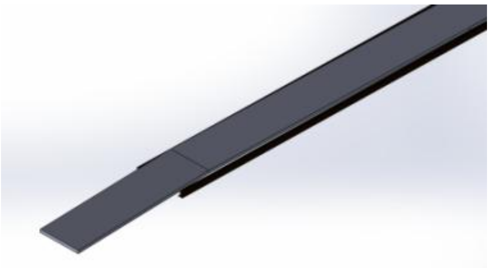
Idea Description

This design concept removes the gaps in the turnout and provides full-section rails. This means that the direct track is similar to a plain track. Since there is no gap, there is no impact force on the track. Consequently, the train can go through at full speed, the rail wear is reduced, and the maintenance needs are reduced.

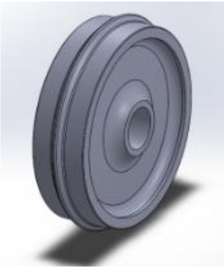
A new solution is imagined to cross the direct track, in order to go to the diverging direction. A kind of bridge enables the train to go over the straight rail. The bridge is set up when the diverging track is on. The bridge is composed of two parts: one lies inside the switch panel, and the other one is situated inside the diverging track. When the bridge is set up, the two parts are actuated and joined to form the bridge. Each part of the bridge consists of a ramp leading to a plateau, and both parts are linked together by their plateau. There is no need for the bridge to be very high: a little more of the height of the wheel flange, which means between 30 and 40mm. The part of the bridge situated in the switch panel is activated by hydraulic cylinders. The part of the bridge situated in the diverging track is translated longitudinally using rollers, until it reaches the straight rail. In order to incorporate the hydraulic cylinders, it may be necessary to have a slab track at the turnout. When the bridge is down, the train goes straight. When the bridge is up, the train runs on the bridge and goes to the diverging track. In order to run on the bridge, the train wheels shall have a tread also on the inner side of the flange. This tread will be in contact with the bridge.

Idea Diagram(s)

Overview of the Diverging Bridge



Ramp and plateau in switch panel



Wheel providing an inner tread for the bridge

Existing Knowledge References

No relevant existing knowledge.

Idea Key Requirement Information	
Design / Build	This design concept may need a slab track to support the moving bridge and to host the actuators. Step change: no frog.
Safety	Reduces the derailment risk, and the risk of rail break in straight track.
Approval / Test / Trial	Needs to be proven.
Maintenance / Modularity / Construction Site Logistics	Low rail wear. Possibility of modular construction using the different pieces of the S&C.
Operate	Improves through speed compared to conventional crossings.
Environmental	No significant difference to today's technology.
Other	Requires substantial change to the vehicle wheels.
WP2 progression capability	Capability for improving the dimensions of the bridge and the locking system.

Idea 5. Integral Switch

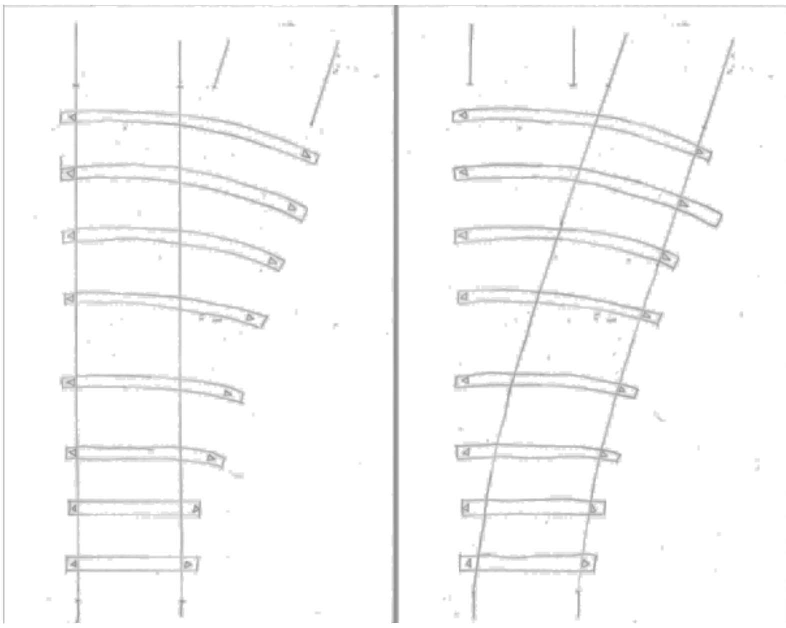
Idea Description

A switch panel is used to direct the vehicle, but there is no conventional switch blade as the entire rails are moved. Using the elasticity of the steel, the rails are rotated at the toe, like for a stub switch. There is no discontinuity in the track geometry, and the rails are full-section throughout the whole switch. The crossing and check rails are no longer required. In the straight position, the track is similar to plain line.

The main difficulty lies in the mechanism to change the track direction, as both rails must be bent a considerable amount. It is proposed to bend the rail using several actuators positioned along each rail. The rails should be bent using rollers placed under them until they reach stops placed on the sleepers, outside the track. The stops and the final position of the actuators give the desired position for the diverging track, for example two clothoids linked by a constant radius curve. A small gap should be left between the moving rails and the rails at the rear of the turnout, in order to have enough space for the rails to move. This gap is also necessary to permit dilatation of the rails due to temperature variations.

The design of this S&C concept follows the will of getting rid of the elements that rise problem in usual S&C: discontinuities in the rail profiles and gaps in the track geometry. Consequently, the safety of the S&C is increased because there is no derailment risk any more at the toe. Since there is no frog any more, the impact forces in the crossing panels are suppressed. A full section of the rail profiles reduces the rail wear. Thus the maintenance effort on this S&C is reduced.

Idea Diagram(s)



Existing Knowledge References

No relevant existing knowledge.

Idea Key Requirement Information	
Design / Build	Simplified design, no crossing, compatible with existing track. However would need more actuators than today.
Safety	Improves the continuity of the wheel-rail contact by suppressing the gaps in the turnout. However, gaps similar to those at rail joints are introduced instead. Overall, safety could be improved.
Approval / Test / Trial	The design needs to be tested, in particular to set up a reliable driving and locking device.
Maintenance / Modularity / Construction Site Logistics	Full-section rails reduce wear. Standard rails are suitable; rail changes could therefore be similar to that of plain line. The operating equipment lacks of modularity. Formation maintenance may be difficult due to the increased amount of actuation required.
Operate	The train can keep its speed in through track. High temperatures, by dilating the rails, as well as snow, may cause difficulties to move the rails.
Environmental	The reduction of impact and of jump in the contact point in the wheel-rail contact contributes to reduce noise and vibrations produced by the system. Increased actuation energy required to move two, full profile, rails further.
Other	If the different routes see different levels of traffic then there a head profile discontinuity will occur.
WP2 progression capability	This concept still needs some work on the operating device and on the transition between the moving rails and the diverging track.

Idea 6. Passive Infrastructure: Separate steering rails

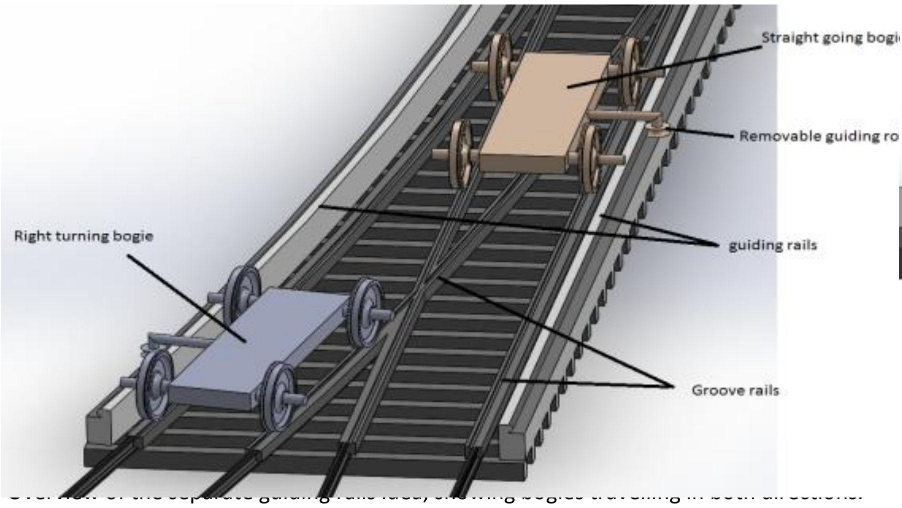
Idea Description

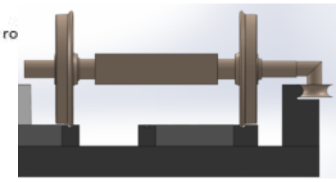
The usual wheel-rail contact is not used in this turnout, new elements of the track are designed to handle on the steering and support functions separately. The steering function will be achieved by guiding rails situated on either side of the track, which interface to removable rollers located on the vehicle. Many rollers may be necessary, maybe one per bogie or even one per wheelset. When required, the rollers are moved into position on the correct side of the vehicle for the desired route.

This idea does not require any moving parts on the track, reducing the amount of maintenance required. Maintenance will now mainly focus on verifying that the rail grooves are clear and that the guiding rails are in good condition due to the forces they experience when steering vehicles. The system will fail safe as the vehicle will continue on the through route should the guiding system fail.

A variation of this design could fix the guiding wheels in place and instead move the guiding rails into position depending on direction.

Idea Diagram(s)





Cross section of the idea, showing the two separate wheel-rail interfaces.

Existing Knowledge References

No relevant existing knowledge.

Idea Key Requirement Information	
Design / Build	Modular construction possible. No moving parts, which makes the construction and commissioning easier. Compatible with existing track.
Safety	Derailment risk reduced since failed on-board steering equipment would mean the vehicle will continue on the through route. Signalling protection system would have to account for this. Rail break risk reduced due to the removal of thin profiled support rails.
Approval / Test / Trial	This design concept needs to be tested regarding the steering of the train, the roller mechanism and the possibility to roll on the wheel flange.
Maintenance / Modularity / Construction Site Logistics	It reduces inspection frequency. It requires less maintenance than usual S&C. The only maintenance is to change rails or to change the guiding rails. This can be done in a modular way. Tamping is possible. Stiffness is rising. Increased vehicle maintenance requirement.
Operate	Good speed in straight track (but less than full speed, because rolling on the flange), reduced speed in diverging track. No steering required for trailing movements. Ballast block, snow and ice in the groove rails are problematic and require to heat the S&C.
Environmental	No known effect.
Other	The rollers have to be implemented on the axle boxes without encroaching on the railway gauge. It will take time to come to market because of the modification of the vehicle (addition of rollers).
WP2 progression capability	It is a long term design concept, because it requires to modify the vehicles by adding removable and controllable rollers on the side of the axle boxes.

Idea 7. Passive Infrastructure: Active Steering

Idea Description

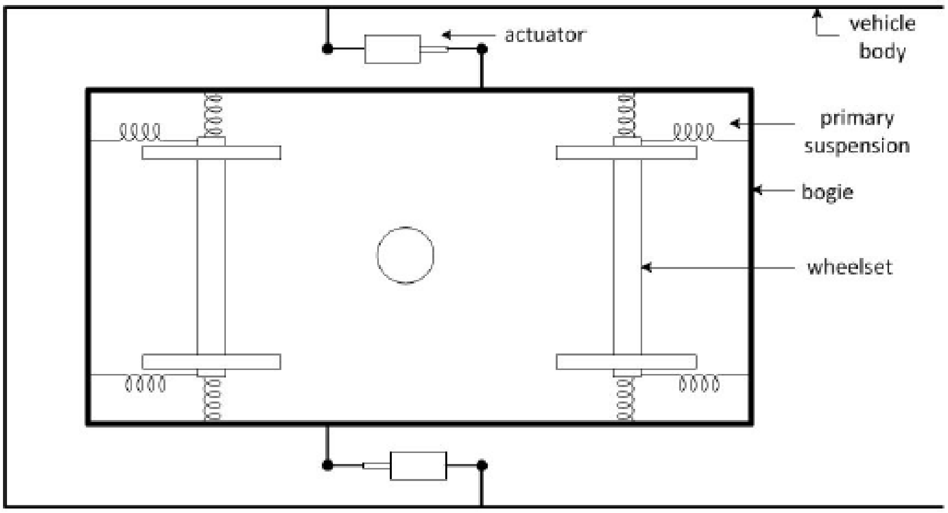
Vehicle based switching moves the active, route-setting, part of the switch from the track to the vehicle.

It is well understood that for actively guided independently rotating wheelsets (either as part of a bogie or in a more radical two axle vehicle) the longitudinal creep forces diminish to almost zero, reducing a predominant wear mechanism. This has been demonstrated for straight and curved tracked and the conjecture is that this will equally apply to more complex geometries such as track switches.

In order to allow the vehicle to actively steer through a passive switch, the elements of a conventional switch that constrain the vehicle to the set route would need to removed, allowing the vehicle to set the desired path. In the absence of conventional switch rails, it is necessary to provide an alternative method of support to the vehicle. The possibilities for a completely passive crossing layout need to be developed further.

Idea Diagram(s)

An example of Active Steering is the addition of an actuator for Secondary Yaw Control as shown below. Other possibilities can be seen in the Existing Knowledge Reference below/



Existing Knowledge References

More information on the different types of active steering is provided in Section 9.2.

Idea Key Requirement Information	
Design / Build	Vehicle: Increased complexity of active actuating elements and the associated control system on-board vehicles. Infrastructure: Reduced complexity, no active components in the ground. Fixed signalling equipment can be reduced.
Safety	Safety aspects similar to automatically guided road vehicles or aircraft.
Approval / Test / Trial	Existing tests are virtual. Actively steered bogies/wheelsets could be tested on conventional railways as a first stage.
Maintenance / Modularity / Construction Site Logistics	A full VBS and passive infrastructure solution would see a significant reduction in infrastructure maintenance and inspection. There would however be an increase in complexity (and possibly maintenance/inspection burden) on the vehicles.
Operate	Signalling/steering moves from the lineside to the vehicle. The vehicle would require knowledge of its location and intended route.
Environmental	Reduced energy usage in switch operation. Reduced energy usage in S&C inspection and maintenance.
Other	To realise the full benefits of VBS would require vehicles and infrastructure that do not have any commonality with today's infrastructure or vehicles.
WP2 progression capability	Full capability to carry out virtual modelling and concept evaluation.

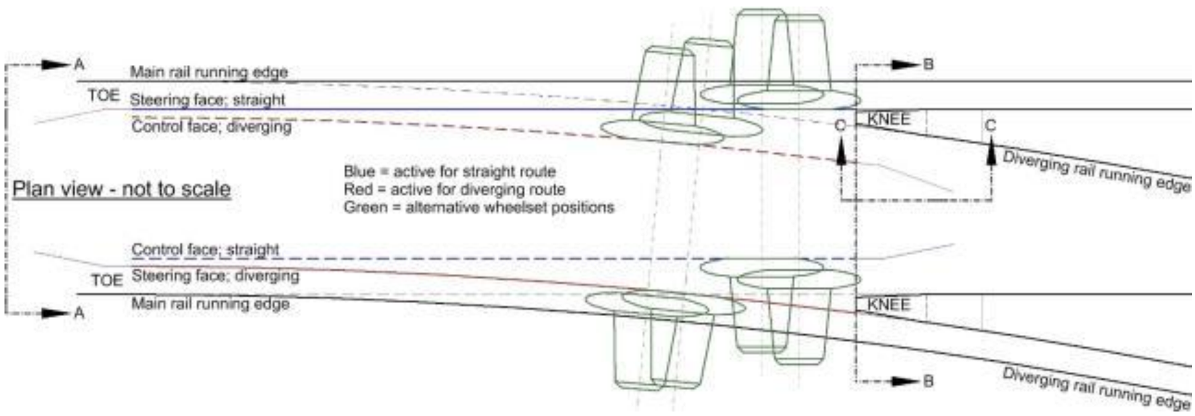
Idea 8. Flange-back Steering

Idea Description

Flange-back steering (FBS) differs from the conventional method in guiding the back of the wheel flange not the front. This isn't unusual; it is how wheels are guided through either of the two paths through crossings, but with FBS the paths are alternatives, actively switched, and the wheel load carrying is separated from the wheel guidance. The principal challenges are to define and evaluate a candidate geometry that enables flange-back steering, simulate and optimise load transfer at the knee, and investigate guidance operating mechanism concepts. Supporting works include identifying materials, opportunities for autonomous inspection and maintenance, and options for different types of rail mounting (including Work Package 3.3 Hybrid Embedded Rail).

The plan view shows the principal guiding and running edges. The blue lines are to guide traffic along the straight route, and correspond to those wheelsets, in green, which are shown on the straight route. Looking from the switch toe towards the knee of the switch, the left blue solid line is the steering face. This is the primary guidance surface ensuring the passage of the wheelset in the straight direction, and preventing the wheel clashing with the knee. The right blue dashed line is the control face. This acts to ensure that the wheel engaging with the knee has adequate shared contact during load transfer. The red lines do the same job as the blue lines but for the diverging route.

Idea Diagram(s)



Existing Knowledge References

Much work has already been completed in the area of FBS, this includes SureSwitch which is explored in more detail in Section 9.1.

Idea Key Requirement Information	
Design / Build	FBS represents a step change in switch guidance. It employs design and manufacturing techniques already known in crossing panels and the concept is scalable to all switch lengths and geometries. FBS modules should be straightforward to implement and be compatible with existing track and signalling infrastructure.
Safety	FBS eliminates many current problems with switches because it does not use a vulnerable switch rail. Consequently there is no chipping of switch tips, and the minimum flangeway is assured by control of the guidance faces.
Approval / Test / Trial	The wheel/rail interface is partly proven in track, because of the similarity to crossing panels, but an increased length of steering is required. Current research is providing a comparison by modelling. The actuation system for selecting alternative routes is unfamiliar and the moveable steering/control bar used to steer traffic is novel, therefore scale model tests and full scale component testing is envisaged to provide support for full approval.
Maintenance / Modularity / Construction Site Logistics	FBS applications are expected to be more modular than conventional switches. Depending on the rail type, the stock rails may not require any machining and therefore replacement should be easier. Modules are likely to be shorter than existing switches. Also the modules can be retrofitted within existing turnouts. This is an advantage in full scale testing and in early adoption. Although existing crossing issues are likely to be exasperated, such as overrun.
Operate	Steering and control bars require a mechanism to operate them but the concept doesn't require a series of switch slideplates, these being the source of high resistance to conventional switch operation. Slideplates and the conventional switch rail/stock rail interface are also a source of operational problems especially where rail wear upsets the switch/stock rail interface and in low temperatures where they can be blocked or obstructed by ice and snow.
Environmental	Slideplate lubrication is a source of environmental pollution which has seen improvements over the last 2 years, so that many switches now use roller mechanisms. The operating mechanism is expected to be enclosed so that leakage of lubricant is reduced.
Other	The solution is universal and will work for any rail type / shape, and whether surface mounted or embedded, on bearers or on a concrete slab.
WP2 progression capability	A plan of activities exists and ERT is working actively on the development. ERT is developing track configurations then providing rail and guidance profiles including through the key wheel transfer areas, and the University of Huddersfield is conducting dynamic simulation studies to inform the development. ERT is also developing practicable options for the mechanisms required to operate the equipment.

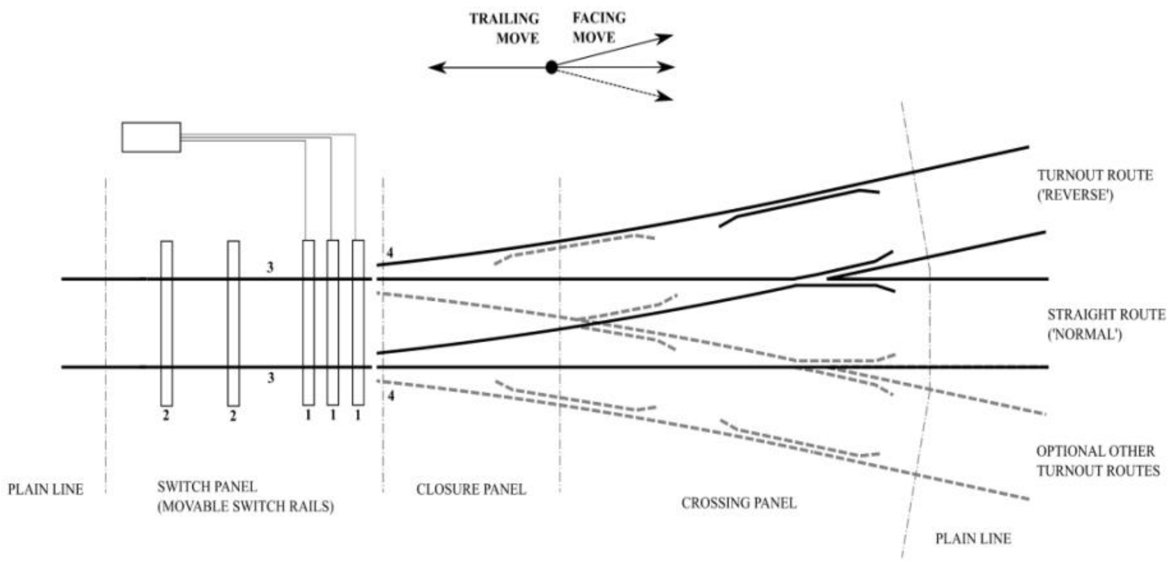
Idea 9. Hopping Stub Switch

Idea Description

The stub switch reverses the elements in a traditional switch, and replaces the long, planed down switch rails with short, stub-ends formed of full section rail which are able to move between two (or more) positions.

Actuation is provided by a multi-channel actuation bank, with the actuation elements contained within bearers near the movable rail ends. Figure 1 shows the general arrangement of a 'Repoint' stub switch. Numbered elements as follows; (1) In-bearer type electromechanical actuators featuring integral passive locking and detection systems; (2) Bearer featuring integral passive locking elements; (3) Bendable, full-section switch rails; (4) Interlocking rail ends. Triplex redundancy is shown, with each actuator/bearer being capable of moving the switch alone.

Idea Diagram(s)



Existing Knowledge References

See SectionB.5.

Idea Key Requirement Information	
Design / Build	Design and manufacture are considered similar to existing point operating equipment. An electronic control system is required to control the parallel and redundant actuators and to mimic the locking system of existing equipment. Such equipment may require novel approval methodology.
Safety	Safety aspects similar to existing point operating equipment. Facing point movements should be safer as some of the failure modes of existing systems are removed. Trailing moves would not be possible.
Approval / Test / Trial	The stub switch arrangement would likely require novel approval methodology. An electronic control system is required to control the parallel and redundant actuators and to mimic the locking system of existing equipment. Such equipment may require novel approval methodology.
Maintenance / Modularity / Construction Site Logistics	Does not use a vulnerable switch rail. Consequently there is no chipping of switch tips. New gaps are introduced comparable with rail joints. Could makes today´s locking redundant because of lower locking block.
Operate	No significant difference to today’s technology.
Environmental	No significant difference to today’s technology.
Other	-
WP2 progression capability	Virtual modelling is the likely limit within the timeframe of In2Rail. Further progress will involve significant capital and design investment in test equipment and facilities.

Idea 10. Rotating Switch Rail

Idea Description

The transition between the stock and switch rail is replaced with a rotating element. The appropriate profiles to guide the vehicle in either the through or diverging routes are machined into opposing sides of the bar. The same approach could be applied at the crossing in place of a swing nose design.

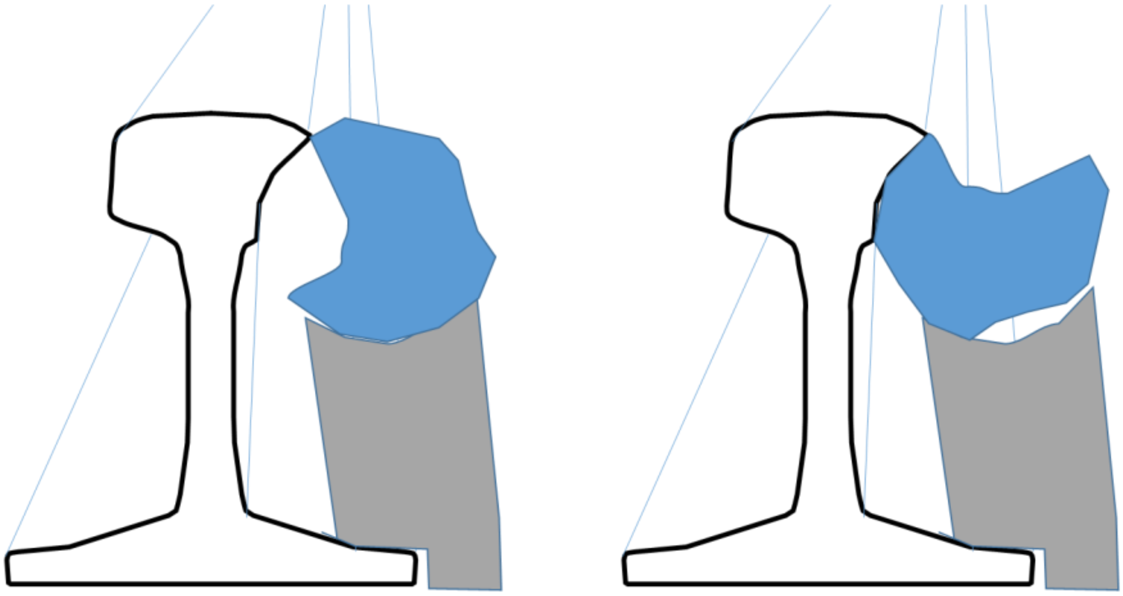
The majority of the length of the switch rail can now be full dimension and fixed in position, reducing the risk of failure.

The system could be mechanically interlocked or independently driven with appropriate locking and detection systems per rotating bar.

With the dimension and tilting angle chosen in the illustration it will be difficult to keep the support surface clean which will lead to failures. Some engineering work is needed to make a good proposal. By supporting the bar at the ends any material located on the running surface would fall away during rotation.

Perhaps the stock rail web and foot and the switch bar support structure could all be combined into a single bulk assembly. The actuation system could also be contained in this assembly. The stock rail head and switch bar could then also be easily replaced.

Idea Diagram(s)



Existing Knowledge References

No relevant existing knowledge.

Idea Key Requirement Information	
Design / Build	Step change with new design.
Safety	Rail profiles and derailment risk same as existing system. Appropriate locking and detection design required.
Approval / Test / Trial	Has been tested in Holland according to the inventor, unclear how and what has been tested. In Sweden the idea is based on other principles than in Holland.
Maintenance / Modularity / Construction Site Logistics	Rotating switch bar actuating mechanism may be complex to maintain. Should be able to supply standard actuator designs for most layouts. Fixed, full depth switch rail is less susceptible to damage and wear.
Operate	Improved reliability by removing susceptibility of the switch becoming obstructed. Novel actuation, locking and detection required.
Environmental	Reduction in size of moving components means less energy required in actuation and heating.
Other	-
WP2 progression capability	Should be discussed as one possible idea to explore further. In larger scale it is worth to include in Shift2Rail.

Idea 11. Vertical moving switch blade

Idea Description

The transition between the stock and switch rail is replaced with a vertical moving switch blade. The same approach could be applied at the crossing in place of a swing nose design.

The system could be mechanically interlocked or independently driven with appropriate locking and detection systems per vertically moved switch blade.

Idea Diagram(s)

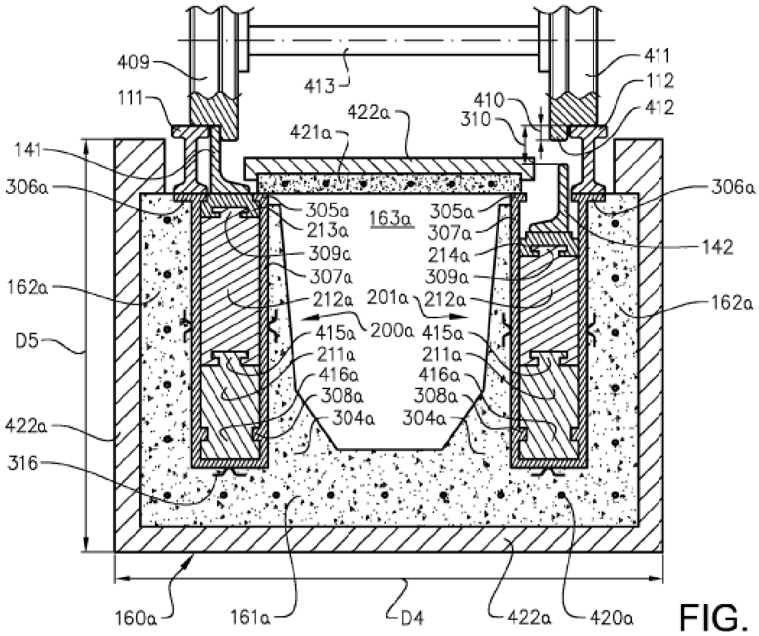


FIG. 4

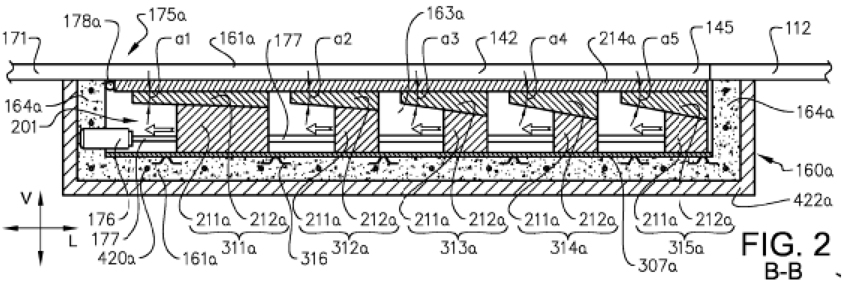


FIG. 2
B-B

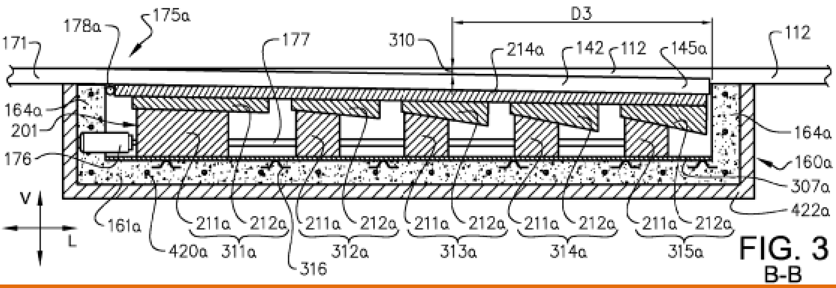


FIG. 3
B-B

Existing Knowledge References

International Patent: WO 2016/148631 A1 as document “WO_002016148631_A1. PDF” in the cooperation tool

Idea Key Requirement Information	
Design / Build	Step change with new design.
Safety	Rail profiles and derailment risk same as existing system. Appropriate locking and detection design required.
Approval / Test / Trial	Has been tested in Holland according to the inventor, unclear how and what has been tested. In Sweden the idea is based on other principles for the movement than in Holland.
Maintenance / Modularity / Construction Site Logistics	To be able to maintain the moving mechanism which is below the switch blade some kind of modular design is needed for inspection and repair. The point motor can be kept outside the moving plates and is easier to access. It is also essential that the container is sealed in a way that dirt does not come into the container.
Operate	Improved reliability by removing susceptibility of the switch becoming obstructed. Novel actuation, locking and detection required.
Environmental	The origin of the idea was to make the design not susceptible to snow and ice and that heating was not necessary. All sliding surface will be frozen at temperature below zero. Therefore it is necessary to heat at least one surface. This heating might be less than what is necessary today.
Other	It has been mentioned that it might be possible to introduce cant of perhaps 40 mm in the lower rail. If so the S&C can have increased speed in diverging route, increasing capacity.
WP2 progression capability	Existing capability because there is willingness from company Vertex to contribute information via Trafikverket.

Idea 12. Multi path panel

Idea Description

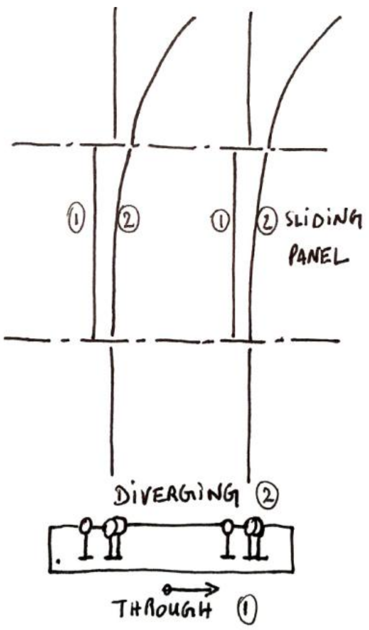
The proposed concept is based on the principle of having a ‘sliding panel’ capable of incorporating highly degradation resistant novel steel compositions. This might take the form of embedded rails or better, can incorporate accurately machined grooves within an appropriate metal insert, thus allowing the desired rail shape and curvature to be implemented. The panel can slide into at least two fixed positions to assume either diverging or through route activation. The entire ‘panel’ sits within a “clean environment” principle for optimal performance and minimal maintenance and human intervention.

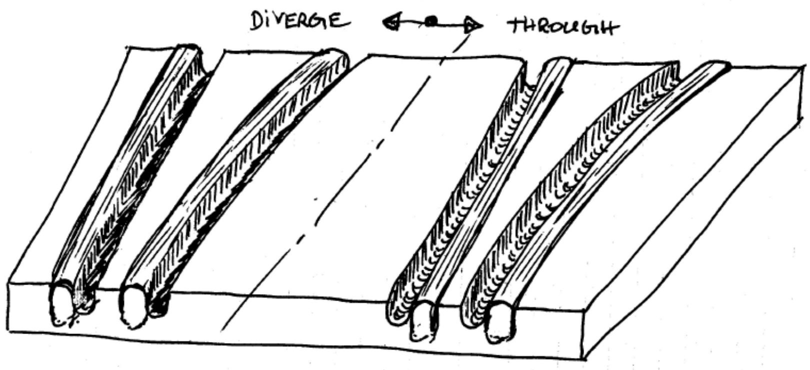
Appropriate sensors and redundancy are required to ensure flaw free functioning. The same concept is applicable to replacing crossings, where the plate would be smaller in size and focused on the crossing footprint area. This could be an initial step towards introducing the approach.

The sliding plate system would be best integrated into slab track applications or part of a complete slab track turnout solution, offering the possibility to manage the consistency of support along each of the panels to ensure an optimum ride and homogeneous vertical settlement along the turnout as well as minimal lateral misalignment over time.

For high speed applications (here only slow speed freight), appropriate design would need to be developed to join the rail end either sides of the panel to ensure a continuous contact transition (i.e. not a right angle joint).

Idea Diagram(s)





Existing Knowledge References

See Section 12B.7B.7.

Idea Key Requirement Information	
Design / Build	Step change with new design.
Safety	Does not use a vulnerable switch rail. Consequently there is no chipping of switch tips. Trailing moves would not be possible.
Approval / Test / Trial	Reliable driving, locking and detection is the development focus. Known rail profiles and geometry can be machined directly into the system.
Maintenance / Modularity / Construction Site Logistics	Does not use a vulnerable switch rail. Consequently there is no chipping of switch tips. Introduces new gaps comparable with rail joints.
Operate	Improved reliability by removing susceptibility of the switch becoming obstructed. Novel actuation, locking and detection required.
Environmental	No significant difference to today’s technology.
Other	-
WP2 progression capability	-

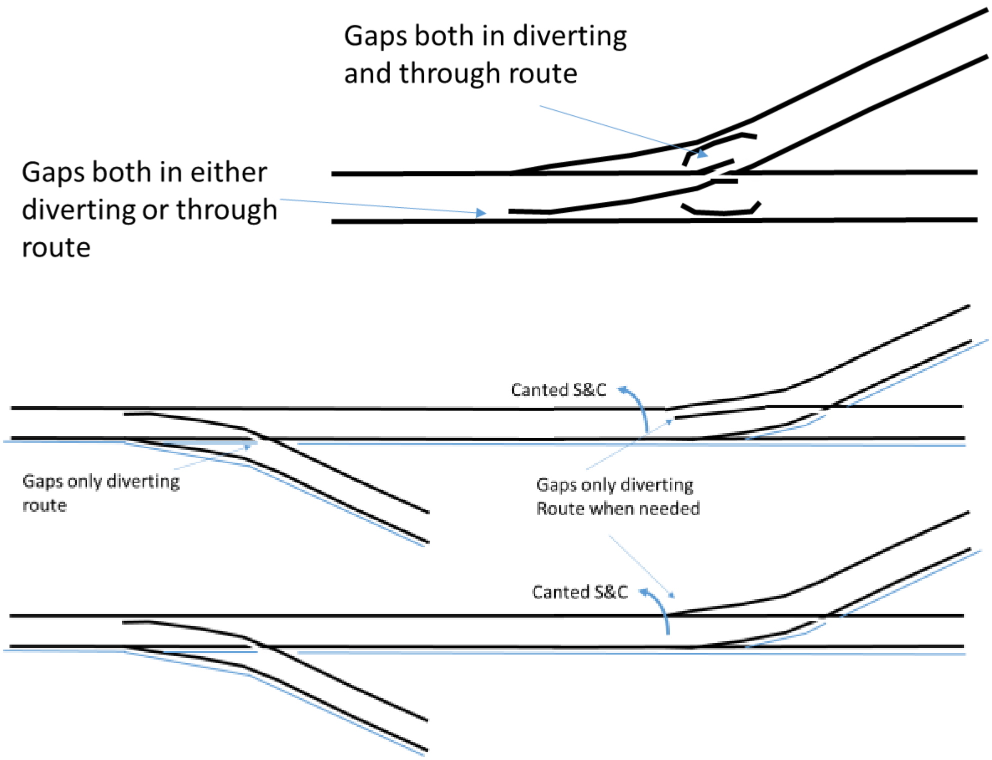
Idea 13. Single Flange Steering

Idea Description

By removing the flange from one side of the vehicle there is no longer a requirement for both switch and crossing gaps on the opposite rail; the 'flat' wheel can be directed in either direction. All of the guidance is carried out by the remaining flanged wheel and correct cant for the diverging route.

If the wheel flange is removed on one side some kind of other measure is needed to enable safety against the increased derailment risk (for instance continuous check rail) some gaps can be eliminated. Assume also that it is possible to just have the through route only in the left leg of the S&C. This is possible by using cant for S&Cs that needs to be placed with a radius on the left leg.

Idea Diagram(s)



Existing Knowledge References

No relevant existing knowledge.

Idea Key Requirement Information	
Design / Build	Half way of a step change.
Safety	Can be used in test track to go further to trains without flanges and thereby eliminate needs for gaps.
Approval / Test / Trial	Even if the design can be made safe, it is no step further. It creates more safety issues than it solves.
Maintenance / Modularity / Construction Site Logistics	Reduced crossing wear leads to reduced maintenance requirements. Reduced gauge face wear on diverging switch.
Operate	No change.
Environmental	Only one switch blade needs to be moved.
Other	Possibly less maintenance and less failures.
WP2 progression capability	No improvement.

7.3 Enabling Technologies

During the Optikrea idea generation process it became apparent that there were numerous solutions suggested that could in fact be applied to many designs of switch and crossing. These suggestions are included in this Enabling Technology section, with the proposition to consider their application in the development of Incremental Improvement and Radical Redesign of track changing systems.

Idea 14. Removable contact surfaces

Idea Description

High performance materials with outstanding strength and hardness properties, such as Boron Steel alloys, are much more resistant to damage. Since these materials are often more expensive it becomes uneconomical to manufacture entire components from them, especially if not all elements of the design require the enhanced material property.

Innovative manufacturing processes can produce these materials in forms that can be applied only to the contact surfaces of the component. This saves on both the cost of manufacture and also the cost of replacement. The component can be refurbished easily by replacing the contact surface, retaining the majority of its original material and installation.

This principle may be difficult to apply to existing switch rails due to their reduced and variable profile, existing stock rails, crossings and wing rails may be better candidates. The varied profile of a crossing may present some challenges.

The concept has been tested in laboratory and a special low speed track for durability. Network test for standard plain line started in summer 2016. The principle has not yet been discussed for S&C.

Non-destructive testing of the material below the replaceable surface will become more difficult.

Idea Diagram(s)

Existing Knowledge References

See Section B.6.

Idea 15. Formation treatments for designed ground support conditions

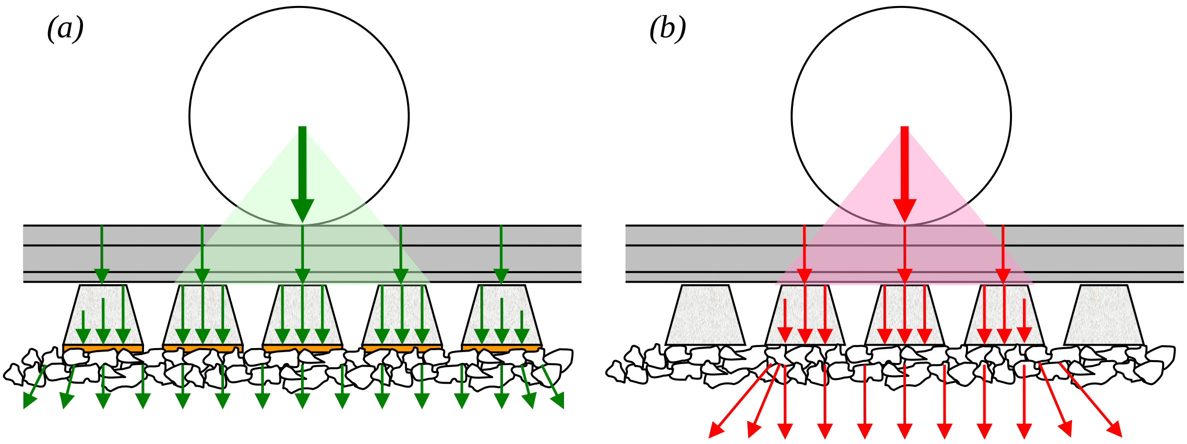
Idea Description

The aim is to improve the substructure and/or tune the performance of the substructure to match that of the superstructure (improved holistic design of the track superstructure and substructure as a single system), by some or all of:

- increasing the thickness of the ballast layer to reduce the loads transmitted to the subgrade;
- enhancing the resilient strength and stiffness of the substructure materials, for example through the targeted use of geogrids, random fibre reinforcement of the ballast, adjusting the ballast grading (particle size distribution curve), introduction of an asphalt underlay, etc;
- adjusting elements of the support system stiffness through, for example, variable bearer width, depth and/or spacing, or the use of under sleeper pads or railpads of controlled variation is stiffness, in a controlled way so as to compensate for changes in the bending stiffness of the rails and crossing components to give a smooth variation in system stiffness and deflection through the whole of the crossing;
- alternative designs of long bearers that avoid undesirable motions involving interactions between tracks.

Idea Diagram(s)

An example of formation treatment is under sleeper pads:



Please see Existing Knowledge References for information on other treatments.

Existing Knowledge References

See References [1][4][5][6][7][8][9][10]

Idea 16. Improved Vehicles: Active Steering

Idea Description

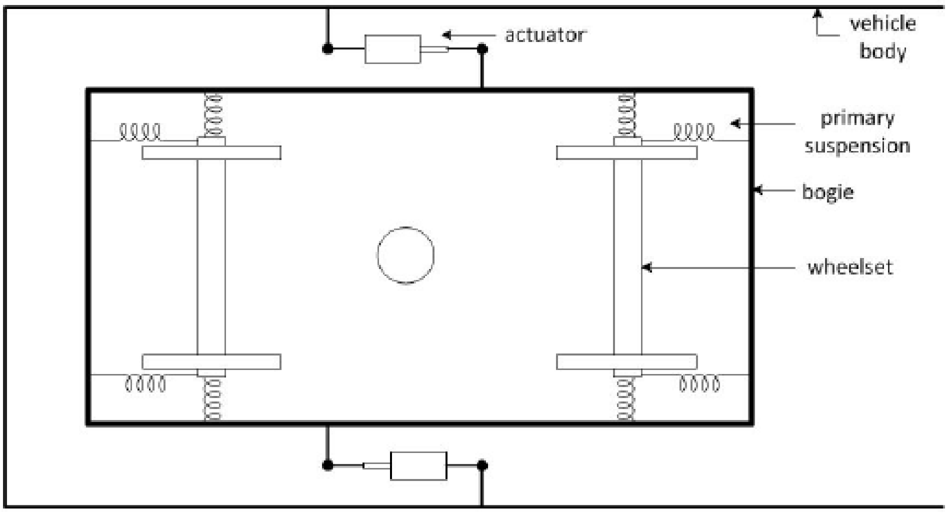
Actively steered rail vehicles are introduced that are compatible with today's infrastructure.

The active steering elements would be used to overcome the inevitable compromises in wheel/rail interface that we introduce due to vehicle and switch geometry. This would bring benefits such as; a reduction in wheel and rail wear, or increased speed through switches.

These vehicles would be compatible with existing infrastructure and enable the development of radical infrastructure.

Idea Diagram(s)

An example of Active Steering is the addition of an actuator for Secondary Yaw Control as shown below. Other possibilities can be seen in the Existing Knowledge Reference below.



Existing Knowledge References

More information available in Section 9.2.

Idea 17. Interleaved Track

Idea Description

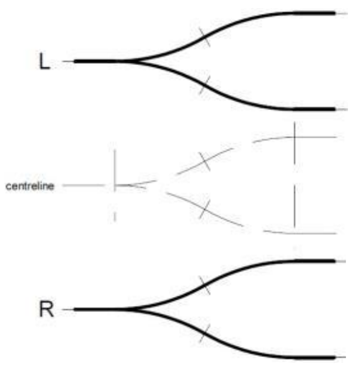
Interleaved tracks provide an opportunity to run two tracks along the same railway corridor. Traffic can be separated by type, with the corresponding track incorporating traffic specific features. The diagram shows embedded twin tracks where the left track has a larger rail profile than the right track, perhaps for heavier freight.

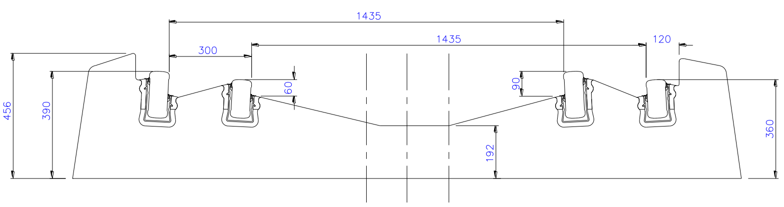
This idea relates to the development of an arrangement for steering vehicles to one track or the other.

Interleaved Track has no extra rail cost (accounting for the same wear rate); at least 50% less delay due to any particular rail defect; use freight lines for high speed passengers during rail change; can have different cant for high speed and for freight; provides alternative track for maintenance and emergencies; enables different grinding regimes appropriate to the traffic type; freight damaged track does not affect high speed performance; enables different rails for different loads; high speed freight enabled. In particular it enables each rail to have its ideal rail head to wheel interface.

Left, right or symmetrical switches can be continued to include a crossing or alternatively used with reverse curves to split a standard track into a twin-gauge track and back again. The left diagram shows the plan-view geometry, and the right diagram shows twin interlaced tracks. Work is required to determine what track switching assets might look like in this configuration.

Idea Diagram(s)





Existing Knowledge References

No relevant existing knowledge.

Idea 18. Continuous and Consistent Rail Support

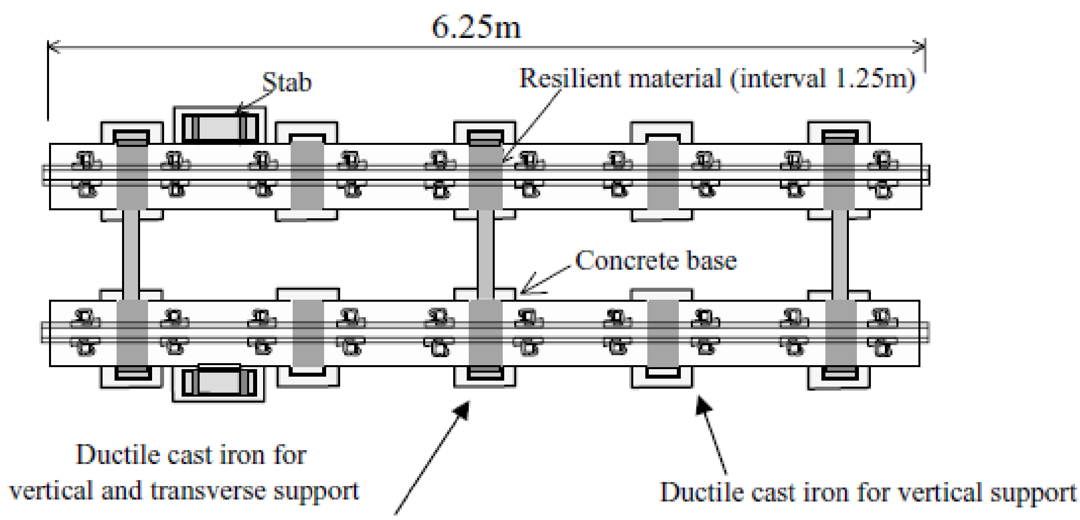
Idea Description

As opposed to the current solutions with discrete bearers, in this idea the rail is continuously in contact with the support system and providing the same level of support at all times and all positions for the rail. This reduces the resonance of the rail as well as reducing the bending moment induced in the rail between supports as a vehicle passes.

Numerous types of continuous support systems are currently available including tubular track, embedded rail and ladder track. These systems use a variety of longitudinal rail supports, either continually retaining the rail by embedding it, or discretely retaining it with surface fasteners.

There's also an opportunity to improve vertical resilience while retaining good resistance to lateral movement of rails under load, to eliminate rail fastenings and to improve life cycle cost by considering novel rail support systems. The task is to consider how best to apply these techniques to S&C.

Idea Diagram(s)



Existing Knowledge References

Further information on current implementations of ladder technology can be found in Section B.8 and in the Innotrack final technical report [11].

ERT has developed its embedded rail with integral lateral and vertical stiffness and an efficient method of installation. Latterly guarded and flanged versions have been developed [11].

8 Idea Evaluation Methodology

In2Rail has to recommend to the Commission solutions worthy of being taken forward in Shift2Rail. Almost all the work packages / tasks require demonstration of the decision process. There are many decisions to be made in the project.

This chapter develops work initiated in the Innotrack project [11] and intends to bring consistency, simplicity and transparency to the decision making process throughout the In2Rail output, and later throughout Shift2Rail. This process will be a key recommendation of In2Rail and also issued as a Guideline updating that in Innotrack.

8.1 Value Analysis Introduction

It is necessary to compare available options which have very differing attributes/benefits. The decisions made have to be transparent and auditable. To achieve this, the analysis system itself needs to be simple, thorough, accurate and unbiased.

This section proposes, develops and explains the use of the system, initially presented in Innotrack, which provides a well proven benefit to cost comparison process that avoids the complex mathematical models often applied in such analyses.

8.1.1 Objective and Aims

The over-riding requirement is that the correct decision is reached without depending on exactitudes:

- it puts a monetary estimate on non-monetary items (like comfort, aesthetics, etc.);
- it focuses on the best value solution within the available funds;
- it can be used for all option decisions whether the cost is known or not;
- it will lead to a more robust outcome/recommendation/decision;
- it shows the value obtained from each Euro or how many cents in each Euro is wasted if/when an option other than the best value option is chosen.

8.1.2 Definitions

The following terms are used in this section:

- **Assessment –** the determination of the benefits / attributes of each option by testing, inspection, monitoring, trials, modelling etc;
- **Evaluation –** the determination of the attributes of an option based on the results of the Assessment or, in their absence, on professional judgement;
- **Analysis –** the final mathematical process providing the required option selection / decision;
- **Value –** the benefit to cost ratio (the bang for the buck).

8.1.3 Process Outline

Assessment and Evaluation is best conducted with the participants engaging in face to face discussion.

It should be noted that the Assessment of each Option (Refer to Step 6 below) may be complex, time consuming and involve monitoring, tests, trials, calculations, FE Analysis, modelling etc. as well as objective judgements. It should identify the problems, concerns, constraints and expectations and assess how well each option addresses them. The 'needs' will be more important than the 'wants'. The needs are those items without which the solution is not a viable one. The needs and wants combine to provide the "importance criteria".

The Assessment must precede the Evaluation of each of the options against the importance criteria. Evaluations based on factual numerical comparison are better than objective evaluations. The cost of each of the options (or an objective comparative number) is the last item to be input. It is not required before the evaluation is complete. It is often determined in parallel to or after the assessments or by others. The Analysis is the final and purely mathematical step. It includes the costs.

The main steps in the basic process are:

- **Step 1.** State the objective: the most critical step requiring careful thought and consensus;
- **Step 2.** Presentation of the issues and problems;
- **Step 3.** Determination of the Assessment/importance criteria used to judge a good outcome;
- **Step 4.** Determine the importance/significance rating of each of the Criteria;
- **Step 5.** Identification of viable options;
- **Step 6.** Assess the options (tests, trials, objective assessment etc.);
- **Step 7.** Evaluate each option against each criteria (ignoring the criteria weightings) using the output from Step 6. The final importance weightings from Step 4 *MUST NOT BE AVAILABLE / VISIBLE* to the evaluators of ***Step 7***;
- **Step 8.** Run the analysis to compare the total benefits offered by each option;
- **Step 9.** Determine the cost of each option (be it all or any of installed, operational, renewal, replacement, removal – life cycle costs);
- **Step 10.** Run the full Analysis to determine the saving offered by the best value option over each of the other options;
- **Step 11.** Recommend this solution be adopted and state the implications of not doing so.

Figure 8.1 presents the value analysis template to be used for evaluating each idea / concept against a chosen benchmark concept. It is recommended that the benchmark is an existing design in order assesses the benefits of replacing existing best practice.

Category	Assessment / Importance Criteria	Importance Weighting	Idea Assessment										
			OPTION A	IDEA 1	IDEA 2	IDEA 3	IDEA 4	IDEA 5	IDEA 6	IDEA 7	IDEA 8	IDEA 9	IDEA 10
			BENCHMARK OPTION *[Usually Existing for Comparison]*	Description 1	Description 2	Description 3	Description 4	Description 5	Description 6	Description 7	Description 8	Description 9	Description 10
Cat. 1													
Cat. 2													
Cat. 3													
Cat. 4													
Cat. 5													
Etc…													

Figure 8.1: Value Analysis Template

8.1.4 Process Modifications for Remote Projects

The circumstances of international projects, such as In2Rail, with a diverse range of organisations operating in different countries/locations on limited travel and time budgets often preclude such physical meetings. However the decisions still need to be made.

Thus an approach is presented here to enable the analysis to proceed based on an electronic iterative process. This is a somewhat less efficient approach but, importantly, arrives at approximately the same benefits/outcome/decision.

The Innotrack guidelines have been revised and the necessary changes also added to enable the process to take place remotely / electronically if face to face meetings are definitely not possible.

In Steps 3, 4 and 7 it is normally possible, when face to face, to enable significant differences of opinion to be debated and for all participants to hear the arguments from both sides before making a judgement. This invariably leads to a consensus view/voting when experienced and wise professionals in the subject are the participants. It also brings all participants up to the level of the best informed.

The master analysis will not be able to be closed out until all the participants have completed all their assessment and the values are within ±2 of a mean (out of 10). However, in order for this to take place remotely the process needs to be managed iteratively. Thus additional steps are necessary.

The key differences with the remote process are:

- For Steps 3, 4 and 7 each participant needs to include their own view before seeing that of the other participants;
- Only in the case of significant differences of opinion, each participant with the extreme ratings needs to explain succinctly their position on the issue;
- As each participant will not initially see the rating of the others, the person managing this process remotely (Work Package or Task Leader) will ask for this explanation when necessary. A column has been provided for this to be recorded;
- The whole group then needs to revisit their rating to take into account any new factors that have been raised. The issue is only closed out when consensus is reached.

Where face-to-face meetings/workshops/debates can take place, a revised Innotrack format (presented hereafter as a new guideline in this project) will be sufficient and compatible with the electronic meeting output. By exception, and where the decision making is not too complex, and the participants not too many, any differences in rating could be debated within a web meeting.

Some items are difficult to assess within reasonable effort (see below). In those cases the evaluation will give an indication, but there may still be a need for additional considerations/analyses. From the Innotrack detailed instructions it will be seen that explanations/definitions/clarity should be provided for each of the importance criteria etc. A comments column is provided where extenuating factors are present for issues that are not (fully) addressed by the analysis.

In some cases assessment may be:

- non-linear (e.g. deterioration which is non-existent up to a limit value and then grows exponentially) or;
- (more or less) binary, e.g. allowed noise levels and safety limits or;
- may involve a very large uncertainty and should perhaps be addressed with a sensitivity analysis (e.g. future operational loads) or;
- very dependent on factors that can't be controlled (e.g. some rail profiles give very large deterioration levels for some wheel profiles);
- complicated by secondary considerations (e.g. logistics issues).

8.2 Pre-Assessment

In section 7, 18 potential ideas for the improvement of S&C are identified and initial qualitative information is provided. Section 8.1 details an extensive Value Analysis process which can be used to compare the value of these extremely varied ideas.

Pre-assessment is a light-weight version of that Value Analysis, used to qualitatively assess the feasibility of each initial idea with the goal of developing the most feasible to the point that they can be subject to the full Value Analysis in deliverable 2.6.

This section describes the structured pre-assessment process and how it relates to the 11 step Value Analysis. Since the idea generation method detailed in section 6 is compatible with the Value Analysis, the goal set in section 6.1.2 is used as analysis step 1, whilst the topic mapping activity in section 6.1.1 relates directly to step 2.

All Task contributors were involved in this process, ensuring that the qualitative assessment is based on relevant expert knowledge.

8.2.1 Assessment Criteria and Weighting

The non-functional requirements, identified in section 5.2, were used as the assessment criteria for pre-assessment; since only initial qualitative information is available for each idea it is not possible to carry out assessment at a lower, more detailed level. A more detailed set of system requirements will be utilised for the full Value Analysis.

Whole Life Cost cannot be qualitatively assessed at this stage and therefore is not included in the initial assessment. Two additional criteria are included; 'Other' allows ideas to potentially add information that isn't captured by existing criteria, whereas 'WP2 Capability' enables assessment of the partner's ability to develop the idea within Task 2.3. This is the determination of assessment criteria required by Step 3 of the Value Analysis.

Each contributor independently applied a relative weighting to each criteria to complete step 4. The pre-assessment criteria in priority order are as follows:

Pre-assessment criteria	Average weighting (%)
Safety	15.70
Maintenance / Modularity / Construction site logistics	14.50
Design / Build	13.80
Operation	13.70
WP2 capability to progress idea	12.50
Approval / Test / Trial	11.60
Environmental	10.00
Other (e.g. quick to get to market)	8.20

Table 8.1 Pre-assessment criteria average weightings

8.2.2 Scoring

Step 5 and Step 6 were completed in section 7 by defining each idea and providing quantitative information against each assessment criteria. Step 7 was completed by each contributor assessing each idea against the pre-assessment criteria based on the qualitative information provided. Scores were awarded between 1 and 10; where 1 is low, 10 is high and 5 is equivalent to the current solution. Critically, the average weighting of each criterion was not known to the contributor during assessment.

8.2.3 Results

Scores and criteria weightings were returned to the analysis coordinator in order to complete the analysis required by Step 8. Criteria weightings were averaged and then multiplied by each score. Total scores for each idea were averaged across contributors to give the final weighted average score; these are presented below in descending score order:

Idea ID	Idea Description	Average Total Weighted Score	Variance from 5.00 (%)
1	Improve guiding kinematics - thicker switch blade	**6.41**	**28.2**
8	Flange-back steering	**5.57**	**11.4**
11	Vertical moving switch blade	**5.18**	**3.6**
3	Removable elastic-mounted crossing nose	**5.13**	**2.6**
A	Existing solution	**5.00**	**0.0**
9	Hopping stub switch	**4.97**	**-0.6**
7	Passive infrastructure - active steering	**4.96**	**-0.8**
3	Hopping switch actuator	**4.87**	**-2.6**
12	Multi path panel	**4.79**	**-4.2**
5	Integral switch	**4.70**	**-6.0**
6	Passive infrastructure - separate steering rails	**4.42**	**-11.6**
4	Diverging bridge	**4.37**	**-12.6**
10	Rotating switch rail	**4.05**	**-19.0**
13	Right hand turnouts	**3.68**	**-26.4**

Table 8.2 Initial idea Average Total Weighted Score

Value Analysis steps 9, 10 and 11 are not possible during pre-assessment, as there is not enough information on the cost-benefit ratio of each idea.

8.2.4 Recommendation

Four ideas were scored higher than 5.00, making them potentially more valuable than the current solution; two further ideas scored just below 5.00. Of these six ideas only 8, 11, 9 and 7 are from section 7.2 and therefore radical S&C designs. Idea 9 is outside the scope of In2Rail.

It is therefore recommended that ideas 8, 11 and 7 are considered for deliverable 2.6.

8.3 Tools for Future Technical Assessment

When utilising the Value Analysis tool for the full Evaluation of concepts developed further in the rest of the project, it will be necessary to obtain relevant information for Technical Assessment of each concept. Collecting of the wheel-rail kinematics and vehicle behaviour through the proposed concepts will be simulated. Outputs can be compared both with one another and also with current reference solutions already in use around the network. A UK type C switch with CEN56 or NR60 geometry (slow diverging – fast through) and/or Swedish 60E1-760-1:15, which is a faster turnout, will be used.

The challenges in terms of improving performance have been described in Section 4. Examples of the type of analysis and the corresponding results are also presented in produced from vehicle dynamics simulation with wheel-rail contact (Figure 4.20 to Figure 4.25). The techniques used are based on multibody simulation software (e.g. Simpack or Vi-Rail) which take into consideration the complex interaction between wheels and rails (creep and normal contact forces), as well as the vehicle suspension behaviour while negotiating complex geometry such as switches and crossings. The outputs produced are listed in Section 4.4.4 allowing a direct comparison with the current state of the art S&C on the network and therefore a quantifiable assessment of safety and performance of the proposed concept. The calculation of the wheel-rail contact requires carefully defined input data especially with current S&C design having variable rail sections, generating discontinuity for the wheel-rail kinematic. This produces transient phenomena and resulting impact loads (see Figure 4.24 for impact on vertical forces in crossings) which react with more or less intensity as a function of the coupled vehicle and track structure design.

8.4 Life Cycle Cost approach and Value based decision making

In2Rail have several issues to address. Namely:-

How to manage decision making between widely disparate participants with

1. Several companies in several countries
2. Limited travel budgets
3. Increased use of web communication
4. How to provide a consistent value assessment approach across In2Rail
5. How to determine the benefits in relation to Life Cycle Costs (LCC) when only concepts or short term data are known

We foresee that these issues are likely to get more difficult throughout the life of Shift2Rail; and indeed Horizon 2020. In2Rail wished some previous project would have addressed this but In2Rail is the first project that seems to be truly seeking to demonstrate and to deliver demonstrable Value for the railway. Thus we have adopted and improved upon the process outlined in Deliverable 2.3.6 of the Innotrack project.

The LCC is an addition of all the costs incurred in the provision of the item until it is removed from the network. This includes:

- Install cost;
- Maintenance cost;
- Renewal cost;
- Removal cost;
- Financing cost.

Although needed in several of the In2Rail work packages In2Rail have done the task in order to recommend to the EC an effective process and a way forward for future EC projects to enable option decisions, including LCC ones, made on a Value and Life Cycle Costing basis to be transparent and auditable. Being appropriate to a Deliverable in its own right this work has thus been used in Section 2.6 but developed and detailed in WP 8.3.

9 Concept Development

Of the ideas generated it was discovered that two were already well developed, Flange-back Steering and Vehicle Based Switching. Some further concept development has already been completed for these ideas in order to determine the potential level of information required to conduct the full value analysis as defined in Section 8. After the Initial Idea Evaluation phase has been completed it is likely that other ideas will be developed to this level.

9.1 Flange-back Steering

The Flange-back Steering (FBS) concept is introduced in Idea 8, where its basic operation is described.

One of the concept arrangements described therein is illustrated in Figure 9.1. The range of FBS applications ERT is working on is called SureSwitch. These dispense with the switch rails of a conventional turnout and replace them with steering and control guides, providing a bearing surface upon the back of the passing wheels.

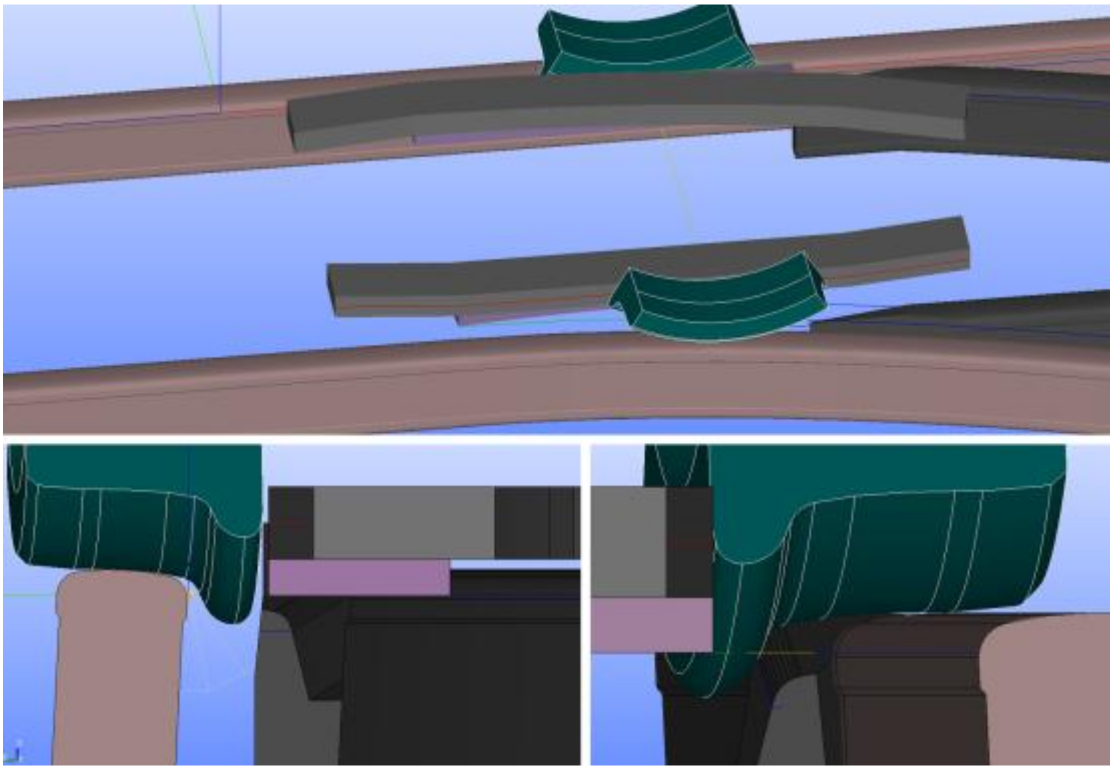


Figure 9.1: SureSwitch Concept

9.1.1 Key Parameters

Figure 9.2 shows elevation cross-sections at two key locations in the concept 'toes' and 'knees'. The black lines represent fixed parts of the switch, while the red and blue lines are alternative guiding edges which must be put in place by a mechanism of some kind.

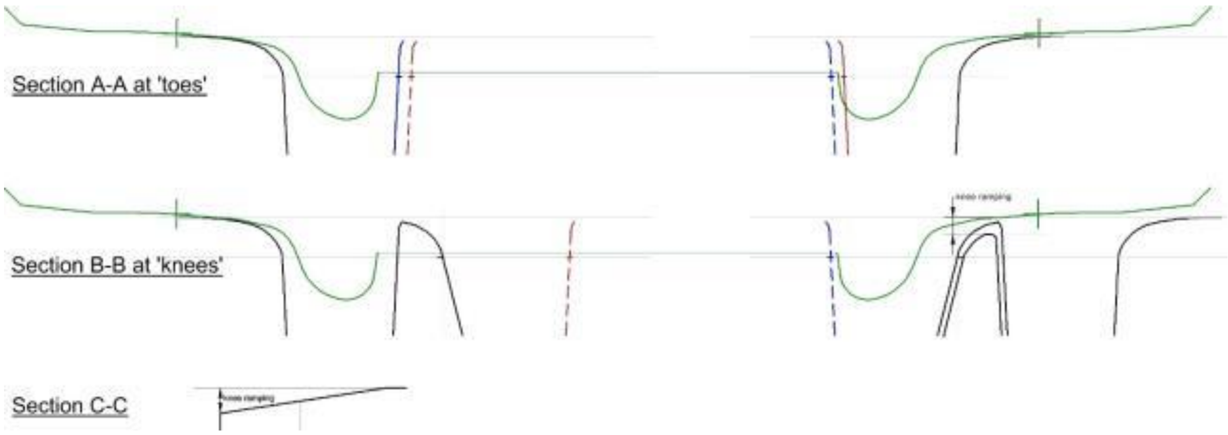


Figure 9.2: Key elevations

To illustrate the principles, diagrams are used which show multiple cross-section views through the switch, at key positions and for both steering and control purposes. The particular scenario used here is for main line type railways with 1435mm gauge, and is illustrated with a P8 wheel. Figure 9.3 focuses on the knee and provides most of the information needed. Figure 9.4 is at the toe and a typical intermediate position in the switches.

9.1.1.1 'Knees'

In Figure 9.3 the active (full blue and red lines) elements are not shown, but instead the knee is a fixed element and is therefore in black. The active control face is a blue dashed line. Nominal dimensions are shown in the top diagram.

The wheelset and track gauge are 1360 and 1435 mm respectively and are both shortened by 1200 mm for clarity. In the other diagrams, gauge is varied from 1432 to 1438 mm and the working dimensions for flangeways are 38 to 41 for the steering face and 41 to 44 for the control face. These are typical of the flangeways used in main line crossings where the tasks of optimising wheel tyre sharing during load transfer and protecting the knee are analogous to the those in fixed crossings.

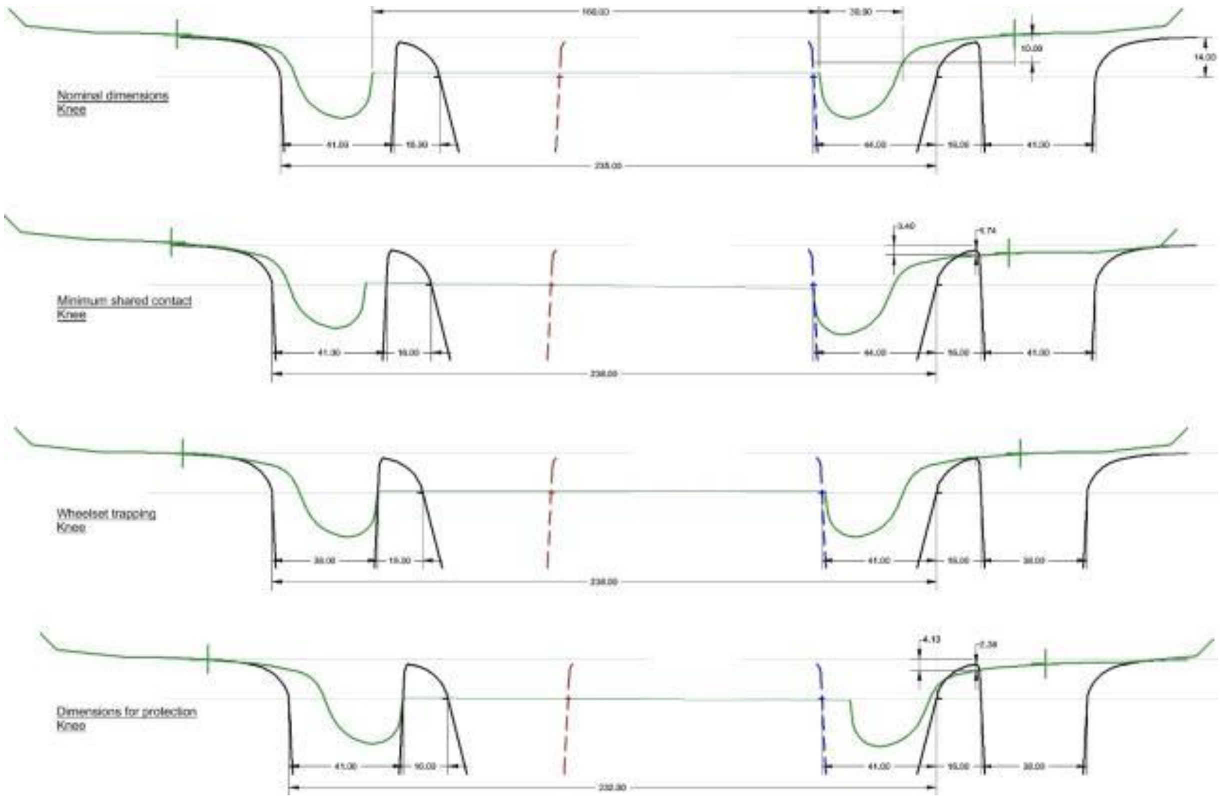


Figure 9.3: Key Cross-sections (Knee)

These parameters in combination are tested in Figure 9.3 for minimum shared contact, avoidance of wheelset trapping, and protection of the knee against clashing with the wheel flange. Knee protection is needed when a wheelset with worn inside flanges (not shown) engages with a flangeway gap at maximum and track gauge at minimum. In the corresponding diagram (bottom of Figure 9.3) there is still adequate clearance laterally but there would potentially be a vertical clash. This is addressed by providing a top relief or ramping of the knee, much like the same relief which is provided on a crossing nose.

Minimum shared contact and the potential for wheelset trapping at the knee are demonstrated in the second and third diagrams in Figure 9.3. Both these are shown at the maximum track gauge, when shared contact is least and the risk of wheelset trapping is highest. The tested combination of track dimensions and tolerances indicates that wider track gauge or narrower flangeways (when unworn) would trap this wheelset and therefore wouldn't work. A control to prevent any trapping is thus required.

Minimum shared contact occurs at maximum track gauge with maximum (and worn) flangeways. These are shown in the second diagram in Figure 9.3. The function of the control face can now be explained. If there were no control face, i.e. if the blue dashed line were missing, then a wheelset which is shifted to the left would have very little contact with the right-hand running rail when first engaging with the knee. The control face limits the 'over-run', or lateral shift to the left, to the size of the control flangeway. It can also be seen that widening the flangeways reduces the shared contact.

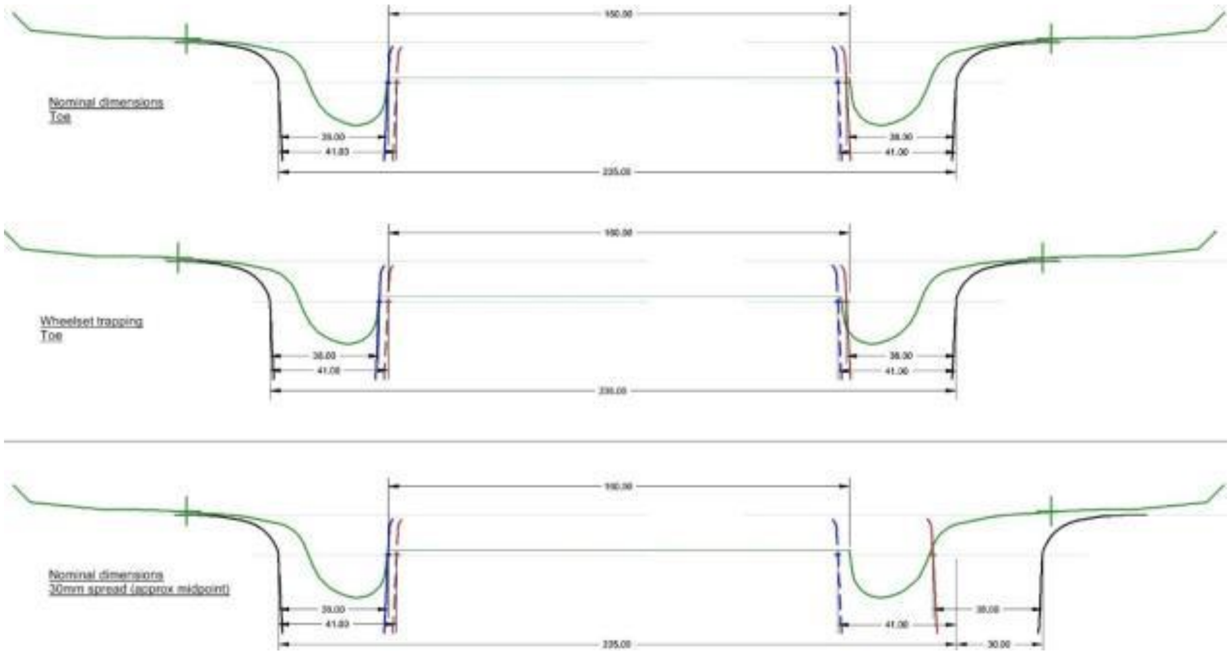


Figure 9.4: Key Cross-sections (Toes)

9.1.1.2 'Toes'

Figure 9.4 illustrates the situation within the SureSwitch body where there are 'switchable' active and retracted steering and control faces. At the toes the switches are shown at nominal dimensions for track gauge and flangeways and also for maximum track gauge.

The bottom diagram shows the various guidance faces at a point somewhere near the middle of the switches.

9.1.2 Parameter Variations

The values of the parameters used in the above illustration are subject to change as more data is gathered and considered. Typical values for urban railways will be different and have different consequences for detailed design. Values for high speed and freight, and values consistent with interoperability requirements, may also be different.

9.1.3 Operating Mechanism

Several different guidance mechanism concepts have been identified. The alternative guiding edges can be placed by moving something like a check or guard rail in or out of position using bending, hinging, rotation, or translation in lateral, longitudinal or vertical planes. Actuation and locking can employ either existing or novel equipment. Detection can provide simple conventional state reporting, more complex measurement, or smarter communication and diagnostics.

The method of operation, that is, how the guidance faces are placed in their alternative positions for straight or diverging, steering or control (of overrun), may dictate the shape of the faces and how they are physically supported. These factors are considered in this section.

9.1.3.1 Translation or flexing

In Figure 9.5 below the principal components are shown in a form in which steering bars (purple) ‘toggle’ simply; either one or the other is engaged. In the upper diagram the straight steering bar is active and guides one wheel while lateral shift is also controlled by the other wheel and the control bar (orange). The control bars in this embodiment are fixed in position; they sit above the steering bars providing some protection, and they incorporate entry/exit flares.

In the lower diagram the diverging steering bar is active. The next wheelset in the facing direction will be guided by it towards the curved route.

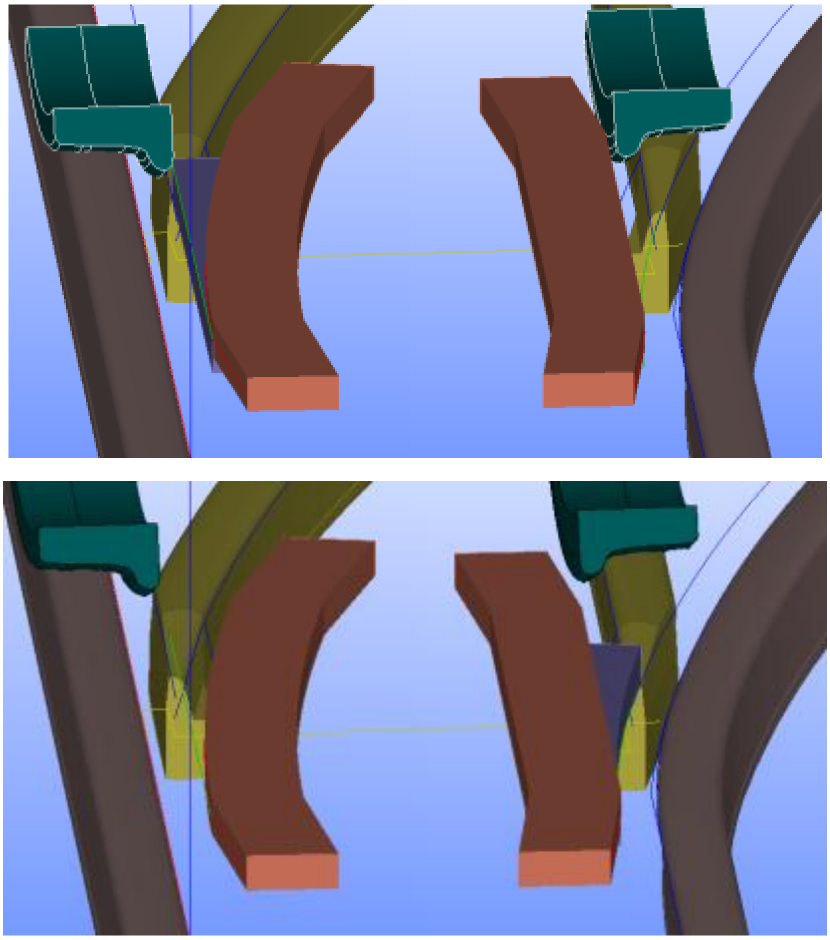


Figure 9.5: Translation or flexure concept

In these diagrams an embedded rail is used but a flat-bottom or other rail can equally be used since at this stage we are only considering the rail-wheel interfaces provided by the steering bar and control bar. The ‘toggle’ is done by lateral translation but a flexural method (as used in conventional switches), or translation in vertical or longitudinal directions or any combination of these as found to be beneficial, could be employed.

9.1.3.2 Rotary

The rotary concept is somewhat different in operation. Control and steering faces are built into two 'states' of a pair of cylindrical arrangements as shown in Figure 9.6 so that when one cylinder presents a steering face the other presents a control face.

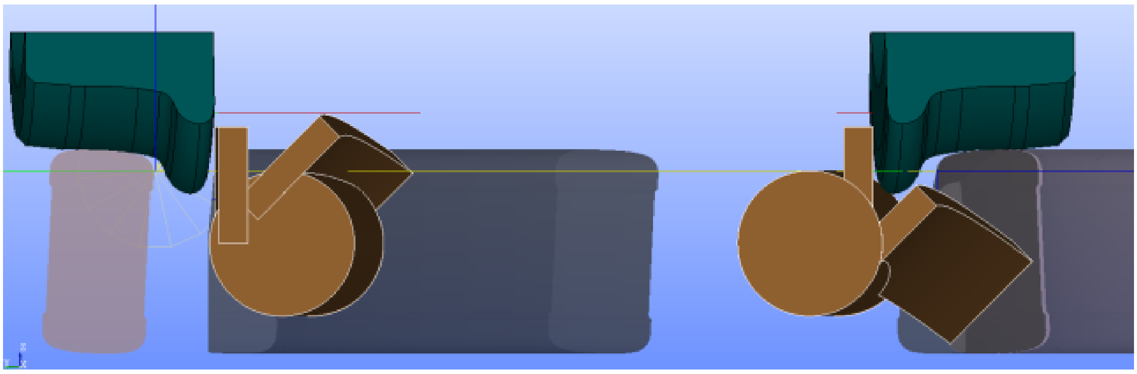


Figure 9.6: Rotary concept

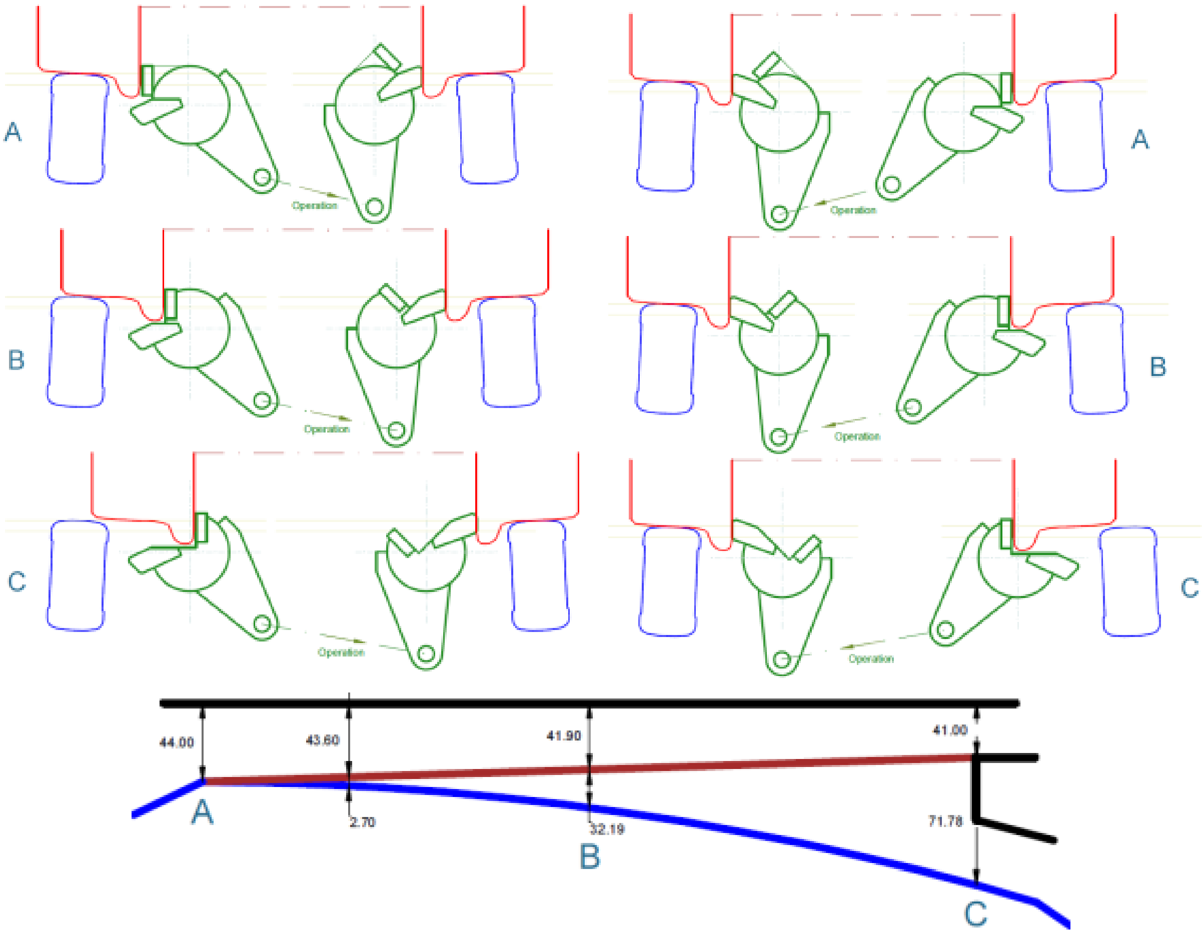


Figure 9.7: Geometry of rotary operation

Figure 9.7 shows that the bars which form the guide faces can be arranged so that wheel flangeway passage is unobstructed. In this example there are three points of operation and there may be three points of locking or detection, or more or less depending on the achievability of integrity of position. These are labelled A B and C and the two position states at each are shown in cross-section. Alternatively the cross-sections can be thought of as those which exist at any one time, one on the left and the other on the right of the direction of travel.

9.1.4 Geometry Solutions

9.1.4.1 Baseline

In conventional switches the switch toes are at the 'Mathematical' intersection Point (MP) of the outer or highside radius and the through or main line running edges. The taper of the switch rail is from the switch toe to the back of the headcut, where the head width is 70mm.

A typical UK switch is used as a benchmark. Its geometric relationships are defined in ref 1. One of the most prevalent and established switch designs is the CV which has a length of switch planing or taper of approximately 4.25m. The CV is taken as a baseline design for comparison purposes and for designing a compatible SureSwitch module. In this design the MP and RP (Real Point, or the physical tip of the switch) are in the same place.

This switch is just one of many in the UK and of even more across Europe and the world. Although they differ in geometry and profile and are optimised for different wheel shapes they have similar principles of operation and the process of designing a compatible and interchangeable SureSwitch module is the same.

9.1.4.2 Equivalent SureSwitch

Whereas the switch tapers from zero to 70mm in conventional switches and is then extended back to give sufficient beam length to flex laterally, in SureSwitch the equivalent core element is the fixed blade. About two-thirds of the tapered part of the conventional switch from the toe end is dispensed with and replaced by the steering and control module.

In SureSwitch the stub of the remaining switch rail is the knee, and the knee is where the spread, or lateral separation of the diverging and the straight running edges, is equal to the wheel flangeway (40mm) plus the knee width (10 to 16mm).

In the vertical range of UK switches [12], for example, the length of the core part of the switch (LSW) of a CV switch (ref 1) is 3646 mm for a steering flangeway of 40mm and a knee width of 16mm. This knee width is typical for fixed crossings, which have a nose of similar configuration to the SureSwitch knee.

Although these switches are common, there are other switch designs in the UK and many other switch geometries around the world for railways from tramways to high speed and from light rail to heavy freight. There is no current reason to believe the Sureswitch principles will not work with these other environments and jurisdictions.

9.1.4.3 Load transfer and guidance

Load transfer and guidance at and near the knee requires a similar treatment to that used for fixed crossings. In Figure 9.3 two of the diagrams show a vertical clash between the wheel profile and the nose which is due to the dipping of the wheel below its normal level as the tyre diverges away from its supporting rail. Although sometimes referred to as 'jumping the gap', this is better described as 'transitioning the gap' and it occurs over a range, not at a single location. This feature is usually matched with a ramp in the knee so the wheel is smoothly carried through and the load transferred with minimum impact. Figure 9.8 shows typical cross-sections through the knee area.

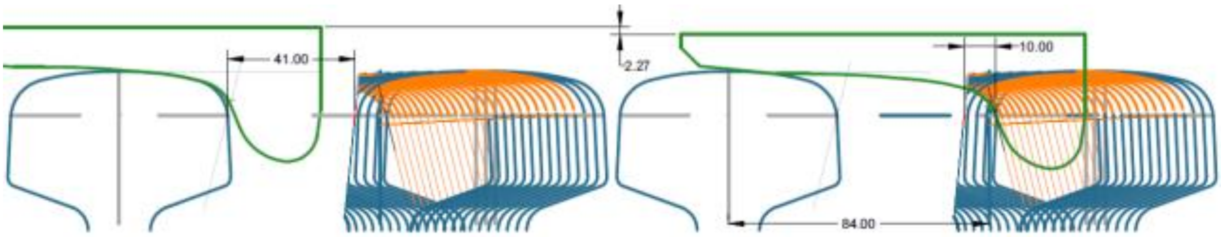


Figure 9.8: Transitioning the Gap

Getting into and out of the SureSwitch requires wheelsets to be brought under guidance control, partly to settle hunting behaviour. This is achieved by fixed guide bars with tapered flangeway. Crossings have analogous requirements which are satisfied by flaring of the wing and check flangeways. Entry and exit flares in common usage have taper angles which are sometimes related to the approach speeds, eg that a UK CV switch has a switch entry angle of 0.52°.

9.1.5 Design and Validation

9.1.5.1 Objective

The object of the current project is to explore whether the SureSwitch concept CAN work, find which of the alternative guidance/mechanism concepts WORKS BEST and in what circumstances, and to enable identification of suitable MATERIALS for the guidance elements and innovative opportunities for AUTONOMOUS self-inspecting, self-adjusting and self-correcting. Validation will be required.

This validation requires desktop studies, virtual trials, manufacture and assembly, laboratory/factory tests and field trials. The core of ERT's current project includes desktop and virtual trials (the latter employing dynamic simulation) of the SureSwitch switches. The extent to which further progress is made depends on the success of these studies in confirming the efficacy of this solution, the input of suitable project partners, and funding.

9.1.6 Applicable Standards

The processes involved in switch design follow the sequence of parts of EN13232. The first part deals with terminology. Note that the term 'knee' is new and unique to SureSwitch therefore not in the standard. The subsequent parts 2 to 4 deal with geometry design, as in figure 1, then design for wheel/rail interaction, and design for switch actuation. This research uses the same processes.

Design for wheel/rail interaction is conducted as follows. The first step is to use the kinematic process described in EN13232-3 to compute suitable flangeways, tolerances and wear to suit the vehicles likely to run on the equipment, as shown in Figure 9.3 and Figure 9.4. This provides detailed information for dynamic simulations of the vehicles interacting with the switches.

Parts 5 to 9 deal with product requirements including manufacturing tolerances. These may be used further downstream, for detailed subsystem and component design.

9.1.6.1 Dynamic Simulation

The profiles shown in Figure 9.8 are translated by ERT into coordinate data which is one of the track inputs to the dynamic simulation process. The technology and expertise for conducting dynamic simulation is provided by the Institute of Railway Research at University of Huddersfield.

Dynamic simulation uses multibody simulation software with virtual vehicles to provide typical forces and to optimise contact and transfer. The steps in this process are:

- convert a conventional CV switch into coordinates and run a simulation as a benchmark;
- use the same overall switch geometry but exchange the conventional switch for a compatible Fixed Blade module (i.e. SureSwitch without steering or control, which is only expected to work in the trailing direction), then repeat the simulation;
- add Steering and Control guide faces and repeat the simulation.

9.1.7 Next Steps

The candidate geometry and the Fixed Blade and SureSwitch modules are not expected to be ‘best solutions’ on first analysis, so it is anticipated that changes will be made based on observations from the dynamic simulation results. We would expect to do a more detailed check of flangeways at the toes and in the body of the switches, and to modify the knee configuration and flangeway flaring. Then we will repeat the dynamic simulation.

Once complete, these findings can be used in the Value Analysis with the aim of determining if the balance of factors is such that the system should be included in the recommendations for Shift2Rail to take forward.

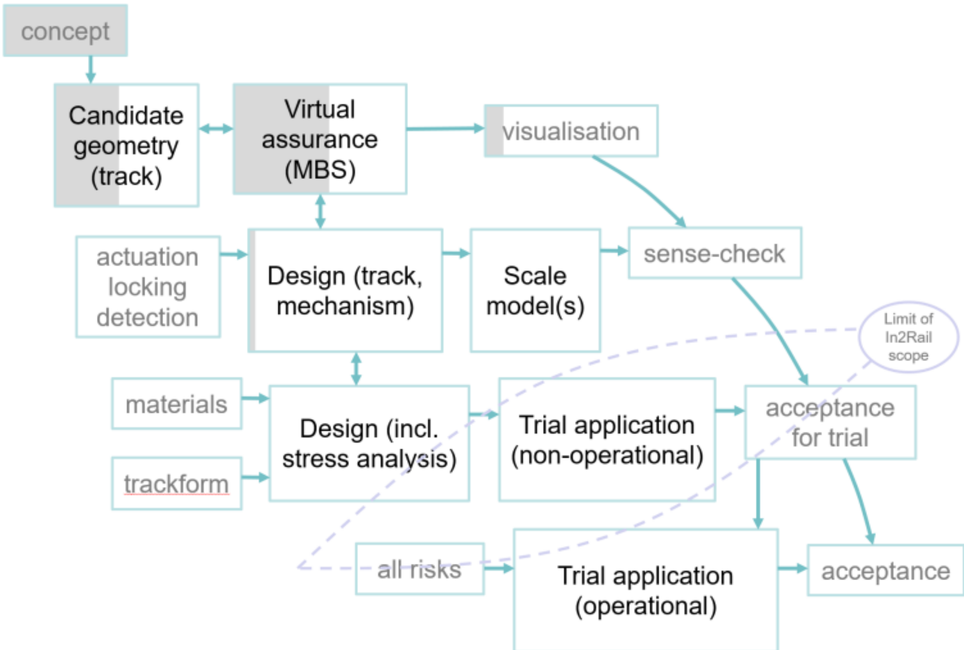


Figure 9.9: Outline Development Plan

Further steps will include considering options for reducing the occupancy, exploring practical solutions for steering and control and for operating the active guide faces, and researching materials for the guide surfaces. We would expect to liaise with researchers in parallel workstreams on autonomy of inspection and maintenance and on methods of detection.

Depending on remaining capacity within the current project, we hope to extend beyond virtual modelling towards physical scale modelling as both a technical visualisation and communication tool. An outline plan of the main steps in the project is shown in Figure 9.9.

Although the studies so far have been based on a typical and widely used UK switch design, we would hope to extend the scope of the study to include the feasibility of modules which would be interchangeable with switches for other railway types and for other European railways' ranges of switches.

9.2 Vehicle-Based Switching

Vehicle based switching moves the active, route-setting, part of the switch from the track to the vehicle. In a conventional switch, the route is set by the position of the switch blades, with the vehicle passively following the set route. Consider a system where the switch is passive and the vehicle actively steers to take the chosen route. This problem is fundamentally difficult to address because it requires simultaneous changes to both track and vehicles. A broad partnership including industry, academia, vehicles and infrastructure expertise would be required to implement such a change. It is also difficult because it challenges tradition and standards, built up on many years of continuous development in a (now) highly regulated industry – part of its inherent awareness of safety and risk, built up the "hard way" by historic catastrophic accidents and failures.

For conventional flanged steel wheel on steel rail systems, current vehicle based switching applications are limited to tramways where the conventional switch is operated from on-board the vehicle, i.e. a vehicle based form of automatic route setting. An application that comes closer to the ultimate vehicle based switching concept would be the automated people movers using rubber tyres on a flat concrete surface, for example Singapore's LRT and those in use at various airports such as Stansted in the UK. In these systems, the lateral forces are provided by the rubber tyre on a concrete surface, as would be the case in a road vehicle. Lateral guidance, the steering input, is provided by a central rail that is also electrified for traction power. Rubber tyre trams and guided busways blur the divide between rail and road type systems further.

Figure 9.10: (Left) Singapore LRT (Jian Kuang via Flickr), (centre) Guided tramway in Padova (Spsmiler via Wikipedia) (right) unguided single to double track transition, Cambridgeshire Busway (Cambridgeshire County Council)

A two-step approach towards vehicle based switching could be proposed. Firstly actively steered rail vehicles are introduced that are compatible with today's infrastructure. The active steering elements would be used to overcome the inevitable compromises in wheel/rail interface that we introduce due to vehicle and switch geometry. This would bring benefits such as; a reduction in wheel and rail wear, increased speed through switches or improved passenger comfort. The second step would be to remove the active parts of the switch and allow the vehicles to steer themselves through the short sections of switch and crossing where full lateral guidance from the track system is not available.

9.2.1 Actively steered rail vehicles

There has been significant effort in the industry to make the load transition from switch rails to stock rails as smooth as possible, e.g. movable crossing nose, kinematic gauge increase to help the axle steer better in the diverging route, lower stiffness switch and crossing panels to reduce vertical forces, modified geometry to reduce wheel movement and impact force. However the demonstrable improvements do not change the fundamental fact that the rapid change of contact condition always leads to dynamic impact loads and accelerated deterioration. However, mechatronic vehicle guidance has not been assessed, either for their impact on current switching technology or how switch design could be rethought to make the most of the potential provided by active vehicle guidance.

Previous work in the field of active vehicle guidance for straight track and curves [14],[15] has identified five distinct vehicle configurations;

1. Secondary Yaw control. The bogie is steered by actuators in place of the conventional yaw dampers, with traditional solid axle wheelsets;
2. Actuated solid wheelsets. Individual conventional solid axle wheelsets within the bogie are independently steered by actuators moving wheelset angle relative to the bogie frame;
3. Actuated independently rotating wheelsets. Similar to b), but the rotation of the 2 wheels within each wheelset is now independent;
4. Driven independently rotating wheelset. Conventional bogie and suspension, with wheelsets where the individual wheels can be driven at different speeds through the curve;
5. Directly steered wheels. Each wheelset is replaced by a steering configuration reminiscent of a road vehicle steered axle, whereby the wheels steered by rotation about the vertical axis, controlled by an actuator.

9.2.1.1 Secondary Yaw control

In the secondary yaw control scheme an actuator is placed between the bogie and the vehicle body. The actuator is placed in the same position as a traditional yaw damper.

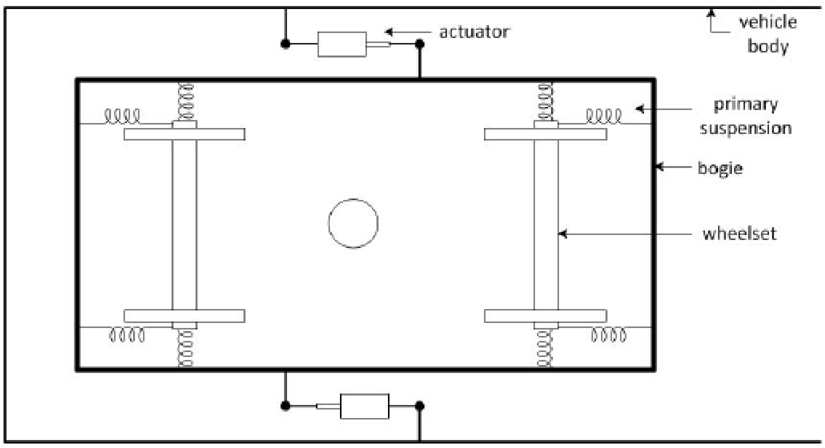


Figure 9.11: Secondary yaw control configuration.

In a passive vehicle, if the primary yaw stiffness is reduced, the curving performance improves but high speed stability is compromised. Secondary yaw control can be used to provide variable yaw damping, overcoming the instability (and a higher potential operating speed), yet allowing improved curving performance. The active control therefore does not improve curving, but allows the use of a soft primary yaw stiffness to improve guidance whilst maintaining stability. Soft primary yaw stiffness has been shown to significantly decrease wear and derailment coefficient [16].

9.2.1.2 Actuated solid wheelset

An actuated solid wheelset system applies a yaw torque directly to the wheelset. This can be done by either using a yaw actuator on each wheelset or a pair of longitudinal actuators working in opposition from the bogie to each axlebox to generate a yaw torque.

An integrated active control approach was studied by a Bombardier-led project [17] where the control torque was applied for both stability and steering. Stability and steering control have different needs because wheelset kinematic modes occur at high frequencies (2 Hz and higher), whereas steering control torques typically have low frequencies (less than 1 Hz). A soft secondary yaw suspension improves curving but degrades stability which is achieved using stability controllers. A full scale demonstrator vehicle on a roller was successfully shown to stabilise at high speeds reducing the natural hunting mode.

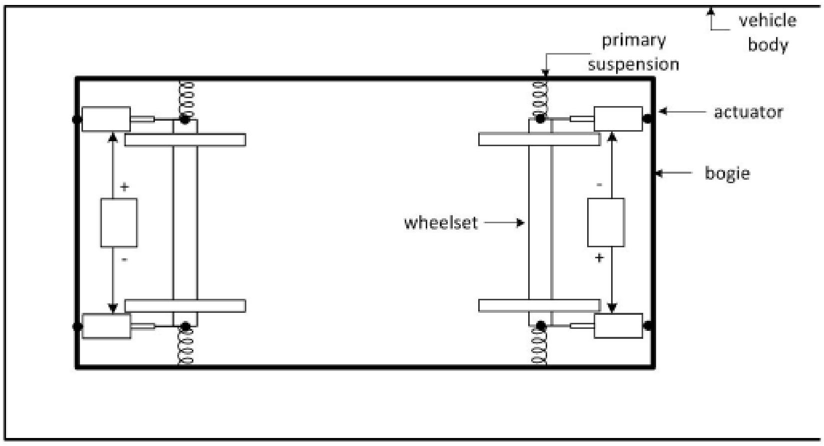


Figure 9.12: Actuated solid wheelset configuration

Curving performance can be further improved by active yaw relaxation [18] where actuators are placed in series with longitudinal springs so that higher frequency oscillations of the wheelset are stabilised by the springs and low bandwidth active control is provided by the actuators. The yaw relaxation allows the wheelsets to take up their natural curving position. Simulation studies show that the leading wheelset has improved curving performance but that of the trailing wheelset are worsened. The best results are obtained when controlling the two wheelsets in a bogie in a coordinated manner such that the difference between the leading and trailing wheelset torques are set to zero and their sum is unaffected.

9.2.1.3 Actuated independently rotating wheelset

A logical progression from the actuated solid wheelset configuration is to apply the same concept to independently rotating wheels. In this configuration, the wheels share a common axle, but are able to rotate about the axle independently. There is no solid connection between the wheels and therefore the longitudinal creep forces are significantly reduced (almost to zero) when compared to solid-axle wheelsets. The actuation effort required for steering is consequently reduced. However, independently rotating wheelsets still suffer from kinematic instability similar to a conventional wheelset, but the stability can be provided by damping rather than a stiffness, which does not affect curving [19]. Unlike solid-axle wheelsets, independently rotating wheelsets need a guidance mechanism that forces the wheelset to follow the track and several strategies have been proposed [20],[21],[22].

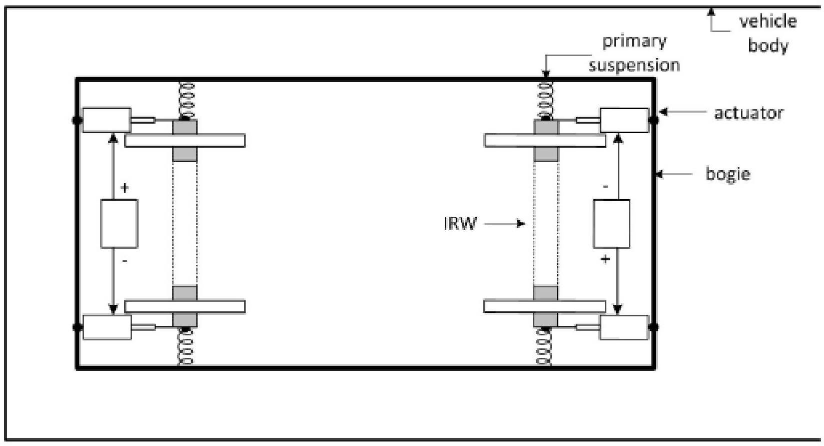


Figure 9.13: Actuated independently rotating wheelset configuration

9.2.1.4 Driven independently rotating wheelset

The aim of driven independently rotating wheelsets is to maintain a difference in rotational speed of the wheels on curves and to drive the wheels on a straight track at the same speed, thus driving the longitudinal creep forces to zero. The relative speed of the wheels is used as the feedback signal, a signal that is already available because it is measured for traction/ braking purposes. Combined strategies for traction and steering have been proposed [23].

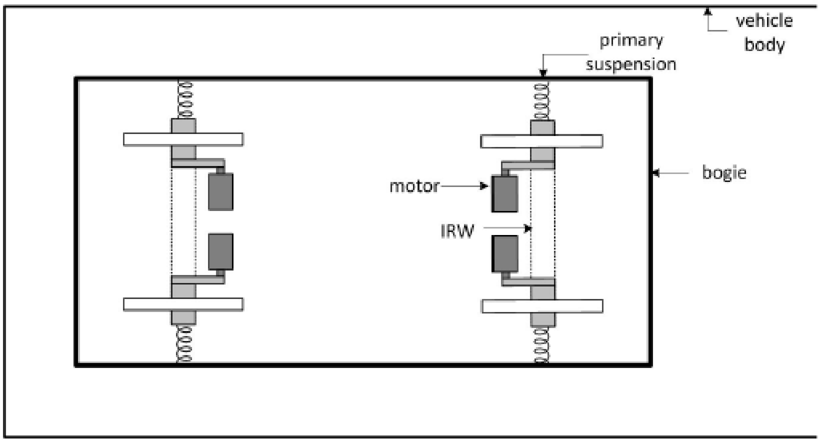


Figure 9.14: Driven independently rotating wheelset configuration

The mechanical integration of the wheel and the traction motor has been developed by SET Ltd. and a prototype "wheelmotor" was retrofitted to a Blackpool tram [24]. Driven independently rotating wheelsets have also been applied to bogie-less vehicles, the motivation being that they are mechanically simpler and lighter [25]. Lighter vehicles lead to a reduction in rolling contact fatigue, reduced maintenance costs and lower energy consumption. Controlling the speed of the motors creates an electronic axle and can mean the wheelsets suffer from all the problems of a solid-axle wheelset including kinematic instability if careful design isn't applied.

9.2.1.5 Directly steered wheels

If wheels are mounted onto a stiff frame as shown in Figure 6 such that their pivots are joined by an active linkage, then the wheels can be directly steered by a lateral displacement of the linkage. This is similar to rack-and-pinion steering mechanism in automobiles where the lateral displacement of the rack imparts a steering angle to the wheels.

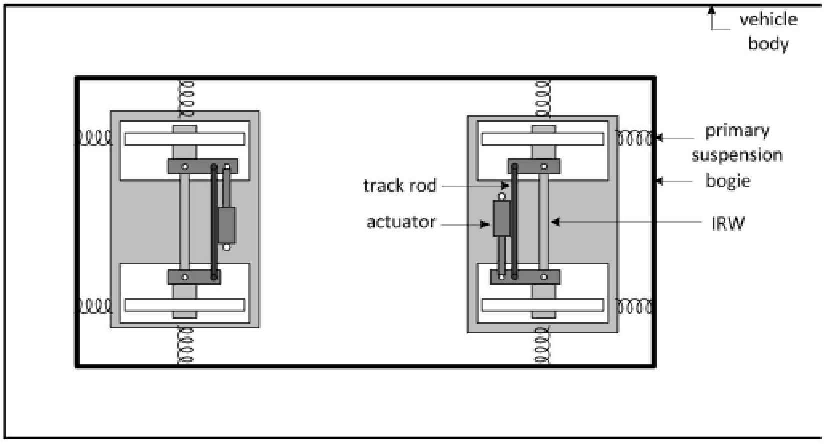


Figure 9.15: Directly steered wheels configuration

The concept of directly steered wheels was first studied by Wickens [26] and the feedback signal was the displacement of the wheel with respect to a reference line fixed to the track. This measurement is not easily accessible but in theory the model shows improved stability and curving performance. DSW was also studied by numerical simulations and tests on a 1/10 roller rig by Michitsuji and Suda [27], where the bogie is designed such that the self-curving ability of a passive wheelset is allowed and an additional steering action is provided on transition curves. In the experiment, the steering action is provided by a motor which also provides yaw damping.

9.2.2 Current Progress

Ongoing work at Loughborough University [13] includes modelling and performance analysis of these five active steering configurations on curved line, plain line, through conventional switches and consideration of passive switches. Performance is being assessed by analysis of lateral and longitudinal creep forces and wear indices. Sensing and actuation requirements are also being identified. This work aligns directly with the objectives of In2Rail WP2 Task 2.3 and has therefore being brought into the In2Rail project to compliment other developments. This will ensure that both the project efficiency and potential solution benefits are maximised through adopting a whole system approach.

It is well understood that for actively guided independently rotating wheelsets (either as part of a bogie or in a more radical two axle vehicle) [28] the longitudinal creep forces diminish to almost zero, reducing a predominant wear mechanism. This has been demonstrated for straight and curved tracked and the conjecture is that this will equally apply to more complex geometries such as track switches. However the impact of the vertical force component over the crossing in a conventional switch and sensing for critical feedback measurements such as wheel/rail relative position also need consideration.

9.2.2.1 Passive vehicle modelling and validation

The wheel rail dynamics of a full railway vehicle with two bogies and two wheelsets on each bogie was developed by extending the model of a single wheelset with a suspended mass. For assessing stability and guidance, the plan view dynamics, which are described by the lateral and yaw modes, are sufficient.

The full vehicle model is run on straight and curved sections of track to assess the longitudinal and lateral creep forces generated at the wheel-rail contact and the consequent wear performance. Two sets of models are developed for the passive vehicle - one in Simulink and the other in Simpack.

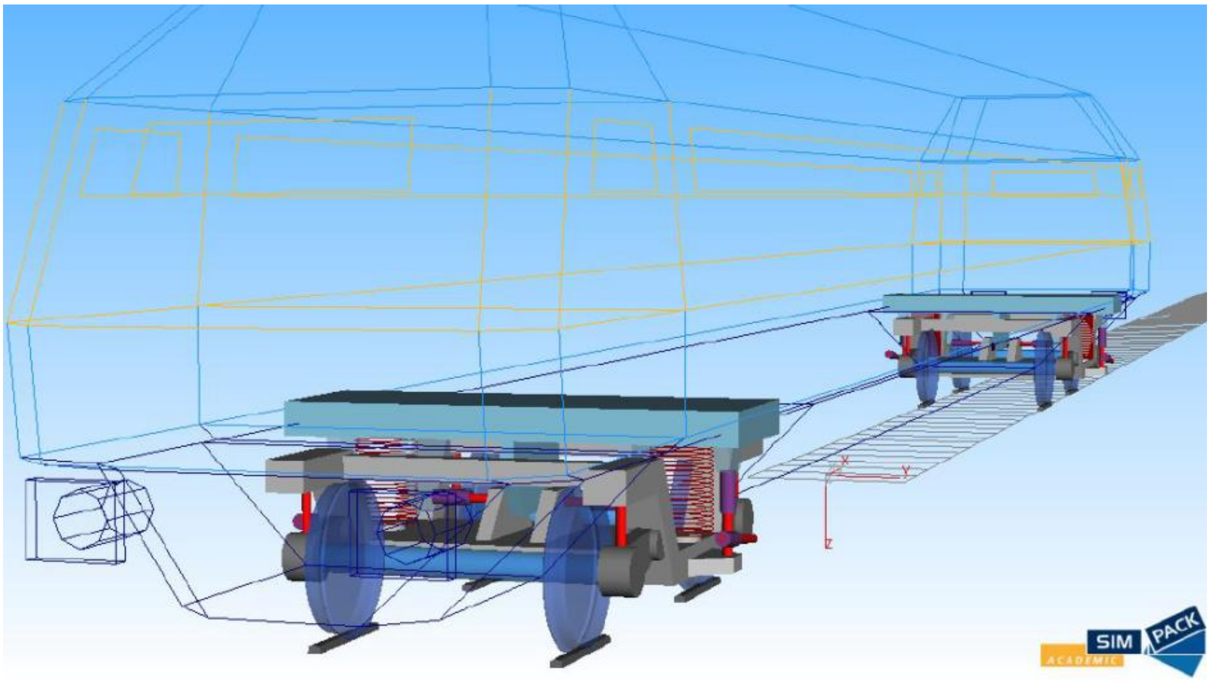


Figure 9.16: Full vehicle model in Simpack

The outputs from the model are the lateral and longitudinal creep forces of each contact point at every rail-wheel pair. The lateral creep force is measured as the tangential force in the lateral direction at the rail contact reference point. Similarly, the longitudinal creep force is the tangential force in the longitudinal direction at the rail contact reference point.

9.2.2.2 Active steering, modelling and performance assessment

For all the active steering configurations, the vehicle modelling is done in Simpack and the controller design in Simulink. The lateral or longitudinal creep forces are the outputs from the Simpack model which are used as feedback signals for the controller.

To date, the secondary yaw control (SYC), actuated solid wheelset (ASW), actuated independently rotating wheelset (AIRW), and driven independently rotating wheelset (DIRW) configurations have been modelled and compared to the passive vehicle case.

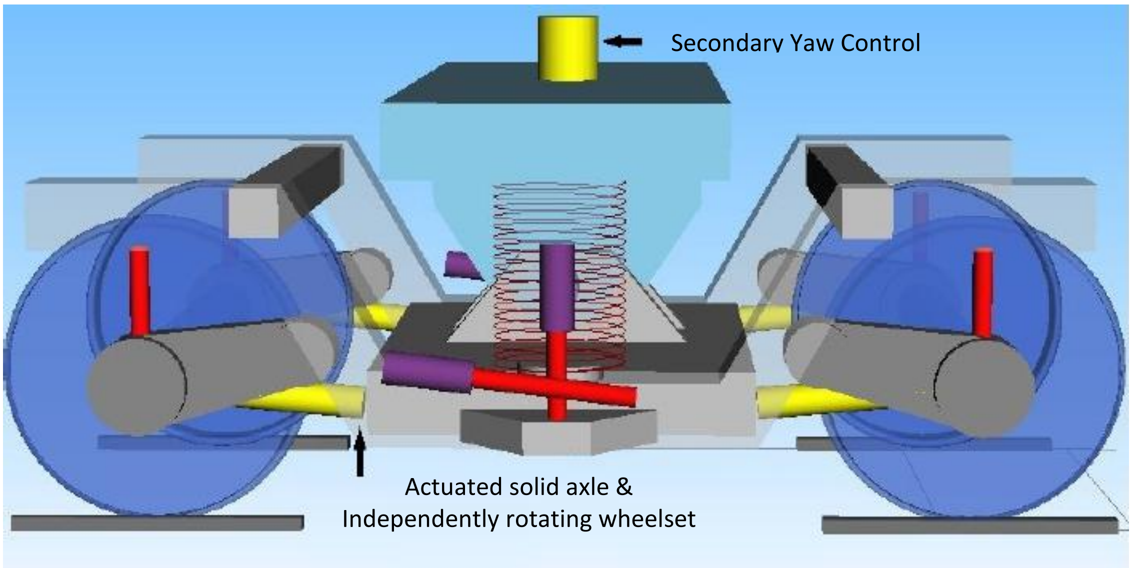


Figure 9.17: Actuator locations for the secondary yaw control, actuated solid axle, and actuated independently rotating wheelset configurations

The longitudinal and lateral creep forces of the front bogie wheelsets were compared to those for the passive vehicle.

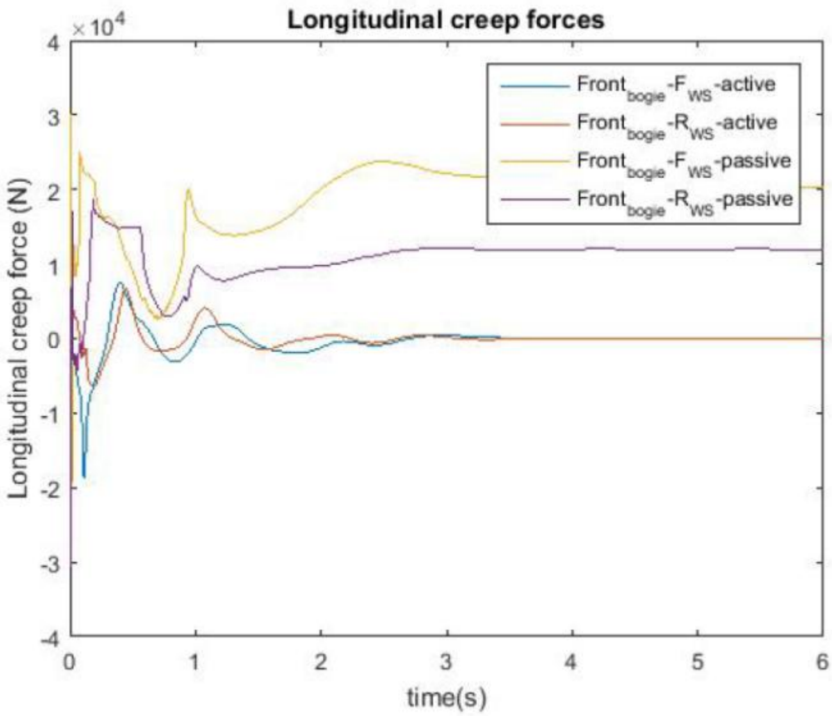


Figure 9.18: Longitudinal creep force, front bogie, front and rear wheelsets

The wear performance as indicated by contact patch fictional energy (Tγ), a function of the longitudinal and lateral creep forces and creepages, listed in Tables 1 and 2.

The longitudinal creep forces are reduced to zero in the actuated solid wheelset, actuated independently rotating wheelset, and driven independently rotating wheelset schemes, although the lateral creep forces remain unbalanced. However the difference in the leading and trailing wheelset lateral creep forces is significantly reduced when compared to the passive vehicle which contributes to significant reductions in the Tγ (contact patch fictional energy) values.

9.2.3 Active vehicle steering through switches

To assess the whole system benefits of combining radical S&C designs with mechatronic vehicles, this work will be expanding further developed to include modelling and simulation of vehicle based switching on both existing S&C and upcoming conceptual designs.

The first stage would be to move from straight and curved plain line to include a conventional switch, utilising CVS switch modelling inputs from the University of Huddersfield. Initially using the passive vehicle model to produce a baseline, and then introducing the various active steering configurations. This is expected to show similar reductions in creep forces and tγ, as already demonstrated for plain line, which should translate to a reduction in impact forces and wear on the switch components.

Following on from active steering through conventional switches, the full benefits of vehicle based switching can be realised when vehicle steering is sufficiently developed to allow the elements of a conventional switch that constrain the vehicle to the set route to be removed, allowing the vehicle to set the desired path.

The vehicle must be able to detect and maintain its lateral position on the rail head and also choose the desired path at a switch. Sensing concepts will be studied, and combined with the active steering elements currently being investigated, and a passive switch model provided by the University of Huddersfield team, with the aim of developing a simulation model capable of actively steering through a passive switch.

10 Conclusions

During the course of the studies conducted within the work package 2 tasks and reported under this deliverable D2.5, a number of key conclusions have been reached.

The work has established the fundamentals of wheelset kinematic behaviour required, with specific regard to the wheelset guidance principles that need to be respected if the passage of a vehicle wheelset from one pair of rails, to another are to be achieved safely; and without detrimentally changing current derailment mechanisms risk or introducing any new ones.

In proposing radical new designs it has been established that a structured methodology was necessary for the evaluation of these new concepts in vehicle guidance, and that these needed to be subjected to an objective “value engineering” process.

The work has successfully defined such a methodology and refined it for the remote nature of collaborative projects. It is recommended that this approach be adopted by all In2Rail Work Packages in the evaluation of proposals.

There are several real design alternatives to existing S&C designs identified that can eliminate a significant number of current failures modes leading to service affecting failures. These alternative designs have the potential to positively impact on the reduction of asset Life Cycle Cost.

During the analysis it has been established that proposed designs may be able to exploit numerous other cross-applicable techniques to realise maximum benefits.

Initially, two alternative designs have emerged, one focuses on the infrastructure and the removal of the failure prone switch blade, whilst the other adopts a whole system approach and discusses the principles of self-steerage of a bogie and the benefits that may be brought to track switching assets.

There are a number of further track orientated radical ideas that require further evaluation before they can be considered as validated candidates for alternative designs. The project will evaluate these ideas before moving into a full concept development stage. After which multiple realistic alternative proposals for track switching assets may be objectively evaluated using the value analysis process outlined.

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12 Appendices

Appendix A: **Fundamental Principles**

A.1 Linear wheel-crossing interaction model

The wheel-crossing interaction will here be studied using a simplified model of the rail and wheel geometries. The contact locations on wing rail and crossing nose are described using linear functions and the wheel profiles are conical. This modelling procedure allows for the derivation of analytical expressions for transition points and impact angle when a wheel passes over a crossing.

A.1.1 Derivation

First the linear functions that describe the lateral (y) and vertical (z) position of the contact points (cp) on wing rail (wr) and crossing (cr) are defined as a function of the longitudinal coordinate x on the form $y = kx + m$. The variable substitution $= \frac{t}{\alpha}$, where t is the nominal thickness of the crossing nose, is performed to find a parameterisation that is independent of the crossing angle α. We get:

$$y_{\text{cp,wr}} = m_{\text{wr},y} - \alpha x = \left\{ x = \frac{t}{\alpha} \right\} = m_{\text{wr},y} - t \quad (8)$$

$$z_{\text{cp,wr}} = K_{\text{wp}} \alpha x = K_{\text{wp}} t \quad (9)$$

$$y_{\text{cp,cr}} = m_{\text{cr},y} \quad (10)$$

$$z_{\text{cp,cr}} = K_{\text{cr}} \alpha x + m_{\text{cr},z} = K_{\text{cr}} t + m_{\text{cr},z} \quad (11)$$

Where $y_{\text{cp,wr}}$ and $y_{\text{cp,cr}}$ are the lateral contact positions on wing rail and crossing nose respectively and $z_{\text{cp,wr}}$ and $z_{\text{cp,cr}}$ the corresponding vertical positions.

Assuming the values $m_{\text{wr},y}$ = -15 mm and $m_{\text{cr},y}$ =25, the lateral contact point trajectories are illustrated in Figure 12.1. The figure illustrates the longitudinal (x) and lateral (y) coordinate axes. The z coordinate is positive downwards. The constants that describe the inclinations and position of the wing rail, K_{wp}, K_{cr} and $m_{\text{cr},z}$ will be determined later through the adjustment of the crossing geometry to a given range of wheel profile conicities. There is no $m_{\text{wr},z}$ as this value is set to zero by default to lock the origin of the wing rail to $z = 0$ at $x = 0$.

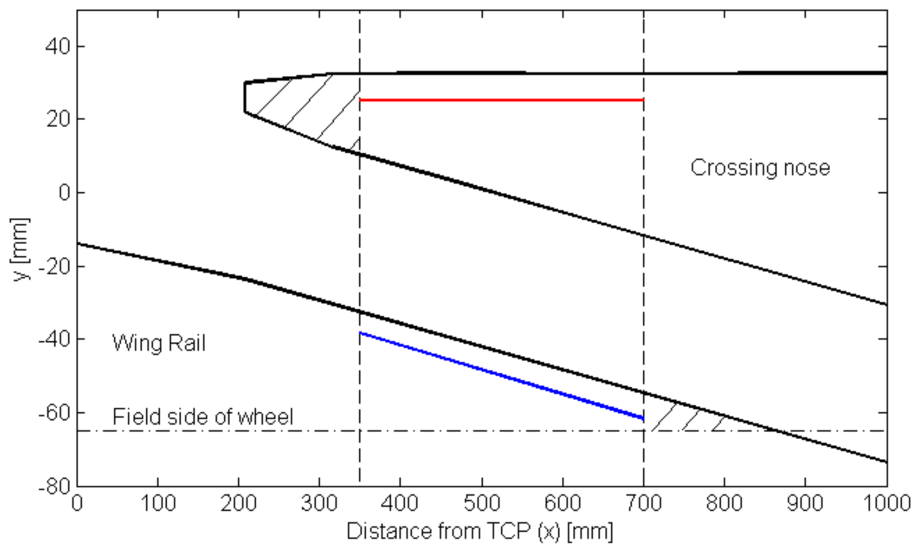

Figure 12.1: Assumed lateral contact point trajectories described using linear functions

Assuming a conical wheel profile the vertical coordinate of the wheel can be described as

$$z_{\mathrm{wheel}} = \lambda y_{\mathrm{wheel}} \tag{12}$$

where λ is the conicity of the wheel and y_{wheel} the lateral coordinate on the wheel profile. A zero lateral displacement of the wheel is assumed. This equation together with the lateral positions for the contact points, (8) and (10), yield the vertical positions on the wheel at the lateral contact point locations.

$$z_{\mathrm{wheel,wr}} = \lambda(m_{\mathrm{wr,y}} - t) \tag{13}$$

$$z_{\mathrm{wheel,cr}} = \lambda m_{\mathrm{cr,y}} \tag{14}$$

The vertical wheel position p when the wheel is in contact with only wing rail or crossing nose can then be calculated as follows using Eqs. (9),(11),(13) and (14)

$$\begin{aligned} p_{wr} = z_{cp,wr} - z_{wheel,wr} &= K_{wp}t - \lambda(m_{wr,y} - t) \\ &= K_{wp}t + \lambda(t - m_{wr,y}) \end{aligned} \tag{15}$$

$$p_{cr} = z_{cp,cr} - z_{wheel,cr} = K_{cr}t + m_{cr,z} - \lambda m_{cr,y} \tag{16}$$

As the wheel position on the wing rail describes a downwards trend (towards increasing p) and the wheel position on the crossing describes an up-going trend (towards decreasing p), the transition point can be found at the intersection when $p_{wr} = p_{cr}$. Setting equations (15 **)** and (16) equal yields:

$$K_{\mathrm{wp}}t + \lambda(t - m_{\mathrm{wr,y}}) = K_{\mathrm{cr}}t + m_{\mathrm{cr,z}} - \lambda m_{\mathrm{cr,y}} \tag{17}$$

Which yields that the crossing thickness at the transition point can be expressed as:

$$t = \frac{m_{cr,z} + \lambda(m_{wr,y} - m_{cr,y})}{\lambda + K_{wp} - K_{cr}} \tag{18}$$

or as a function of the longitudinal position x

$$x = \frac{m_{cr,z} + \lambda(m_{wr,y} - m_{cr,y})}{\alpha(\lambda + K_{wp} - K_{cr})} \tag{19}$$

The impact angle β can then be expressed as the difference in vertical wheel trajectory inclination of the wing rail and crossing nose at the transition point. First calculating the relevant derivatives

$$\begin{aligned} \frac{dp_{\mathrm{wr}}(x)}{dx} &= \frac{d\left[K_{\mathrm{wp}}\alpha x + \lambda\left(\alpha x - m_{\mathrm{wr,y}}\right)\right]}{dx} = \alpha(K_{\mathrm{wp}} + \lambda) \\ \frac{dp_{\mathrm{cr}}(x)}{dx} &= \frac{d[K_{\mathrm{cr}}\alpha x + m_{\mathrm{cr,z}} - \lambda m_{\mathrm{cr,y}})]}{dx} = \alpha K_{\mathrm{cr}} \end{aligned} \tag{20}$$

And computing the difference at a transition point yields

$$\begin{aligned} &\beta = \frac{dp_{\mathrm{wr}}(x_{\mathrm{trans}})}{dx} - \frac{dp_{\mathrm{cr}}(x_{\mathrm{trans}})}{dx} = \\ &\alpha\left(K_{\mathrm{wp}} + \lambda\right) - K_{\mathrm{cr}}\alpha = \\ &\alpha\left(\lambda + K_{\mathrm{wp}} - K_{\mathrm{cr}}\right) \end{aligned} \tag{21}$$

It can be thus be observed that the impact angle is proportional to the inclination of the wing rail and crossing nose as well as the conicity of the wheel.

K_{wr} and K_{cr} can either be taken from an existing crossing design, or they can be determined from the range of wheel profile conicities that are going to pass over the crossing. The latter procedure will be used in the following to determine the average impact angle required in order for a given range of wheel profile shapes to pass.

A.1.2 Crossing geometry adjustment

Assuming an extension of the transition zone as illustrated in Figure 12.1 and assuming a maximum and minimum conicity wheel, the shape of the crossing nose can be determined.

By inserting t_{s}, which is the crossing nose thickness at the start of the transition zone, and wheel conicity λ_{s}, which is the largest conicity wheel that should pass over the crossing, into Eq. (17) it is obtained that.

$$K_{\mathrm{wp}} t_{\mathrm{s}} + \lambda_s\left(t_{\mathrm{s}} - m_{\mathrm{wr,y}}\right) = K_{\mathrm{cr}} t_{\mathrm{s}} + m_{\mathrm{cr,z}} - \lambda_{\mathrm{s}} m_{\mathrm{cr,y}} \tag{22}$$

By inserting t_{e}, which is the crossing nose thickness at the start of the transition zone, and wheel conicity λ_{e}, which is the largest conicity wheel that should pass over the crossing, also into Eq. (17) it is obtained that.

$$K_{wp}t_e + \lambda_e\left(t_e - m_{wr,y}\right) = K_{cr}t_e + m_{cr,z} - \lambda_e m_{cr,y} \tag{23}$$

Through these equations we have thus created dependencies between the wheel profiles that should make their transitions at the start and end of the transition zone, and the wing rail and crossing inclinations.

By subtracting (23) from (22), we obtain

$$\begin{aligned} &K_{wp}(t_s - t_e) + \lambda_s t_s - \lambda_e t_e + m_{wr,y}(\lambda_e - \lambda_s) = \\ &K_{cr}(t_s - t_e) + m_{cr,y}(\lambda_e - \lambda_s) \end{aligned} \tag{24}$$

By performing the variable substitutions

$$\lambda_e = \lambda_s - \delta \tag{25}$$

$$t_e = t_s + T \tag{26}$$

where δ is the wheel conicity range ($\delta = \lambda_s - \lambda_e$) and T the crossing thickness change ($T = t_e - t_s$) in the transition zone, K_{cr} and K_{wp} can be solved for as

$$K_{cr} - K_{wp} = \lambda_s + \frac{\delta(m_{wr,y} - m_{cr,y} - t_s - T)}{T} \tag{27}$$

K_{cr} and K_{wp} are now solved for using the criterion that the average wheel trajectory slope should be the same for wheel trajectories on both wing rail and crossing nose. As the vertical wheel positions on wing rail and crossing nose are linear functions in λ, the criterion is formulated saying that the slope of the vertical wheel trajectory should be equal but opposite on the wing rail and crossing nose at the transition point of a wheel with average conicity $\bar{\lambda}=\frac{\lambda_s-\lambda_e}{2}$. The equation becomes

$$\frac{dp_{\mathrm{wr}}\left(x_{\mathrm{trans},\bar{\lambda}}\right)}{dx} + \frac{dp_{\mathrm{cr}}\left(x_{\mathrm{trans},\bar{\lambda}}\right)}{dx} = 0 \tag{28}$$

Using Eq. (20) we get:

$$\alpha\left(K_{wr} + \bar{\lambda}\right) + \alpha K_{cr} = 0 \tag{29}$$

Which can be written as:

$$\alpha\left(K_{wr} + K_{cr} + \lambda_s - \frac{\delta}{2}\right) = 0 \quad (30)$$

And yields

$$K_{wr} = \frac{\delta}{2} - K_{cr} - \lambda_s \quad (31)$$

(31) in (27) gives

$$K_{cr} - \left(\frac{\delta}{2} - K_{cr} - \lambda_s\right) = \lambda_s + \frac{\delta(m_{wr,y} - m_{cr,y} - t_s - T)}{T} \quad (32)$$

Which can be written as:

$$K_{cr} = \delta\left(\frac{m_{wr,y} - m_{cr,y} - t_s}{2T} - \frac{1}{4}\right) \quad (33)$$

We can thus see that the crossing nose inclination will have to be proportional to the wheel conicity range δ and the crossing nose thickness range in the transition zone T.

Assuming the numerical values $m_{\mathrm{wr},y}$ = -15 mm, $m_{\mathrm{cr},y} = 25$, $t_{\mathrm{s}} = 22$ mm, $t_{\mathrm{e}} = 45$ mm(yields T =45 mm), $\lambda_s = \frac{1}{25}$, $\lambda_e = \frac{1}{50}$ (yields $\delta = \frac{1}{50}$) the constants K_{wr} and K_{cr} can be calculated from (32) and (33). The constant $m_{cr,z}$ can then be calculated using for example Eq. (17). The vertical wheel trajectories of wheels λ_s and λ_e for this parameter setting are illustrated in Figure 12.2. The vertical contact point locations on crossing and wing rail for this parameter setting are presented in Figure 12.3. This figure complements the lateral contact point locations in Figure 12.1.

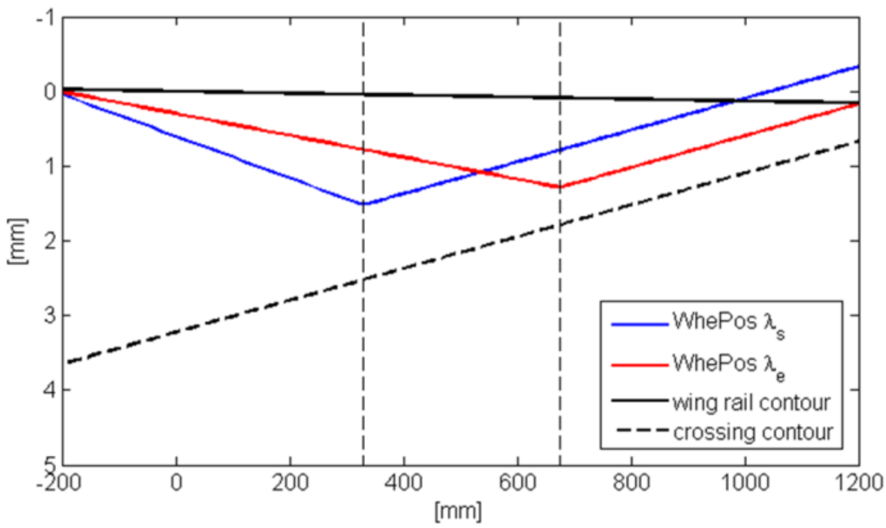

Figure 12.2: Vertical wheel trajectories for a crossing geometry adjusted to wheels with conicities λ_s and λ_e

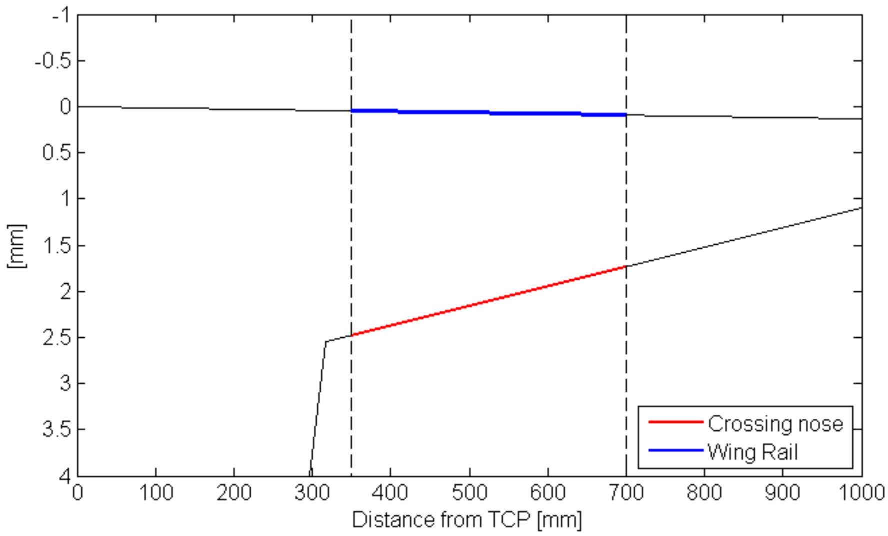

Figure 12.3: Vertical contact point locations on wing rail and crossing nose

A.1.3 Average impact angle

By inserting the average λ as $\bar{\lambda} = \lambda_s - \frac{\delta}{2}$ and Eq. (31) for K_{wr} into (21) it is obtained that

$$\bar{\beta} = \alpha \left(\lambda_s - \frac{\delta}{2} + \frac{\delta}{2} - K_{cr} - \lambda_s - K_{cr} \right) = -2\alpha K_{cr} \tag{34}$$

Inserting Eq. (33) yields

$$\bar{\beta} = \alpha\delta \left(\frac{t_s + m_{cr,y} - m_{wr,y}}{T} + \frac{1}{2} \right) \tag{35}$$

Which with the substitution $k = t_s + m_{cr,y} - m_{wr,y}$ yields:

$$\bar{\beta} = \alpha\delta \left(\frac{k}{T} + \frac{1}{2} \right) \tag{36}$$

With the assumptions used in this model, it can thus be concluded that the average impact angle for wheels that pass over a fixed crossing is proportional to the crossing angle α, inversely proportional to the crossing nose thickness range T in the transition zone and proportional to the range of wheel profile conicities δ that should be able to pass through the crossing with transitions in the transition zone. With a smaller range of wheel profile shapes in traffic it would thus be possible to adjust crossing geometries accordingly and reduce impact angles and thus impact forces and associated degradation. The constants joined together in k also have their influence, but the range of realistic values is rather small.

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Appendix B: **Existing Knowledge**

B.1 Kinematic Gauge Optimisation

Kinematic Gauge Optimisation (KGO) in the switch panel to improve steering, lower axle angle of attack and reduce lateral steering forces. This also allows shifting the wheel load transfer area to a ticker section of the switch rail to improve resistance to damage.

Reference solution: FAKOP® and CATFERSAN

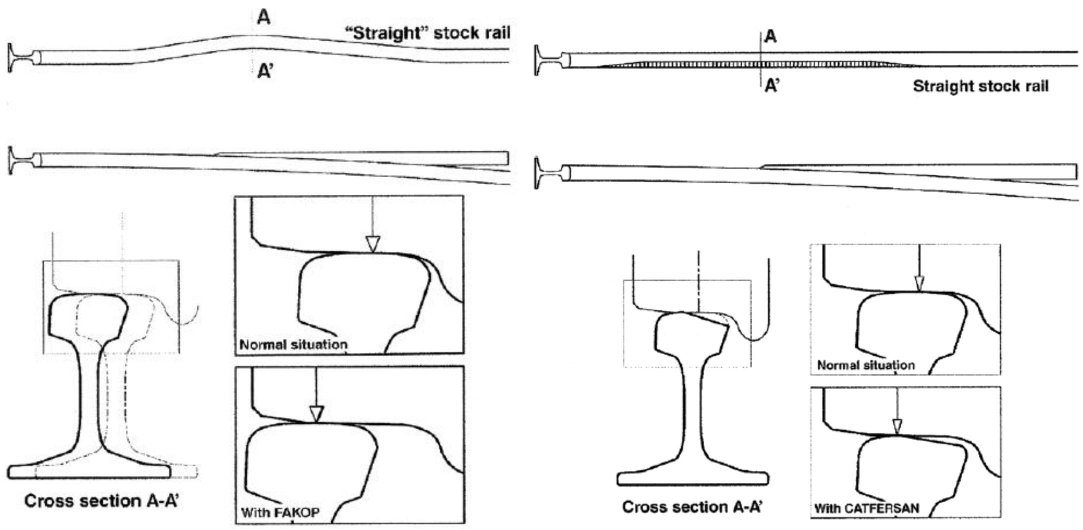

Figure 12.4 Kinematic Gauge Optimisation studies from [3]

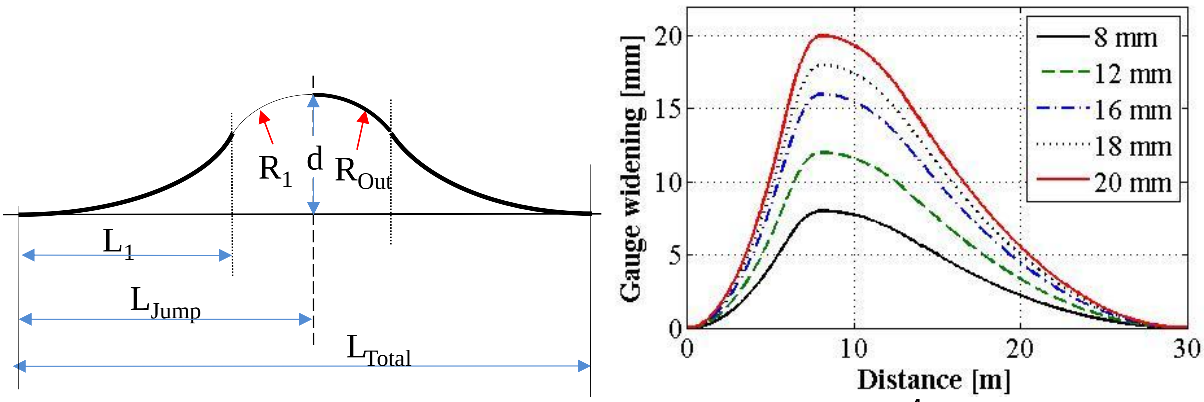

Figure 12.5: Kinematic Gauge Optimisation studies from [4]

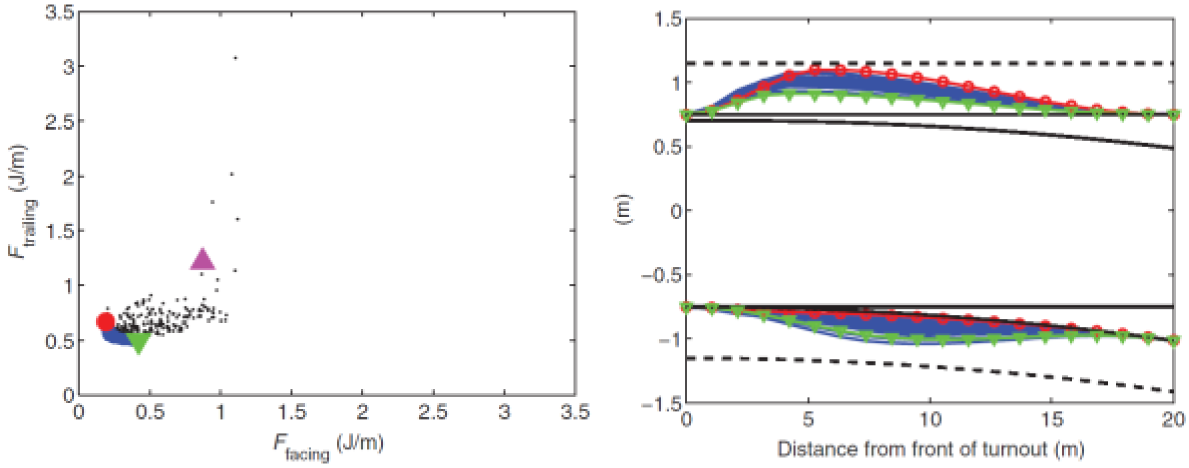

Figure 12.6: Kinematic Gauge Optimisation studies from[5]

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B.2 Support stiffness optimisation in S&C

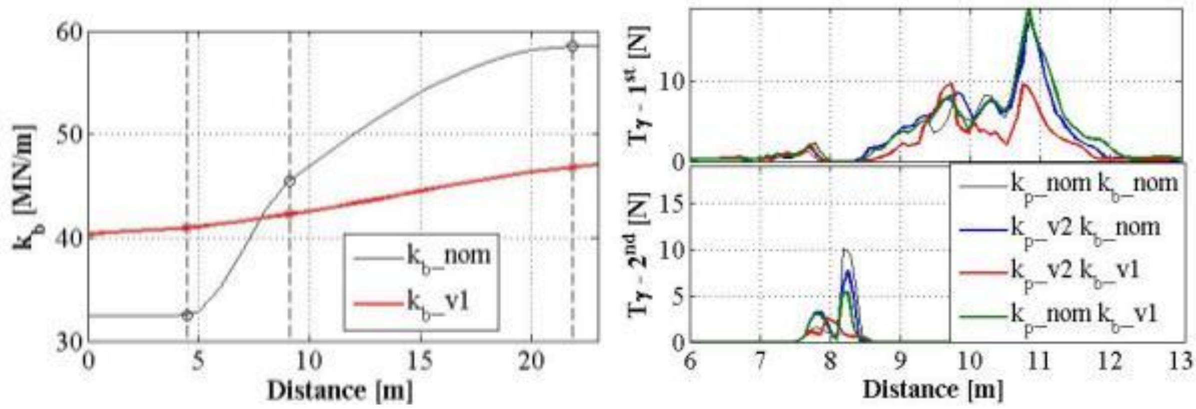

Figure 12.6a: Track support stiffness plot and associated damage index

An investigation was completed within Innotrack looking at levelling the support stiffness through the turnout highlighted the need for a more consistent support stiffness in crossing and switch panels to reduce both wheel-rail contact damage and support maintenance.

Demonstrator of steel plain line track with initial intended application and design for S&C.

Figure 12.6b: Ladder track for improved plain line track support stiffness

[5] Pålsson B.A., Nielsen J.C.O. – Track gauge optimisation of railway switches using a genetic algorithm – 2012, Vehicle System Dynamics (vol. 50, pp. 365-387).

B.3 Kinematic motion and dynamics impact loads in crossings

SUSTRAIL project investigated the impact of wheel shape on the vertical dynamics forces at crossings, highlighting the needs to take into account a representative range of wheel shapes in the geometrical design of railway crossings. The same approach is valid for the assessment in switches geometry design.

This approach is taken further in Capacity4Rail using a fully comprehensive dynamics simulation environment to established the difference in behaviour of a range of crossing geometry and provide an optimisation platform for the next generation of crossing geometry in the UK.

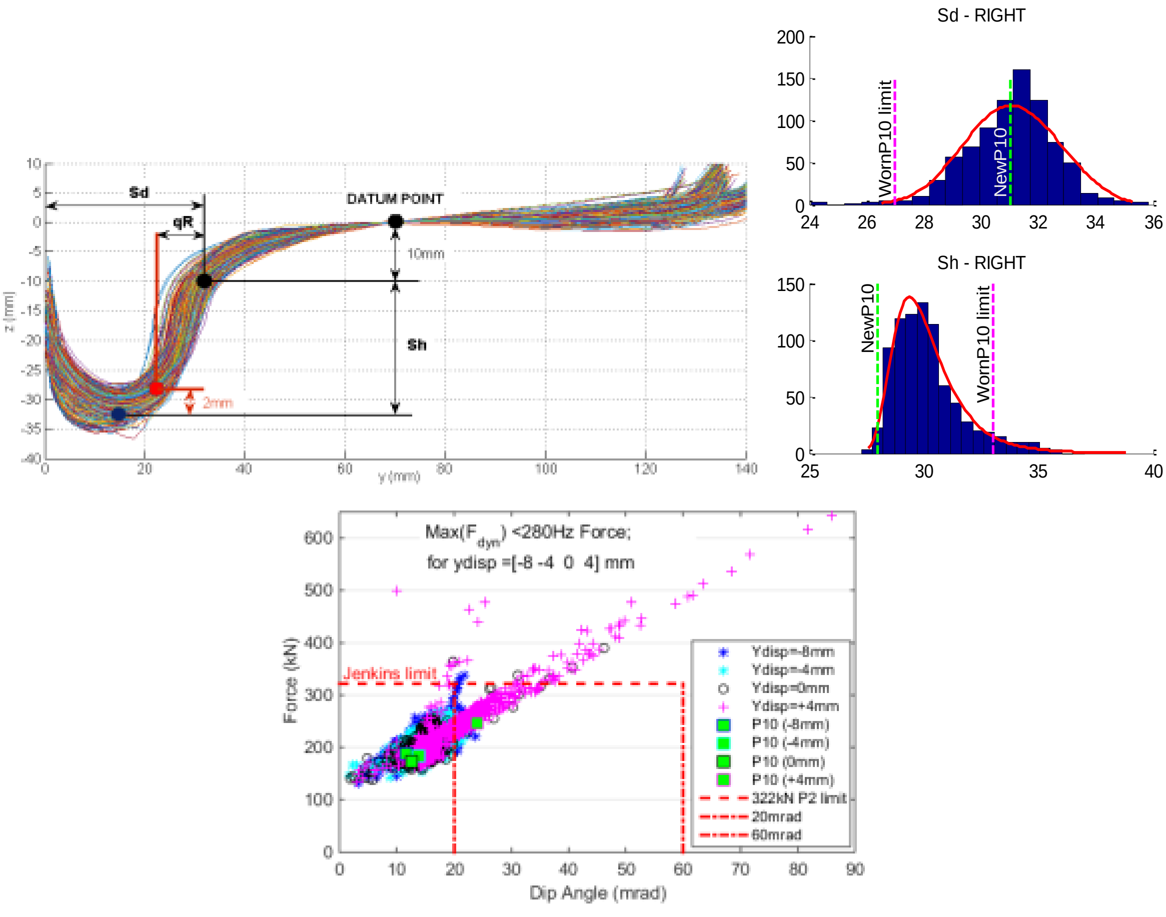

Figure 12.7: Work completed in SUSTRAIL [6] and [7]

[6] Bezin Y., Coleman I., Grossoni I., Neves S., Hyde P., Bruni S., Alfi S., Rantatlo M., Jönsson J., Aslam M., Lambert R., Beagles A., Fletcher D., Lewis R. – D4.4 Optimised switches and crossings systems – 2015, SUSTRAIL (265740 FP7).

[7] Bezin Y., Grossoni I., Alonso A. – The Assessment of System Maintenance and Design Conditions on Railway Crossing Performance – 2014, Proceedings of the 2nd International Conference on Railway Technology: Research, Development and Maintenance. Civil-Comp Press, Stirlingshire, United Kingdom

B.4 Use of under sleeper pads in turnouts

Use of USP in turnout has been investigated in the UK at a trial test site. Modelling has been carried out in SUSTRAIL to demonstrate the benefits in terms of reducing the dynamics loading and ballast pressure.

Voids under crossings are likely to occur when the dynamic load impact from the wheel transfer is abnormally high and where maintenance and support is poor. The dynamic wheel-rail forces are highly non-linear phenomena depending on the vehicle speed, the wheel and rail transfer geometry, the support stiffness level and its variation along the crossing panel. The simulation results here show the expected increase in the dynamic wheel rail contact force as the support to the crossing degrades (number of voided bearers and size of the void). Additionally the simulation demonstrates the mitigation effect of using USP (reducing peak force and eliminating stress raiser), which in themselves should limit the formation of any voids in the first place, as demonstrated from results in Section 5.6.3 of [6].

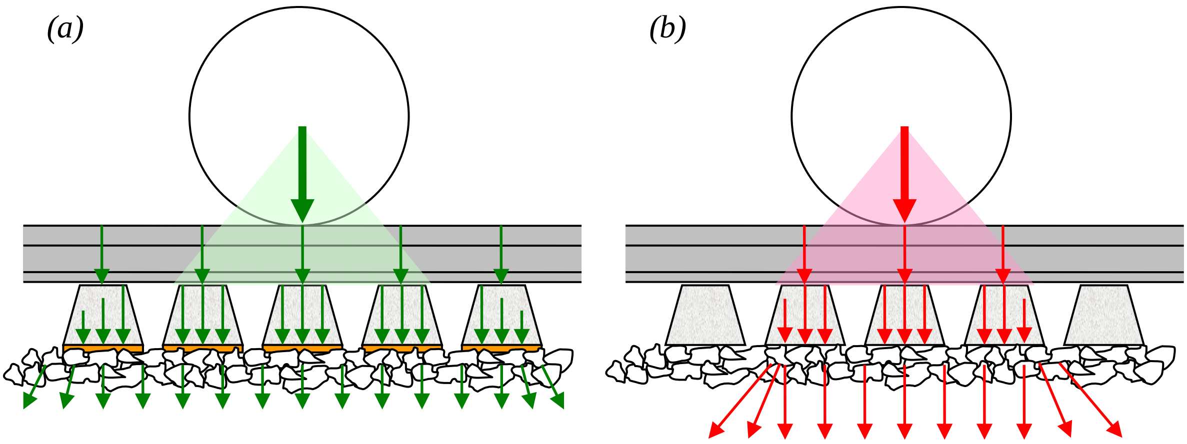

Figure 12.8: from SUSTRAIL [6]

B.5 Repoint Project

The Repoint project at Loughborough University has been under development for over five years, beginning with concepts looking to increase rail capacity without building new railways, analysis of UK rail performance data showed that the rail network is negatively affected by switch failures to a greater degree than failures of any other asset.[8] A cross industry focus group was established to generate candidate track switching solutions to reduce switch failure, ranging from improvements to existing equipment through to new concepts for track geometry and wheel-rail interface. These were then evaluated against a set of essential functional requirements developed for track switches as a part of this research, and against a set of non-functional requirements forming a set of trade-offs.[9]

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

[8] ORR (Office of Rail Regulation) Online Data Portal – Total journey count reporting. url: dataportal.orr.gov.uk. Accessed: 2013-10-12.

[9] Bemment S.D., Ebinger E., Goodall R.M., Ward C.P., Dixon R. – Rethinking rail track switches for fault tolerance and enhanced performance – 2016, Proceedings of the IMechE (Part F: The Journal of Rail and Rapid Transit, p.0954409716645630).

B.5.1 Repoint hopping stub switch

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

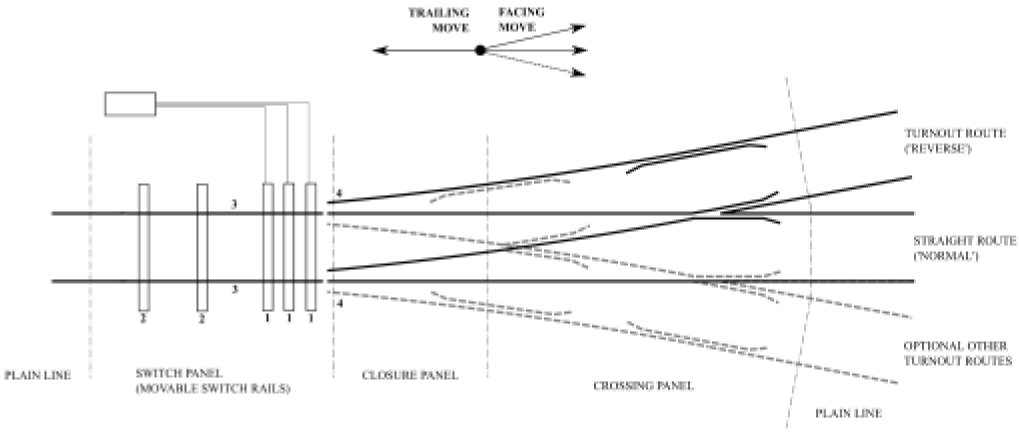

Figure 12.9 Repoint hopping stub switch arrangement

Figure 12.9 shows the general arrangement of a 'Repoint' stub switch, with an optional second turnout route shown dotted. Numbered elements as follows; (1) In-bearer type electromechanical actuators featuring integral passive locking elements with detection system; (2) Bearer featuring integral passive locking elements; (3) Bendable, full-section switch rails; (4) Interlocking rail ends.

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

The theory of passive locking is that when the rail is in one of its stationary, lowered positions, it is unable to move in any direction apart from directly upwards. It is a requirement to lift the interlocking rail ends to disengage them. When the track is lifted, it is free to move laterally, but not longitudinally. Thus the rail hops between adjacent positions. If an actuator is isolated for whatever reason, the adjacent unit(s) can still actuate the switch, as the lifting action will unlock the isolated unit. It is this feature which enables redundant actuation to be provided as part of the `Repoint' concept, something not possible with the conventional switch. The general arrangement of the components within each actuator bearer is shown in Figure 12.10.

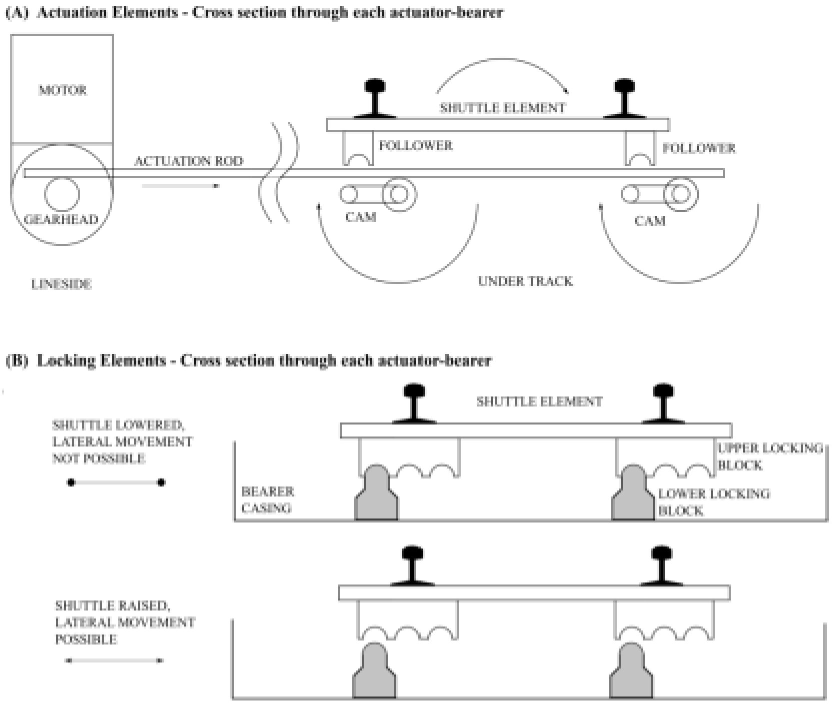

Figure 12.10 Repoint actuator/bearer

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

B.5.2 Repoint light

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

B.5.3 Further development

The Repoint intellectual property is the subject of 3 published patents.[10,11,12] A scale demonstrator of the concepts has been constructed in a laboratory at Loughborough University at 384mm gauge.

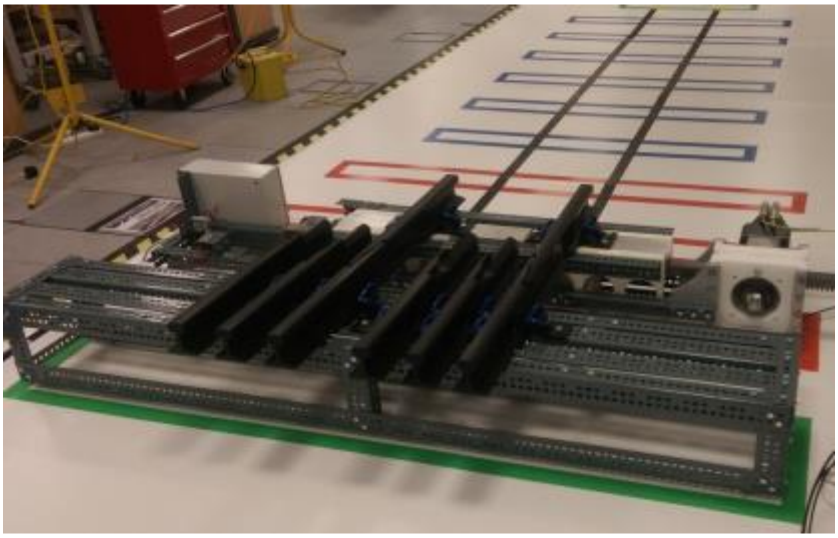

Figure 12.11 Repoint Demonstrator

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

B.5.4 Funding

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

[10] GB Patent: Loughborough University. 'Railway Points Operating Apparatus' (GB 2516706), 2013.
[11] GB Patent: Loughborough University. 'Railway Points' (GB 2516707), 2013.
[12] GB Patent: Loughborough University. 'Railway Track Crossing' (GB 2516712), 2013.

B.6 Rerail

Trafikverket has followed a project with “replaceable rail head”, Rerail, over 10 years’ time. The material is a high performance steel based Boron and Carbon as alloy elements. The material and the production method was developed to make collision-protection beams and the material is able to absorb much energy as it deforms. A web-link to the project is www.rerail.se.

As this material is manufactured in sheets it is suitable for making a replaceable head. On ordinary rail head it is necessary to mill the old rail and then snap on the new head.

This concept has already been tested in laboratory and has during summer 2016 been installed in ordinary track in Sweden for evaluation.

Figure 12.12: Illustration of a rail with a replaceable head

The basic idea is that further replacement saves material as the rail foot, web and most of the rail head can be reused (88% of the material). The material is also tougher and more wear resistant than ordinary rail steels, see Figure 12.13.

The idea of a replaceable rail head is not easily adapted in the S&C where the wear and rolling contact fatigue is most critical, namely in the transition areas. On a milled switch blade there is not enough material for this type of solution so the two main areas to explore is the stock rail and the crossing and wing rail.

Stock rail has in diverging route both head checks and longitudinal cracks that is limiting service life of the diverging route. A new material might be a step change.

Crossing and wing rail has plastic deformation, wear and cracks which also can be improved by a stronger material. The formation of a replaceable head has not yet been explored and is more difficult as the profile varies over the length and both wing rail and crossing should preferably be in the same material. The final solution might involve a total redesign of the crossing panel.

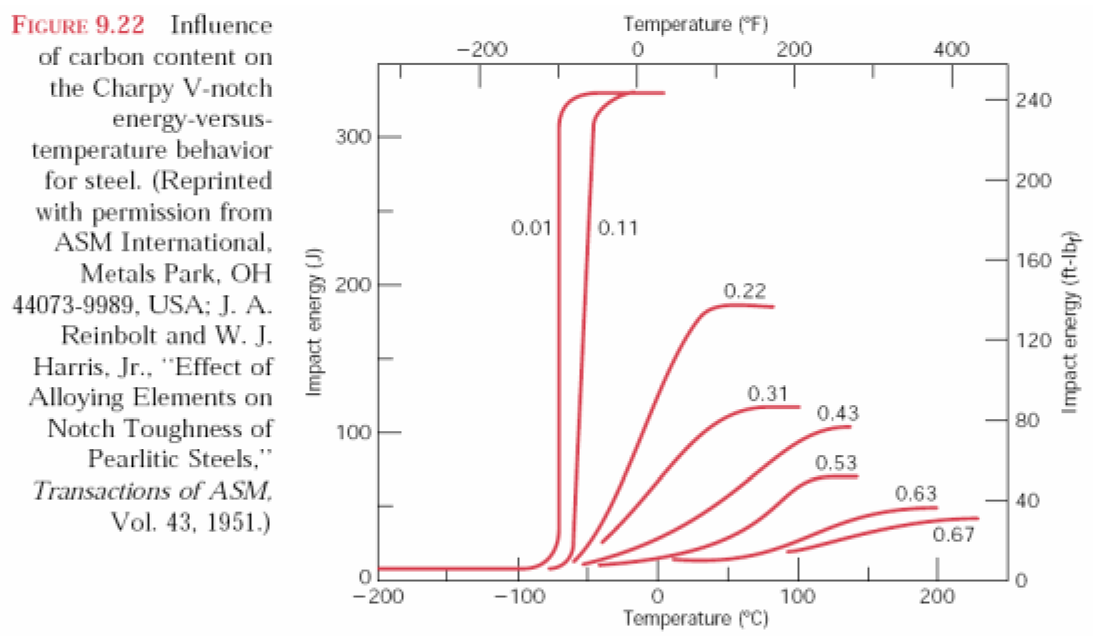

Figure 12.13: Illustration of the influence of Carbon on toughness

B.7 Italian Ferry Port

There is an existing example of a sliding panel switch in an Italian ferry port. This design allows for three different directions to be selected, thus also allow far more flexibility than conventional switches, especially in busy station terminals.

Figure 12.14: Italian ferry port sliding panel switch

B.8 Ladder sleepers

The ladder sleeper system has been developed at the RTRI of Japan Railways to provide maintenance-free and silent track system[13]. In order to avoid the problems in contact mechanics, risk of track buckling of continuous welded rail tracks and rolling and impact noises occurring when the rail is simply replaced to a heavier one, the ladder track aims at achieving high flexural and shear rigidities, and the optimal mass by means of a "combined rail" composed of steel rails and a ladder sleeper.

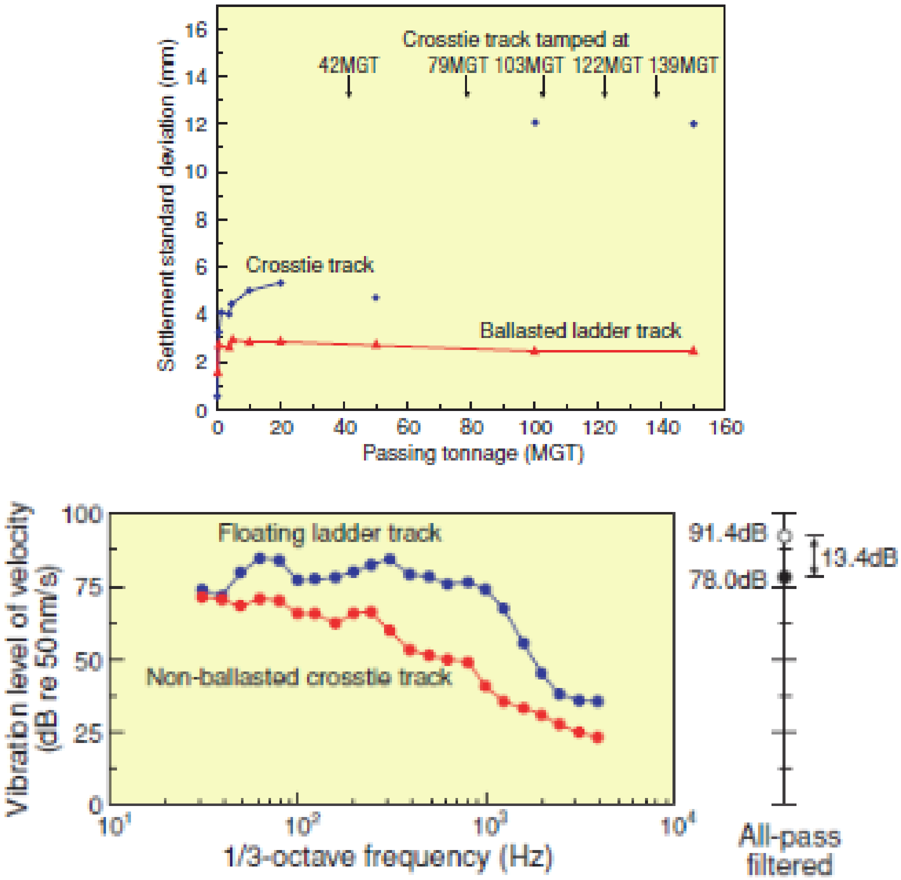

Figure 12.15: Track settlement chart and vibration assessment for floating latter track and non-ballasted crosstie track

The elastically supported ladder track system is composed of ladder sleepers, ductile bearings and a concrete base. The ladder sleeper is made up of pre-stressed concrete longitudinal beams, rubber bearings, buffer pads, isolators and steel pipe connectors[14].

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[13] Okuda, H. et al. Dynamic load, resistance and environmental performance of floating ladder track, 2004, QR of RTRI (Vol. 45, No. 3).

[14] Xia, H. et al. Dynamic analysis of rail transit elevated bridge with ladder track, 2009, Front. Archit. Civ. Eng. China (Vol. 3, No. 1).

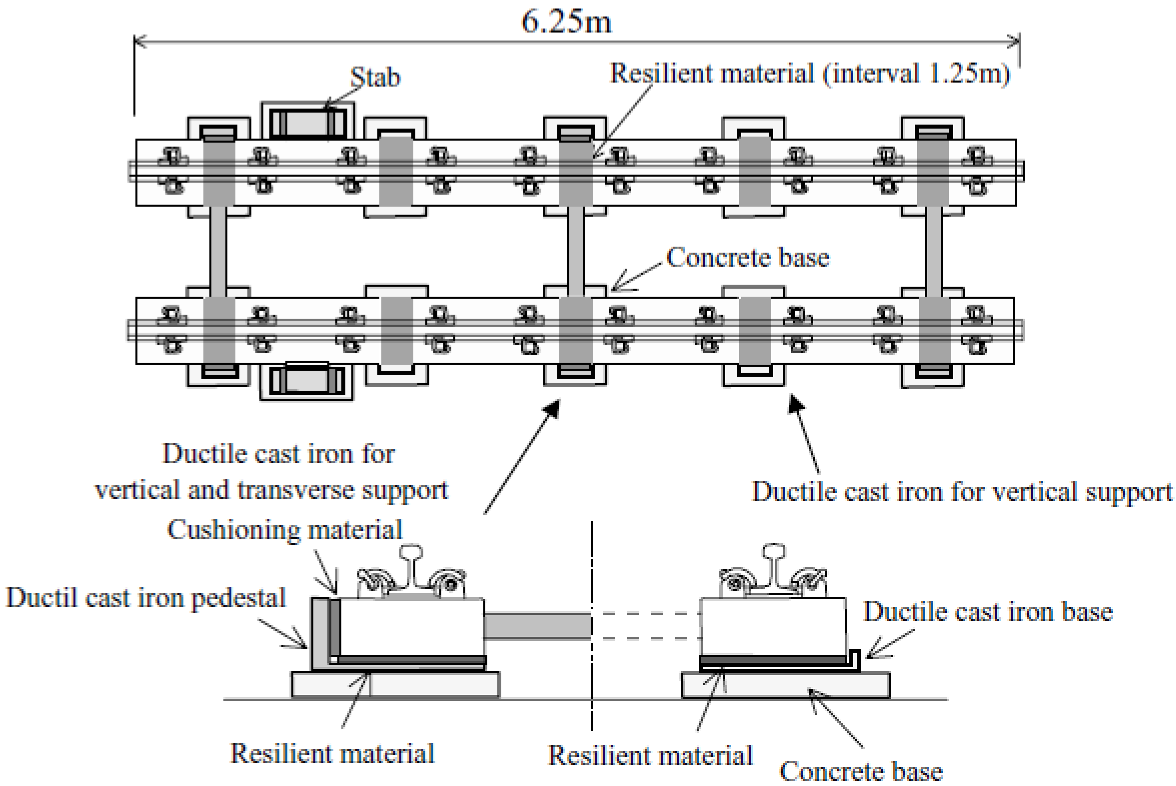

Figure 12.16: Floating Ladder track schematic

There are two types of floating ladder track:

- Resilient material type: the vertical load is supported by the resilient material (usually polyurethane or rubber) under the sleeper. The longitudinal movement is restrained by the two stabs extended from the outer surface of longitudinal sleeper and the transverse movement by pedestals mounted on the track bed at an interval of 2.5 m;
- Resilient mounting type: the ladder sleeper is supported by rectangular or circular resilient mounting devices allocated at an interval of 1.56 m. The mounting device possesses the function to restrain longitudinal and transverse movement of the sleeper.

B.8.1 Literary review

Several studies have been performed in order to assess the dynamic performances as well as the vibration and noise of ladder track.

Regarding the dynamic performances of ladder track, in [15] it has been demonstrated that the maximum bending moment experienced by the floating ladder track under the severest running condition of Shinkansen train on a weld irregularity is still within the allowable range. In [14], it is shown how the vibration reductions are greater than the case of slab track.

[15] Tanabe M. et al. – Computational model of a Shinkansen train running on the railway structure and the industrial applications – 2003, Journal of Materials Processing Technology (Vol. 140).

Also, the reductions in accelerations increase with increasing speed. A safety analysis to assess the post-derailment behaviour during an earthquake of a Shinkansen train over a ladder system is presented in [16] and shows that this track type with guards attached is effective to prevent the wheel deviating from the track even after derailment during the earthquake.

Regarding the vibration and noise performances of ladder track, in [13] the frequency analysis of measured vertical vibrations has demonstrated how this system can reduce up to 13 dB the vibration levels in comparison with non-ballasted cross-tie track. Similar results have been found with field experiments at the trial section of an elevated bridge on Beijing Metro Line 5 [17]. Other train-running experiments on steel railway bridges show a 10.5 dB(A) reduction in vibration velocity level at main girder web in comparison with directly fastened track bridges [18].

Finally, corrugation has been also studied. For example, in [19] an optimisation routine using the multipoint approximation method has been developed to reduce the track vibrations and it has been demonstrated efficient to effectively avoid the rail resonance which is the main reason for serious vibration and rail corrugation in the Beijing subway.

[16] Tanabe M. et al. – A combined multibody and finite element approach for dynamic interaction analysis of high-speed train and railway structure including post-derailment behaviour during an earthquake – 2010, IOP Conference (Series: Materials Science and Engineering, Vol. 10).

[17] Xia H. et al. – An experimental study of train-induced structural and environmental vibrations of a rail transit elevated bridge with ladder tracks – 2010, JRRT (Vol. 224).

[18] Watanabe T. et al. – Estimation of structure-borne noise reduction effect of steel railway bridge equipped with floating ladder track and floating reinforced-concrete deck – 2010, Journal of Mechanical Systems for Transportation and Logistics (Vol. 3, No. 1).

[19] Yan Z.-Q. et al. – Optimization of the dynamic properties of the ladder track system to control rail vibration using the multipoint approximation method – 2014, Journal of Vibration and Control (Vol. 20, No. 13).

Appendix C: **OptiKrea Ideation Methodology**

Appendix C: describes the process steps taken during the OptiKrea Idea Generation workshop.

C.1 Modified 635

(10 min * number of participants):

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

C.1.1 Presentation of Ideas and Feedback

(5 min + 10 min * number of participants)

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

C.1.2 Gallery viewing

(10 min):

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

C.1.3 Presentation of Ideas and Feedback

(5 min * number of participants)

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

Appendix D: **Undeveloped Ideas**

These ideas were conceived during the Idea Generation process outlined in Section 6 but they have not been developed to the initial assessment and evaluation phase. They are included here as a record of the Idea Generation Process.

Idea Description
Long transitions to reduce impact loads
Separate S&C by traffic type, for specialised solutions
Enhanced material forming for improved manufacture and repair
Half swing nose crossing at front of switch
Temporary transition support
aterial innovations
Materials for reduced rail head wear
Materials that are easily re-formable
Materials with an intrinsic repair capability
Replace rails with a continuous construction which can reform as required (e.g. liquid, powder, reconfigurable pins)
Remove restraints to permit ideal geometry with independently supported rails. Adjustable in all dimensions to suit optimum rail-wheel interface
Eliminate transitions with dynamically positioned wheel flanges
Utilise passing vehicle energy, self-energised

Table 12.1: Undeveloped Ideas

Appendix E: **Idea Evaluation Matrix**

The Idea Evaluation process is in Section 8.2. This matrix is live at time of writing.

	STEP 4 - Group Assessment Criteria in Categories		STEP 5 - Contributors rank each group category (out of 10)		STEP 3 - Generate Assessment Criteria	STEP 6 - Evaluate each idea against each group category (out of10)			
Ref	**Criteria Category Name**	**Average Category Weighting (%)**	**[Contributor Name]** (One set of weightings generated per contributor)		**Assessment Criteria**	**Idea Assessment**			
		Ø %	**Ranking (1-10)**	**%**		**Benchmark**	**IDEA 1**	**IDEA ...**	**IDEA 12**
1					Represents a step change				
2					Simple and with limited number of individual components				
3					Better robustness				
4					Longer livetime				
5	Design				Enables modularity				
6	Build				Scalable to accommodate multiple switch lengths and geometries				
7					Based on existing technology				
8					Entails long transitions for low loads				
9					Easy to implement and compatible with existing track and signalling infrastructure				
10									
11					Reduces tendency to derail (at least as safe as current!)				
12	Safety				Reduced risk of rail break (at least as safe as current!)				
13									
14					Proven trough validated simulation				
15					Proven in tests				
16	Approval				Proven in track				
17					Meets current European standards (TSI)				
18	Test				Good quality of the wheelset steerage				
19					Good continuity of wheel-rail contact at the points				
20	Trial				Good continuity of wheel-rail contact at the crossing				
21					Easy to get approvals				
22									
23					Reduced inspection frequency				
24					Reduced adjustment required				
25					Reduce maintenance intervention				
26					Enables automated/remote inspection and maintenance	**Not practical to show all Ideas**			
27	Maintenance	**Complete**			Low wear				
28					Low forces on construction	**Scoring under development**			
29	Modularity	**Not required in D2.5**			Low tendency to corrode				
30					Low tendency to generate fault in level	**To be included in next Deliverable**			
31					Easy to maintain track geometry and track support				
32	Construction site logistics				Full tamp-able (if ballasted track)				
33					Improved electrical isolation				
34					Improved cable management				
35					Improves installation process				
36					Improves commissioning process				
37									
38					Enables interoperability				
39					Improves track availability				
40					Improves through speed				
41					Improves turnout speed				
42					Increased permissible load				
43	Operation				Higher reliability				
44					improved track quality retention (rail alignment)				
45					Low stiffness heterogeneity				
46					Low sensitivity to high and low temperatures				
47					Low Sensitivity to frost and snow				
48									
49					Low noise impact				
50					Low vibration impact				
51	Environmental				Low energy consumption during production				
52					Low energy consumption during operation				
53									
54	Other				Quick to get to market				
56									
57	WP2 Capability to Progress Idea								
58									
59									
60	Σ	0%	0	0%					

Figure 12.17: Idea Evaluation Matrix (Work in progress)