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Designing an inset railway switch using a dedicated computational tool

H. Magalhaes[1], P. Jorge[1], Y. Bezin[1], A. Foan[2] and Phil Winship[3]

[1]Institute of Railway Research, University of Huddersfield, UK
[2]Andy Foan Limited, Nottingham, UK
[3]Network Rail, UK

Abstract

A railway turnout is a complex mechanical system used to divert trains from a particular direction or track. Due to the wheel load transfer from one rail to another, high vehicle-turnout forces occur, leading to rapid degradation of the railway turnout and increasing maintenance costs. Although the optimization of railway turnouts wheel-rail interface designs is highly beneficial, efficient tools capable of automatically creating turnout models for assessing their wheel-rail interaction performance are not the current practice. This work proposes a comprehensive computational study focused on the design of an inset switch rail. A dedicated computational tool was created to generate the switch rail geometry based on the manufacturing operations. This tool requires simple inputs, like profiles and paths of extrusion and cutting Boolean operations, to automatically determine a set of rail profiles that represents the switch design. Large sets of designs are quickly created by changing the paths of some Boolean operations. A total of 320 alternative switch designs were analysed and compared by performance indicators extracted from multibody simulations. Both through and diverge routes and facing and trailing directions were considered. An overall scoring is applied by considering several weighting combinations so that a number of designs can be proposed to best suit certain operating conditions or customer requirements.

Keywords: turnout geometry, switch modelling, wheel-rail interaction, optimisation methods.

1 Introduction

Railway turnouts are susceptible to high maintenance due to the severely high wheel-rail contact forces that occur in turnouts, which lead to degradation of the rails and track differential settlement. Although the optimization of railway turnouts wheel-rail interface designs is highly beneficial, efficient tools capable of automatically creating turnout models for assessing their wheel-rail interaction performance are not the current practice. Modelling of switches and crossings (S&C) as new or worn to assess their performance has been the focus of several recent papers [2,3] published in the wake of the international S&C benchmark [1], but it remains a very specialised and complicated task.

In the framework of several European projects [4-5], the University of Huddersfield has collaborated with a number of industry partners and in particular with Andy Foan Limited (AFL) [6] to develop a methodology to create a wide variety of turnout models with different switches and crossing designs to be used and evaluated in the multibody software VI-Rail. In [4], multibody simulations of railway vehicles negotiating up to 35 different switch designs (amongst 4 large families) were assessed through a wide range of conditions including through/diverging routes, facing/trailing directions, varying speed, varying vehicles, varying wheels, among others, which enabled assessing the wear/fatigue on the rails, the impact loads transmitted to the track infrastructure as well as the response of the vehicle, which allow evaluation of passenger comfort.

While a number of recommendations were made as a consequence of this last work [4], one was to further investigate the inset type of switch and stock rail machining, including establishing whether the conformal topping should be 'sharper' and/or ‘higher’. Inset switches were partially developed by British Rail research in the late 1970’s and have been used at selective sites (e.g. Shrewsbury) as targeted remediation. While, based on analysis to date, inset switches are shown to have potential benefits as a remedial measure, they are yet to be fully developed and validated for specific cases.

In order to achieve such a study, it was necessary to employ a different methodology from [4] to avoid the different manual steps used previously that involved using various CAD software to create the track model, making the computational study time-consuming and preventing the application of optimization procedures.

2 Methods

The methodology employed in this work comprises the four consecutive steps shown in Figure 1. In step 1, the parameterization of the switch design and track layout is defined either by the user or by an optimization algorithm. In step 2, the *SnC_Design* tool, which has been developed in this work is used to create the stock and switch rail components as well as track models to be used in a multibody software of choice, VI-Rail in this case. Step 3 is to assess the performance of switch designs by: (i) performing kinematic analyses that characterise the wheel-rail kinematics; and (ii) performing multibody simulations, representing a vehicle negotiating the four track models through-facing, through-trailing, diverging-facing and diverging-trailing. In step 4, the performance of the different switch designs is quantified through selected performance indicators, which are related to damage mechanisms, running safety, and comfort.

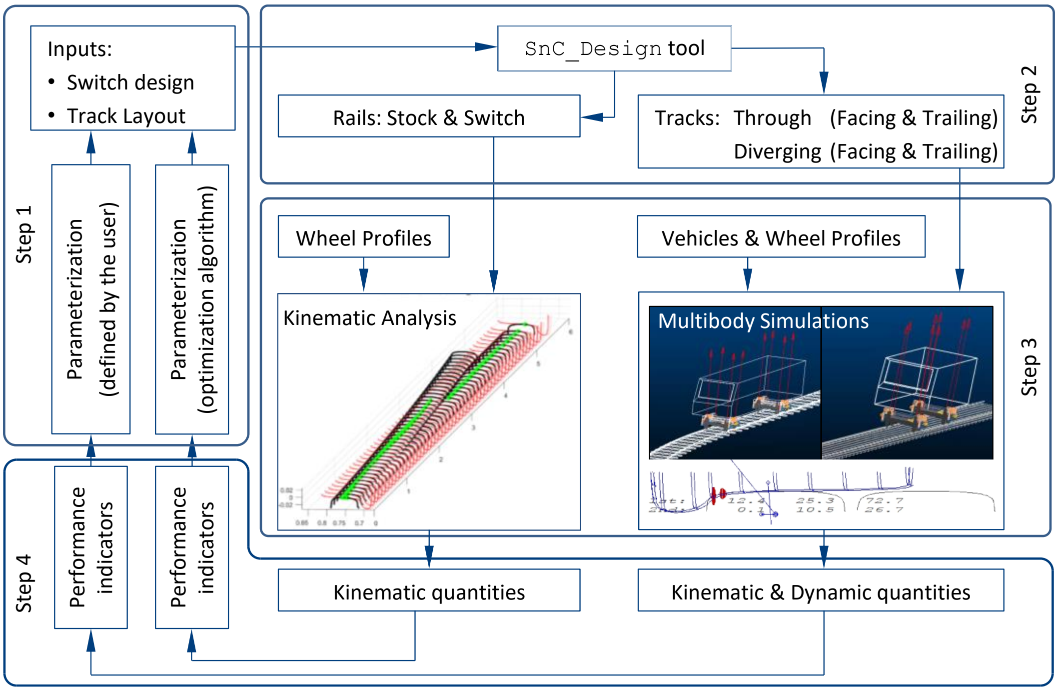

Figure 1: Methodology to enhance switch designs.

It is highlighted that the results obtained from the multibody simulations, which comprise kinematic and dynamic quantities, are the primary reference as they represent an advanced modelling option of higher level of details. On the other hand, the kinematic analysis is a simplified approach that prescribes the wheel vertical motion for a selected lateral displacement where a single contact with the rail is ensured for every longitudinal position. If the quantities obtained between the kinematic analysis and multibody simulations show a good agreement, then an optimization procedure of switch designs can be performed using kinematic analysis alone which represents a much lower computational cost, and multibody simulations are used only to verify the performance of the best switch designs. Otherwise, a batch of switch designs is prepared, where selected features are varied, from which track models are created for each design, and multibody simulations are performed to assess the switch design performance using a deterministic approach.

A single turnout allows incoming traffic to take different routes, or conversely to converge onto the same routes depending on the direction of movement, as shown in Figure 2. A total of four scenarios are considered to study the performance of the different switch designs. The vehicle speed is 100 km/h in the through route and 43 km/h in the diverging route, which corresponds to the maximum allowable turnout speed in the UK C type switch of 245 m curve radius.

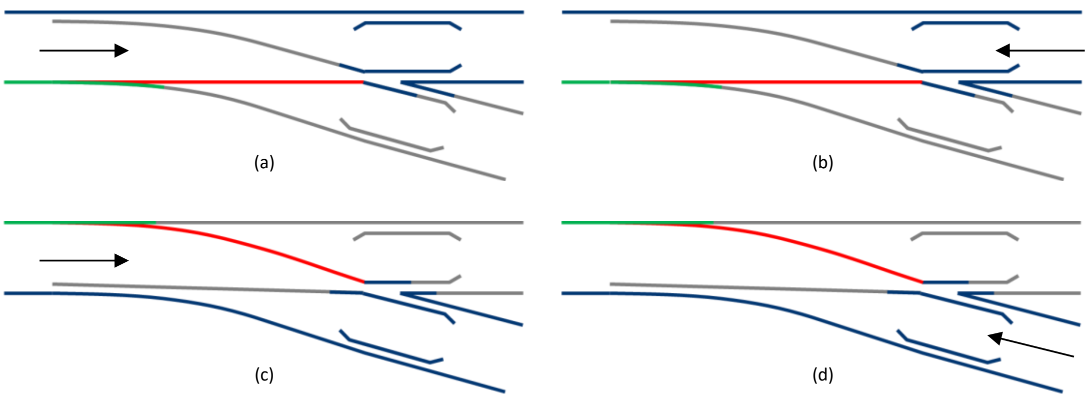

Figure 2: Case scenarios: (a) facing-through; (b) trailing-through; (c) facing-diverging; (d) trailing-diverging.

3 Results

The geometry of the pair stock-switch rails results from machining operations that are represented by the Boolean operations "Subtract" and "Intersect", which are implemented in the *SnC_Design* tool and illustrated in Figure 3(a) and (b). Thus, the rails geometry is provided as a set of rail profiles, as shown Figure 3(c), which are then used for the kinematic analysis and multibody simulations.

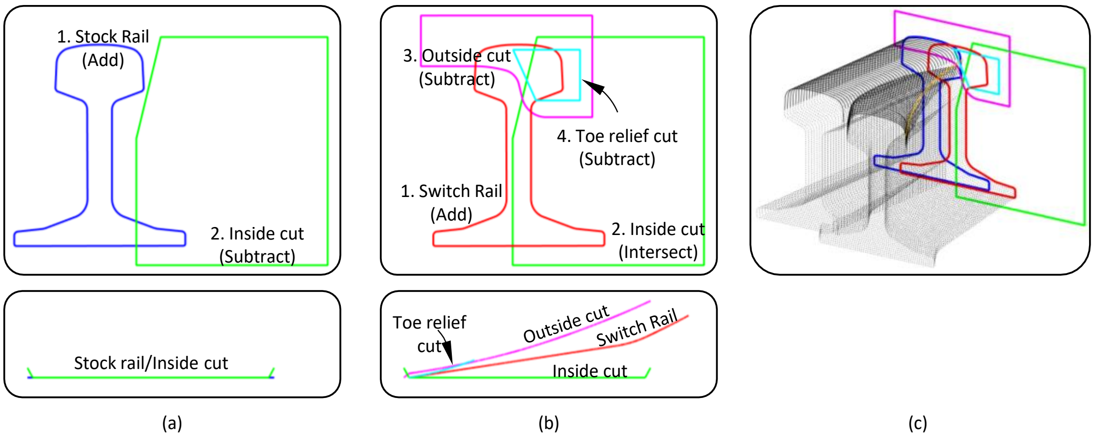

Figure 3: Boolean operation to obtained (a) stock rail and (b) switch rail. (c) Switch-stock rail model.

From a preliminary analysis, where 29 switch designs proposed by AFL are tested, the variation of the horizontal inside cut and vertical outside cut paths greatly impacts the switch performance. Therefore, these paths are parameterized to create a batch of alternative inset switch designs that are shown in Figure 4 (a) in dashed black line whereas the thick blue line is the original case proposed by AFL based on current historical knowledge. The inside and outside cuts have been combined leading to 320 alternatives to the inset switch design. To distinguish the alternative designs, a code with four digits is used, where the first and second digits are related to the longitudinal and lateral variations performed in the inside cut path, whereas the third and fourth digits are related to the longitudinal and vertical variations performed in the outside cut path.

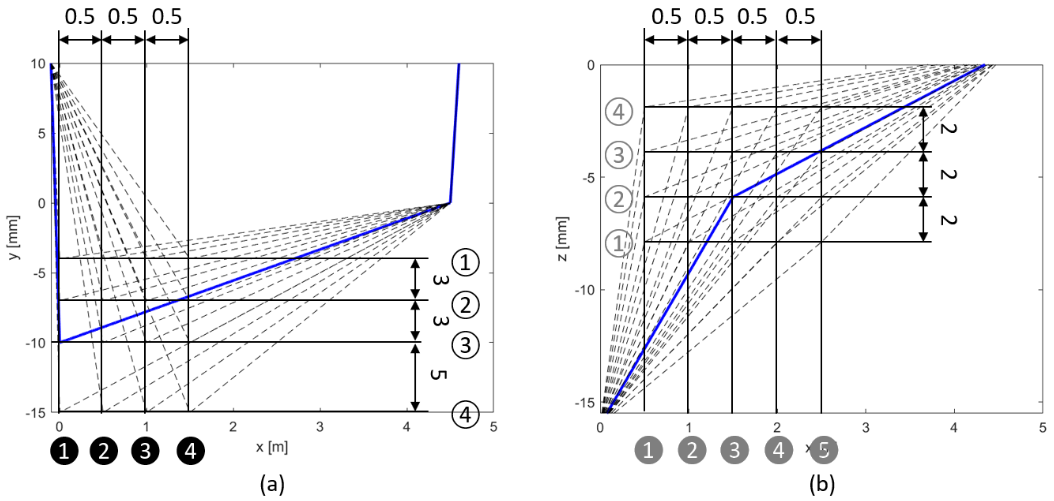

Figure 4: Batch of alternative inset switch design variations where (a) shows the horizonal inside cuts and (b) the vertical outside cut.

Multibody simulations of a passenger vehicle negotiating the facing and trailing directions on the through and diverge routes are carried out on the 320 designs. The selection of the best designs is strongly affected by the weights given to each selected performance indicator (e.g. acceleration, maximum force etc…). Therefore, five scenarios are adopted with different weights as listed in Table 1, which priorities different damage mechanisms.

	Facing / Trailing							
	Through route		Through route					
Parameter	B_{MAX}	$(B/Thic)_{MAX}$	B_{MAX}	Y_{MAX}	∫(Y)	$(B/Thic)_{MAX}$	A_{CB}	Jerk
Scenario 1	0.50	0.50	0.17	0.17	0.17	0.17	0.17	0.17
Scenario 2	0.75	0.25	0.25	0.25	0.25	0.10	0.03	0.03
Scenario 3	0.50	0.50	0.15	0.15	0.15	0.50	0.03	0.03
Scenario 4	0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00
Scenario 5	1.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00

Table 1: Weight scenarios for performance indicators.

Figure 5 illustrates the cutting path achieved for those. The overall best design originates from scenario 3 (3323) leading in the diverging route to a very significant (-25%) improvement in maximum lateral force and a reduction of 7% for the sum of lateral forces. The overall average reduction (improvement) in performance criteria is 7%.

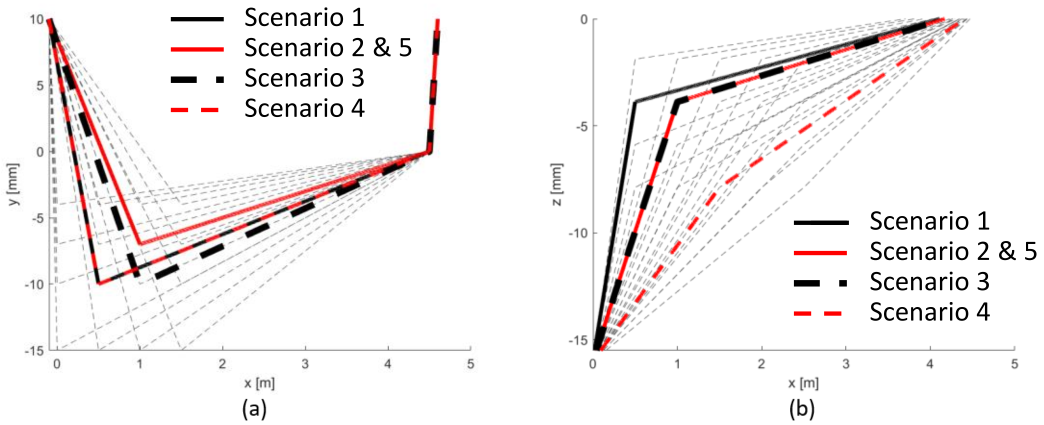

Figure 5: Comparison between best designs from scenarios 1 to 5 of the horizonal inside cuts (a) and the vertical outside cut (b).

4 Conclusions and Contributions

This work proposes a comprehensive computational study focused on the design of an inset switch rail. To support this work, a dedicated computational tool is developed to replace the common manual and time-consuming task of modelling a switch rail geometry. The so-called *SnC_Design* tool requires simple inputs, like profiles and paths of extrusion and cutting Boolean operations, to automatically determine a set of rail profiles that represents the switch design. Thus, large sets of designs can be quickly created as well as their wheel-rail interaction studies that are performed through multibody simulations and kinematic analysis. This work shows that the dynamics of the vehicle-track interaction led to results that do not systematically match well with the kinematic quantities obtained from the kinematic analysis, therefore, only the results obtained with the multibody simulations are used to support the design of the inset switch. From the 320 alternative switch designs, which were derived from a design proposed by AFL, and by considering the facing and trailing directions as well as the through and diverging routes, thousands of multibody simulations have been performed. The selection of the best design is made based on selected performance indicators, which are defined to capture the rail and track damage as well as passenger comfort. The quantification of performance to obtain an overall scoring is made by considering several weighting combinations so that a number of designs can be proposed to best suit certain operating conditions or customer requirements.

Overall, the best designs are achieved with an inside cut up to 10 mm over 1 m, while the outside cut needs to rise reasonably fast to 4 mm below top of the rail over 1 meter. The fatigue of the switch points can be further protected by lowering (-8 mm) and delaying (1.5 m) the outside cut as obtained in scenario 4. A future step is to use an optimization algorithm to parameterize the switch model while considering more design variables and using the overall performance indicator as an objective function.

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