

Design of new generation of switches and crossings

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<https://doi.org/10.5592/CO/FTCE.2019.13>



Scientific Symposium FUTURE TRENDS IN CIVIL ENGINEERING
Zagreb, Croatia, 17 October 2019

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Abstract

Switches and crossings are the essential elements of railway lines. In 2016, the S-CODE (Switch and Crossing Optimal Design and Evaluation, Shift2Rail) project was initiated, which seeks radically new ways of changing trains between tracks with regard to the growing capacity and reliability. The fundamental objective of the research activity at this stage is to find reliable and robust designs with low life-cycle costs, low carbon footprint, and low maintenance. The use of new materials, manufacturing processes, electronic equipment, and signal processing and mechatronic solutions, is investigated.

Key words: railway track, permanent way, switches and crossings, diagnostic systems, Shift2Rail, rail paradigm shift

Oblikovanje nove generacije skretnica i križišta

Sažetak

Skretnice i križišta su ključni elementi željezničkih pruga. Godine 2016. pokrenut je S-CODE projekt (Optimalan dizajn i procjena skretnica i križišta, Shift2Rail) čiji je osnovni cilj osmisliti potpuno nove sklopove za prolazak vlakova između kolosijeka s obzirom na sve veća prometna opterećenja i pouzdanost konstrukcije. Temeljni cilj istraživačke aktivnosti koja se provodi u ovoj fazi projekta jest pronaći dovoljno pouzdano i robusno oblikovanje skretnica i križišta koje bi rezultirao što manjim ukupnim troškovima tijekom njihova trajanja, nižom emisijom ugljika i zahtijevao što manje održavanja. U sklopu projekta istražuje se mogućnost primjene novih materijala, postupaka proizvodnje, elektroničke opreme, obrade signala i mehatroničkih rješenja.

Ključne riječi: željeznički kolosijek, gornji ustroj, skretnice i križišta, sustavi za dijagnostiku, Shift2Rail, promjena paradigme o željeznici

1 Introduction

1.1. Switches and Crossings – the most complex part of track

Switches and crossings (S&C) are the essential elements of railway lines, allowing a change in direction, or the transfer of a vehicle from one track to another. The structure of railway turnouts is rather complicated in comparison with the plain track; it consists of a large number of special components forming switches and crossings panels. The control and command system, as well as the diagnostic and actuating system, are also part of the switches, and they are increasingly being used in response to a general increase in service speed. Higher velocity induces an increase in the radii of curvatures of the branch track in switches, and this then leads to the elongation of the movable turnout parts.

With an increase in train speed, axle load and an overall operating load, and with an increase in the complexity of turnouts, higher dynamic effects are caused by the passing rolling stock. In particular, the interrupted running edges located in fixed crossings are the most common place of dynamic load, with an increased volume of maintenance work such as overlay welding or tamping. Moreover, significant changes in track stiffness play a role in terms of dynamic load. These significantly increase maintenance demands and shorten the lifespan of these structures, leading to higher life cycle costs.

1.2. Optimal design and evaluation of switches and crossings – visions for future

The S-CODE (Switch and Crossing Optimal Design and Evaluation) project, initiated in 2016, seeks radical new ways of changing trains between tracks in response to existing problems occurring in switches, and considering the growing capacity and reliability of railway transportation. The University of Birmingham is the coordinator of the S-CODE project, supported by Shift2Rail, while other members of the consortium are partners from academia (Brno University of Technology, abbr. as BUT, Loughborough University, University of Pardubice, abbr. as UPa), turnout manufacturer (DT – Vyhybkarna a strojirna), and other industrial partners dealing with switches from various perspectives, such as the current regulation, construction, transport, installation, etc. (Rhomborg-Sersa, RSSB, COMSA, Ferrovial). In the framework of the project, proposals of new concepts are considered, on the one hand, from a completely new and innovative perspective of switches functionality, and, on the other hand, in terms of solving individual partial problems in the field of sensors and monitoring, turnout components, and innovative materials and solutions for kinematic systems for redesigning movable parts of newly proposed turnout devices. The project also includes the validation and assessment of the solutions. This article provides an in-depth description of new concepts for switches, with an emphasis on the Single Slender Switch and Vehicle Based Switch concepts, which are described in greater detail in subsequent sections.

1.3. S-CODE project objectives

In order to develop the project, the consortium set out its high-level aims, and detailed the technical ambition for TD3.2 in the MAAP of Shift2Rail, to identify the key objectives that will help provide radical new ways of changing trains between tracks in order to improve capacity, reliability and safety, while reducing investment costs and life-cycle costs. The most important objectives are:

- Develop a modular switch and crossing (S&C) architecture that allows subsystems to be easily changed or upgraded such that the gains in S&C system performance available from the adoption of new concepts can be realized progressively without the need for complete system renewal, thus enabling faster realisation of benefits;
- Realize resilience-based design methodologies, maintenance-free and degradation-free systems, and self-adjusting technologies that will allow complete self-inspection and self-correcting and healing functionality through the development of an S&C immune system;
- Develop concepts that utilize new materials and construction techniques, together with an optimized wheel–rail interface to realize a new movement principle which has the potential to contribute to the reduction of life-cycle costs;
- Significantly increase the allowable running speed of trains while also dramatically decreasing the switching time.

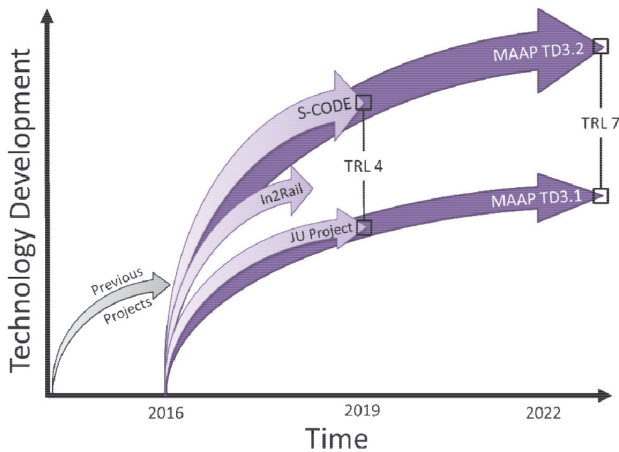


Figure 1. S-CODE relationship to Shift2Rail MAAP technology demonstration

1.4. S-CODE structure and time schedule

The project implementation was divided into three basic phases:

- Phase 1: Requirements and initial design solution;
- Phase 2: Technology development;
- Phase 3: Evaluation and demonstration activities.

The first stage focused on key requirements for switches and crossings. Experience with existing designs and technologies, best current solutions and recent research and development were summarized (e.g. [1], [2]). A number of current and historical turnout concepts were reviewed and evaluated, the principal aim being to test whether new technologies will allow implementation of some previously rejected concepts considering current safety and reliability requirements.

The second phase of the project focused on detailed design solutions and was divided into three basic subsystems each corresponding to one work package:

- WP3 Next generation control, monitoring and sensing systems;
- WP4 Next generation design, material and components;
- WP5 Next generation kinematic systems, actuation and mechatronics.

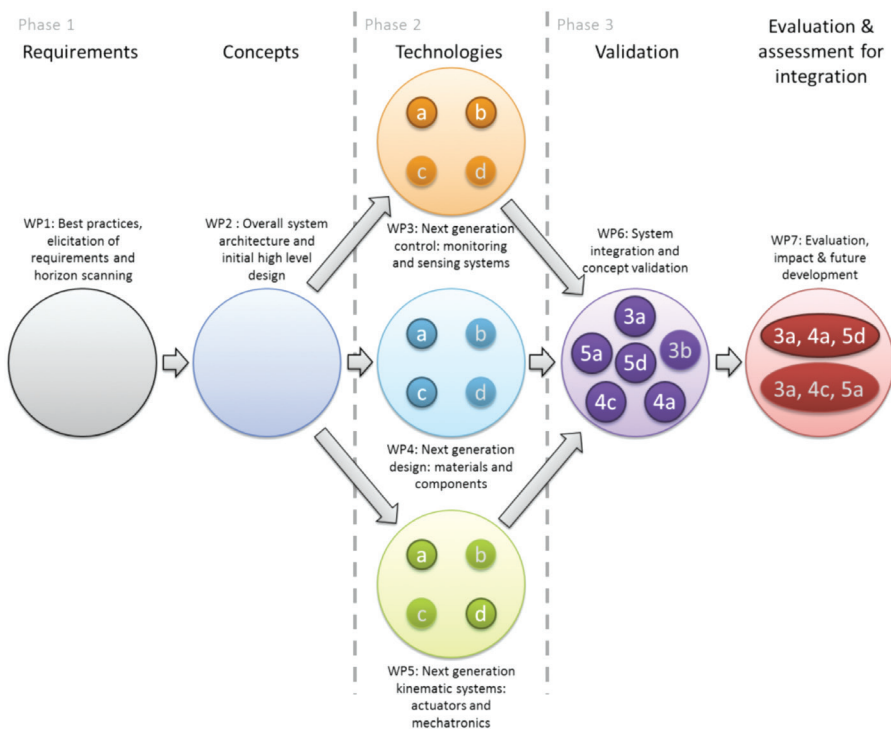


Figure 2. S-CODE work package interaction

At this stage, the fundamental objective of the research activity was to find reliable and robust designs with low life-cycle costs, low carbon footprint, and low maintenance. The use of new materials, manufacturing processes, electronic equipment, and signal processing and mechatronic solutions was investigated. A matrix of technologies was developed for each of the subsystems at different levels of development, and the most promising one was assessed using developed advanced analytical models. In the current third phase, the solutions found in the individual subsystems are evaluated in detail with a view to enabling their integration. Demonstrators are being assembled and tested under laboratory conditions. The aim is to identify those solutions that will be developed further in the follow-up projects.

2. Diagnostics and monitoring – analytic system for dynamic effects analysis

2.1. Design of diagnostic system

As stated in the introduction, the S&C are subjected to high dynamic loads. Dynamic impacts exert load on all components of the turnout, not only on rails or sleepers but also on actuators and all other components. Therefore, one work theme in WP3 within the S-CODE project is the dynamic impact monitoring. The main aim of this work theme is to develop a system for automatic monitoring and evaluation of dynamic effects in S&C. The system is based on the evaluation of measurements of vibration obtained through acceleration sensors.

The system has to be:

- compatible with the existing control command and signalling systems.
- autonomous – it has to work without human intervention.
- maintenance-friendly – it will not be necessary to uninstall it from the track.

In summary, the main motivations for the development of the system are:

- Dynamic effects substantially reduce the lifetime of the S&C construction and all its components.
- To capture early defects in transition geometry and minimize the impact of dynamic effects on the development of defects.
- The system should help with maintenance planning.
- The system should also generate maintenance recommendations (increasing wear or degradation of structure support, etc.).
- Evaluation of dynamic effects of individual trains and specific vehicle types.

It is anticipated that in the future the system might also be able to:

- Categorise and identify presence of defects.
- Calculate track parameters such as stiffness.
- Advise manufacturers about component use and wear rates.
- Support the design of new components with reduced dynamic effects.

The basic feature of the system is that it consists of several separate modules. The first module is located in front of the S&C and its task is to determine which type of multiple-unit or locomotive is passing based on the measured vibration acceleration signal. This is referred to as the Train Identification System (TIS). The system can also measure train speed, but there are more options to measure it in other parts of the wider system. The train then passes through the S&C and the Dynamic effects Evaluation System for the Switch (DESS) and the Dynamic effects Evaluation System for Crossing (DESC). The DESS and DESC measure and evaluate the dynamic effects on relevant switch components.

Depending on the type of train (multiple-unit or locomotive) and speed, each train is assigned a category in which the results are compared and ranked. Only the same types of trains with the same speed can be compared. Reference data for the different categories of trains was collected during the first days of operation of the system. The system then evaluates which dynamic parameters increase in each category and how much they increase by, and recommends adequate maintenance if appropriate. Because the system will always have several categories in which it will evaluate, it is possible to neglect the influence of an increasing wheel wear, or wheel reprofiling, which certainly has an influence on dynamic effects through change in transition geometry. The system will evaluate increments per day, week, and month. The stiffness of the entire structure will undoubtedly also have an effect on dynamic effects. This stiffness will change over the year with regard to temperature and precipitation. These effects have to be monitored in the trial operation of the system as well. The basic concept of the system is shown in Figure 3 below.

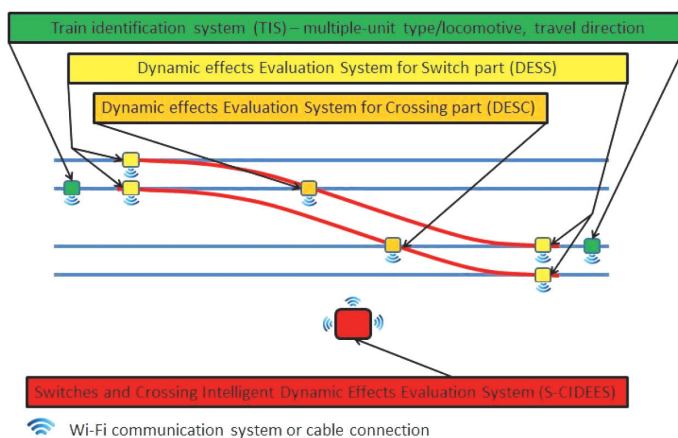


Figure 3. Single crossover – system placement

An architecture has been designed for implementation of the monitoring concept. The design is shown in Figure 4 below. The system generally works in three steps. The first step is to measure data and send it to a computer outside of the track, where the data is evaluated (the second step) and the results are sent to the results collection

server. The system will be taught for the first few years and system optimisation will also take place. In order to support this approach, raw measured data will be sent to the raw data collection server in the second step. In the third step, the results will be evaluated, raw data will be re-evaluated and the system will be optimised. The advantage of this variant of the system is that the measurement modules can be less expensive and more compact because they will only be measuring and sending data. It is likely that the modules in the S&C will also be less costly. Another advantage may be that the optimisation of the system will take place in fewer units - several S&Cs can send data to one computer outside the track. Due to the fact that units in the track are simpler, a longer lifetime can be expected.

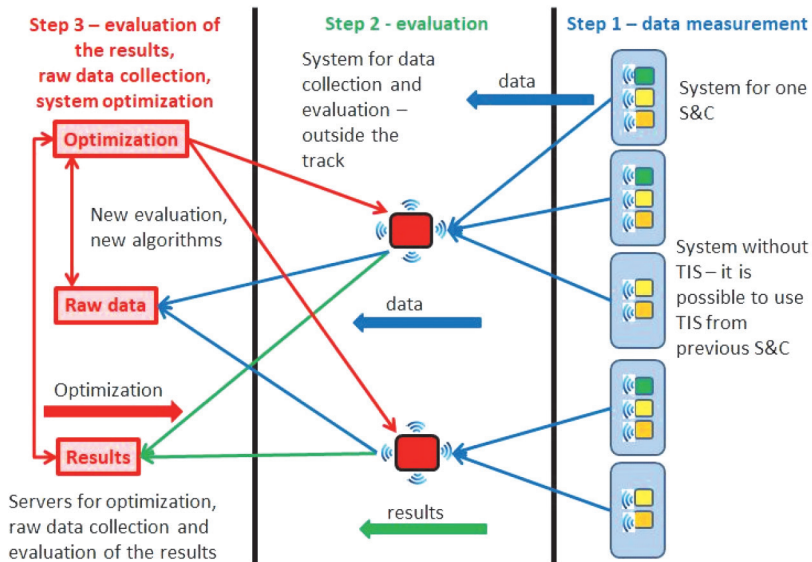


Figure 4. Design of diagnostic system

2.1. Operation of diagnostic system

The system will use learning algorithms to evaluate the dynamic effects within the switch. A long-term research and data collection activity will be required before the system is expected to operate completely autonomously and to make full use of its potential. There is still little data to teach the system, even if the data is actually being collected. The system can learn on the basis of the data already acquired, and the more maintenance cycles the system undergoes, the more accurate it will be. It is expected that the system will be able to categorise and determine a specific type of fault in the future including, for instance, prediction of the lifetime of the components in the S&C. Even though the system is still learning, it can already be of benefit to infrastructure

managers as it can monitor the increasing dynamic effects and thus indicate potential faults through alternative analysis methods. The basic concept of the way in which the future system will operate is illustrated in Figure 5 below. The system will continually collect and evaluate the data in this first phase for several years. After this first phase, the system will be able to generate maintenance recommendations and to manage S&C maintenance planning. After the maintenance, it will be able to evaluate the efficiency of maintenance work, which is a key issue for infrastructure managers. In particular, after the maintenance the system will re-measure and analyse the data and based on the results it will recommend and plan new maintenance activities, or recommend replacement of a faulty component. These recommendations will also be relevant to manufacturers who can prepare themselves in advance for manufacturing and replacement of such components. At the same time, the data obtained during the lifetime of the component will be used for future development of new design solutions.

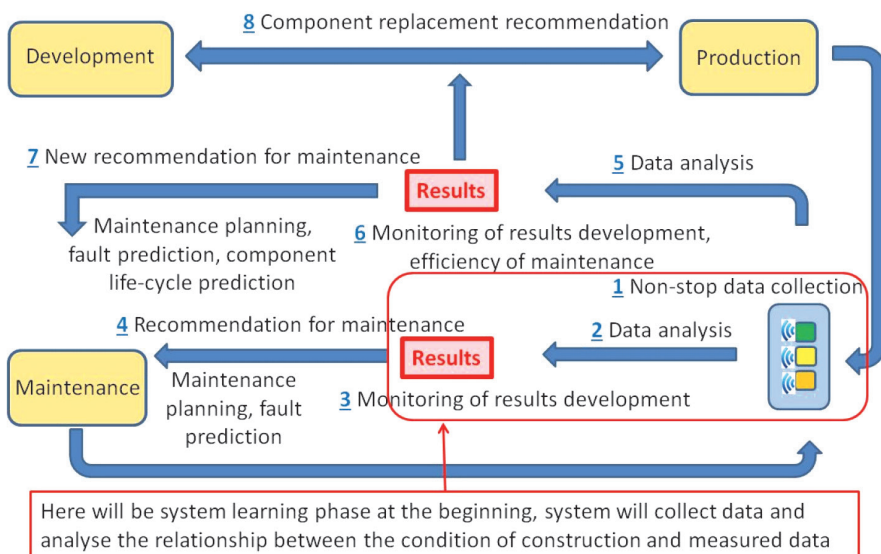


Figure 5. System operation scheme

3. Integration and optimisation of S&C Infrastructure

3.1. Review of technologies developed

Innovative technologies for S&C were chosen based on SWOT analysis of prospective technologies, which were further developed up to the technology readiness level 4 – evaluation in laboratory environment. The following technologies are being developed:

- innovative types of rail fastening (see Figure 6),
- composite plastic sleepers and bearers,

- self-healing and high-damping concrete,
- resilient ballast bed – Neoballast,
- nanomaterials.

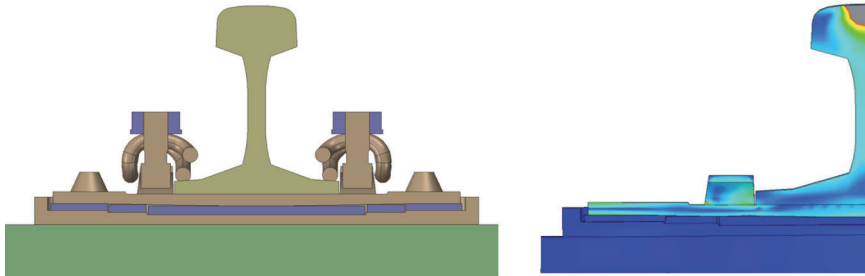


Figure 6. Example of innovative rail fastening

The S&C wheel–rail interface model was significantly enhanced, and the substructure S&C model was developed. Both models were designed to provide advanced tools for evaluating static and dynamic responses for selected technologies related to rail support. Static and dynamic analyses were conducted for composite plastic sleepers, Neoballast and a combination of these two technologies. At the same time, static and dynamic analyses were performed for standard S&C structures to compare the efficiency of new technologies.

Laboratory tests of plastic composite sleepers and Neoballast were preceded by appropriate analyses so as to obtain mechanical properties as needed for static and dynamic analyses. In addition, separate finite element analyses of innovative types of rail fastening and composite plastic sleepers with holes and cavities were carried out to accommodate advanced devices for monitoring dynamic effects, and for the installation of data acquisition systems and energy harvesting units.

The rail infrastructure optimization and integration strategy has been developed for selected technologies. The solution achieved is characterized by modularity and self-healing behaviour, and by increased durability and lifespan due to reduced dynamic effects. The monitored technologies do not require any specific technological processes of installation, maintenance and removal, so that they can be implemented immediately after development to further technology readiness levels and following implementation of necessary approval procedures.

3.2. Wheel/rail interaction model

Research activities have resulted in the introduction of a new approach to computation of the dynamic behaviour of a railway vehicle passing over a turnout. This research is a follow-up of long-term investigations in the field of vehicle–track and vehicle–turnout interaction ([3], [4], [5]). The new approach takes into account the transition of the wheel–rail contact point from the wing rail to the crossing nose. This is visible from

the presented result plots of the wheel force in terms of the wheelset rolling on the rail with an inconstant railhead profile as well as inconstant rail support parameters (stiffness of the rail support).

As to railhead profile variability, the dynamic effects of the vehicle are significantly different to the simplified wheel–rail contact model with constant rail profile used so far. The new approach to computation of the wheel–rail contact enables acquisition of more exact courses of the appropriate turnout component loading.

It is possible to carry out simulation computations of the dynamic behaviour of the vehicle–turnout system (based on the improved software SJKV, UPa) for any new type of turnout which is exactly described by the following parameters:

- dimensions of the turnout,
- exact description of the shape of appropriate components (rail profiles along the full length of the turnout),
- mass parameters of the turnout dynamical model,
- parameters of both rail supports and other components along the full length of the turnout.

Use of the radically improved wheel and rail interaction which was implemented in the UPa software SJKV leads to the following new opportunities (compared with the previous approach):

- Analysis of dynamic effects of the vehicle running on the exactly determined trajectory of the turnout rails (theoretically defined as well as measured).
- Consideration of the variability of rail support parameters along the full length of the turnout.
- Optimization of the running surface design of a particular turnout component.
- Analysis of the wheel and turnout rail profile wear to increase their service life and operational safety in high-speed conditions.

The results of the computational simulations performed show a possible decrease of wheel impact forces in the crossing part (crossing nose) of the turnout of up to 10% for the proposed solutions (Neoballast, composite sleeper) in given conditions (speed, track geometry, vehicle parameters).

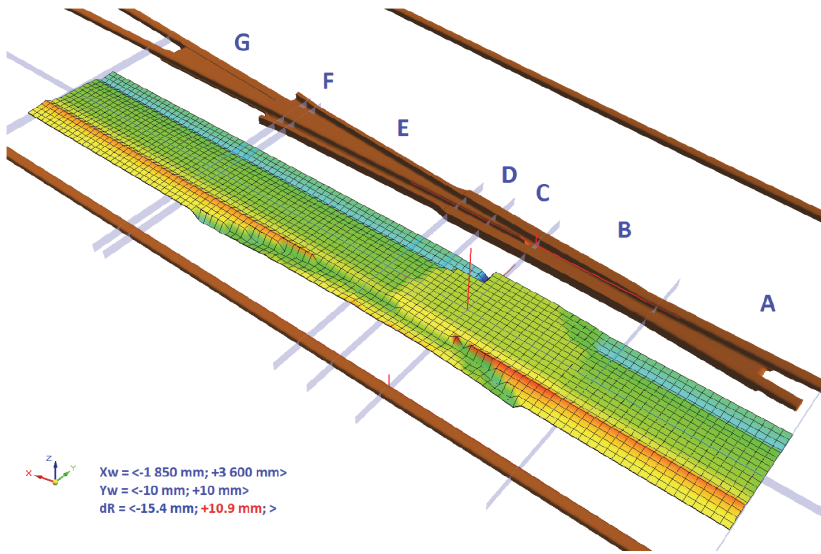


Figure 7. Values of Δr function along the crossing

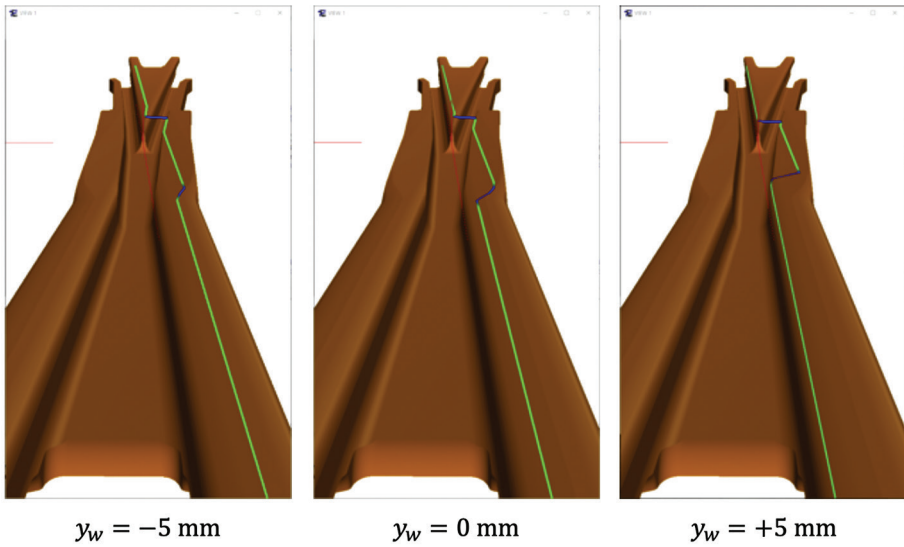


Figure 8. Example of contact point position at different lateral positions of the wheelset

3.3. Advanced substructure model

The correct computational model of the S&C structure was developed with the application of the FEM in the ANSYS software. The geometry of the model matches the details of the drawing documentation. The turnout geometry was transferred from the 3D CAD format using the SAT format directly into the ANSYS system, which was appropriately adopted for the discretization used in the FE analysis. The model obtained is very finely structured and, at the same time, it is suitable for correct calculations, see Figure 9. The modelling respects the shape of the rails, the variety of sleepers and bearers, the rail fastening, the clamping forces, and other details. The S&C superstructure model is completed by the substructure model (ballast bed, substructure layers on the Winkler's model of subsoil).

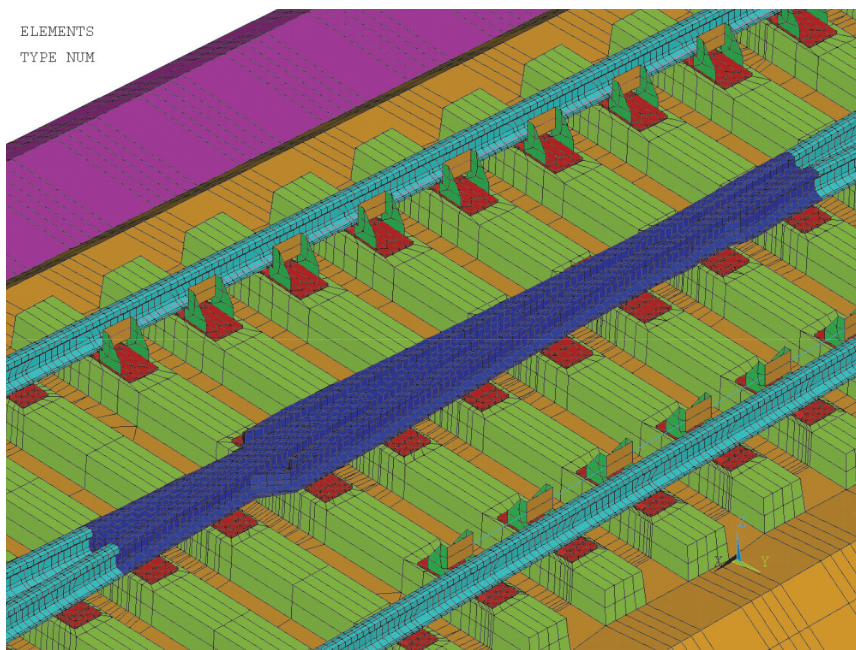


Figure 9. Detail of crossing model by FEM

The properties of structural materials were taken from laboratory and in-situ tests. We can reasonably expect that the model correctly describes basic dynamic properties of the design. The functionality of the model has been verified on the test variant of the calculation. The results are documented graphically in the report. Variants of static response have been dealt with, varying with the sleepers or bearers used and the material of the ballast bed. The influence lines of wheel forces (two forces at 112.5 kN of one axle) were calculated over the entire length of the track rails, and in the track in front of and behind the S&C structure. The simulation calculation with

the help of influence lines determined the interaction between the four-axle vehicle and the track. The simulations were made taking into account the vehicle's running speed of $200 \text{ km}\cdot\text{h}^{-1}$ and real track irregularities.

The calculated interaction forces of the four-axle vehicle acting on the railhead were applied in dynamic response calculations. The dynamic response of each variant of the track layout was solved. The response corresponds to running of the railway vehicle in a straight line on the straight branch in the direction from the top to the heel of the structure.

The calculations were made by direct integration of motion equations. To specify the time and positional variable forces, the ANSYS program has been customized by the special macro-control process of the force applied to the model. For each variant, the fields of displacement, strain and stress were obtained, see example in Figure 10. The extensive results contained in the database are presented graphically.

The results show that the dynamic response is heavily influenced by stiffness changes in the substructure. This effect is significant in the S&C panel. The stiffness changes of the rail support along the track length can be corrected by changing the component stiffness or by an appropriate design arrangement in exposed areas. In the case of the crossing model, there are strong dynamic impacts when a wheel is passing the crossing. An increase in elasticity does not help in this case; it is necessary to change the contact geometry between the crossing and the wheel.

The technologies investigated, Neoballast and composite plastic sleepers, increase the track bed elasticity, i.e. reduce the vertical track stiffness. This phenomenon contributes to a more homogenous stiffness along the track and reduces dynamic effects, leading to lower stresses and a more uniform stress distribution throughout the substructure. Consequently, higher durability and a prolonged lifespan can be expected.

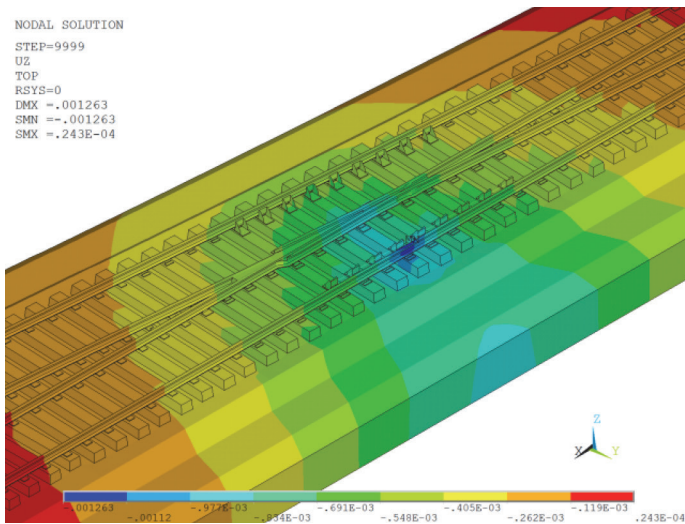


Figure 10. Displacement field of vertical deflection from wheel load – dynamic stiffness

4. New turnout concepts

4.1. Review of new concepts

A total of 22 turnout concepts were identified in the first phases of the S-CODE project and the in-depth literary review, both in the field of new switch concepts, which have been dealt with and presented in various projects in the past years and from historical sources. Some concepts were more common and more conventional in nature, some concepts were historical in nature and have been forgotten, and some of these concepts were almost unsolvable in terms of today's technological development. For the purposes of further development, the subsequent 5 concepts have been selected using a sophisticated assessment that includes various switch characteristics and parameters:

- Back to Back Bistable Switch;
- Pivoting Switch;
- Sinking Switch;
- Single Slender Switch;
- Vehicle Based Switch.

The first concept, which is further developed, is the Back to Back Bistable Switch, see Figure 11. It concerns further development of a turnout concept developed at Loughborough University, which is labelled as ©REPOINT ([6], [7]). It is a turnout with a switch panel with obtuse switch tongues, while the rail joints are very oblique in design with a special geometry. Given the special geometry of the rail joints, it is not possible to move movable parts only in the horizontal direction when switching, but these obtuse switch tongues must be reloaded on a circuit path, that is, through a combination of vertical and horizontal movement. This movement is used for a completely innovative way of locking and securing the switched switch panel. In the S-CODE project, this possibility of switching is also extended to creating a movable obtuse point frog.

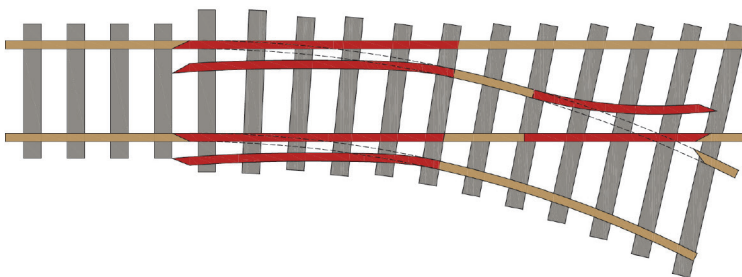


Figure 11. Back to back bistable switch

Although the rail joints are extremely oblique in design, with special geometry, it is clear that this spot will still be very critical in terms of dynamic stress during operation. In contrast, the great advantage is the use of the same rail profile along the entire length of the switch. This concept will require further solutions due to a vast number of problems, such as incorporating the turnout into long-welded rails, resistance to braking and acceleration forces, and proper security due to switch non-trailability when driving from the wrong direction. In the framework of the S-CODE project, this concept is being further developed at the University of Birmingham and partially at Loughborough University.

Another concept that has not been further developed to such an extent is the Pivoting Switch concept, see Figure 12. A change in direction is ensured by relatively short segments, which are considered only up to the height of the rail heads. Essentially, it is a rigid design of obtuse switch tongues located on a pin. This concept is based on a historical concept of switches that was abandoned a long time ago. In particular, Verifications were made to find out whether today's technology could follow up on this concept, come back to it, and develop and innovate it further in some suitable way. Upon completing the assessment, the pursuit of this concept was abandoned, since the prospect of application is very low at this moment, i.e. the only possible application that can be considered is for short switches with small radii, mainly used in tram lines. Due to the problems identified during analysis, it is a question whether this solution would be suitable even for tram lines.

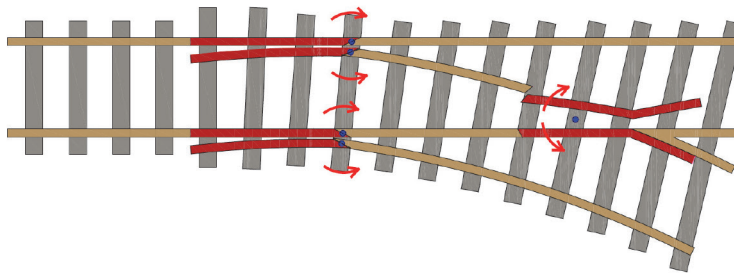
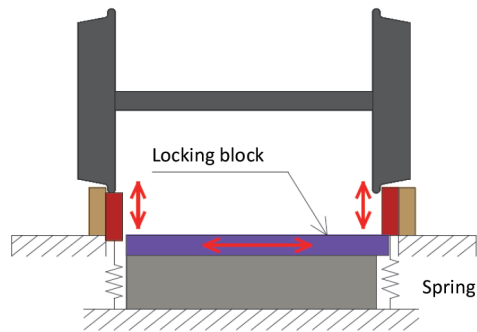


Figure 12. Pivoting switch

The Sinking Switch concept uses the principle of the vertical movement of switch tongues and elements in the crossing area, which creates a path for the wheelset in the given direction, see Figure 13. During development, the possibility of pressing down these vertically sliding elements was also considered using the vehicle's wheel flanges, which was subsequently assessed as dangerous. An uninterrupted running edge when filling the grooves may be an advantage, if it is well constructed, as barriers and security are easy to solve. This concept is also highly developed in a similar design in the framework of a Dutch project for a new switch concept under the trademark ©Winterproof ([8], [9]), which is why it has not been developed further within the S-CODE project.

View from the switch tip

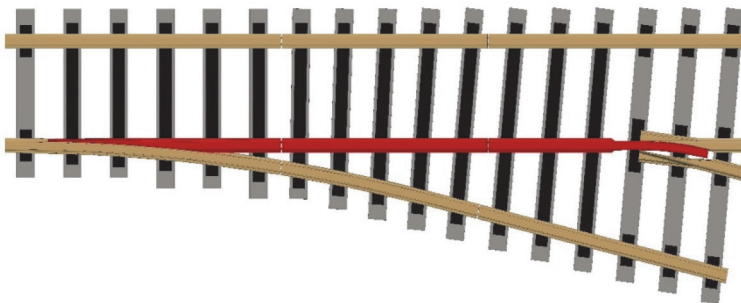
**Figure 13. Sinking switch**

The Czech partners of the S-CODE consortium are primarily dealing with the Single Slender Switch and Vehicle Based Switch concepts. The former is a turnout concept wherein a single long movable part is used from the beginning of the switch section up to the frog. In the latter, the direction choice of passage through the turnout is transferred to the vehicle. Both concepts are described in detail in the following sections.

4.2. Single Slender Switch

4.2.1. Full Single Slender Switch

Firstly, the Single Slender Switch was elaborated with a single long switch tongue across the entire length of the switch, see Figure 14. The solution of the concept was divided into 3 partial issues. The first is a solution for the 'switch panel', i.e. the point of the switch tongue's contact with the stock rails and the wheel transition. The second partial solution is the 'crossing panel', i.e. the point where the switch tongue is in contact with fixed rails at the end of the switch. The last area solved was the issue of switching and locking the switch tongue.

**Figure 14. Single Slender Switch**

The ‘switch panel’, i.e. the detail of the switch in which the switch tongue should be alternately in contact with the straight and curved stock rail, proved very difficult to solve. The tip of the switch tongue solution, which should function with the stock rail from both sides, leads to a solution wherein the switch tongue would be very thin, prone to breaking and unstable as vehicles pass. The running edge geometry itself is another problem, because a solution with smooth geometry of both running edges of the single slender switch can not be found, see Figure 15.



Figure 15. Detail of the tip of the Single Slender Switch

Compared to the geometrically unsolvable ‘switch panel’, the ‘crossing panel’ solution of the Single Slender Switch concept proved much more practical, usable, and functional. The movable rail in the crossing has the shape of a stock rail and the connecting fixed running rails have the shape of a conventional switch rail. The wheel transition is thus very similar to the conventional switches in the switch panel section. The fixed point, in terms of possible dilation, is expected on the point of the long double-sided switch tongue.

This concept requires a great deal of effort for switching and closing switch systems. There is a great length of switching in the area of the switch tongue point, which nears the rail gauge. Given the length of the switch tongue, it is also expected that a large number of switching devices would need to be installed across the entire length of the switch, in both lateral and vertical directions. It would also be necessary to lock the switch tongue in the longitudinal direction, so that the single slender switch would be able to withstand longitudinal (braking and acceleration) forces. The switching and locking systems should thus also allow for a sufficient single slender switch temperature expansion.

4.2.2. Single Slender Switch in the crossing panel

Due to the problems identified in the switch part and crossing, an optimised solution shown in Figure 16 was used. Essentially, a new type of crossing with movable parts was created from this. In this case, it is assumed that the movable rail will be connected to the fixed centre rails of the middle section, and the area of the switch rail contact with the fixed rails of the frog section will be the same as in the previous

case. However, due to the rail joints used, it will be necessary to design a different switching mechanism compared to the previous solution, so that it would be possible to move the switch rail across oblique rail joints. The solution can be in the form of the switch rail being moved in the longitudinal direction of the switch, subsequently moved into the correct position transversally, and then once again moved back to the joint, in which a certain preload can be considered.

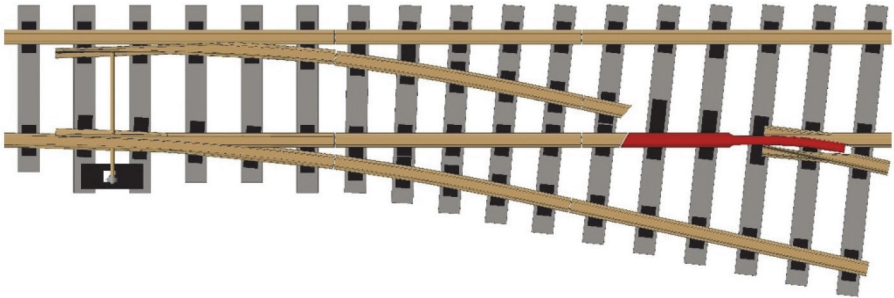


Figure 16. Optimized solution for Single Slender Switch

4.3. Vehicle Based Switch

4.3.1. Basic design principle

A greatly discussed question over the course of the S-CODE project was the possibility of vehicle switching that is controlled directly by vehicles when passing through switches. Practically, the question of whether a vehicle at a switch could turn the switch in the desired direction by itself was being dealt with, using a completely fixed switch without movable parts. This resulted in several proposals, some of which belonged more to the sphere of sci-fi or were physically unsolvable, but some were more feasible. Two alternatives have been selected for further development, wherein the first uses a change in the entire paradigm of railway transport to date, which is a problem for possible application to the railway transport system due to non-existence of a transitional phase, and the second alternative, given its character, is more suitable, mainly for tram lines.

4.3.2. Vehicle Based Switch with Paradigm Shift

Due to the kinematics of the bogie movement in a curve, the very low friction coefficient between the steel wheel and the steel rail, which is the primary assumption of the efficiency of railway transport (very low rolling resistance compared to road transport), it is not entirely possible to turn the entire vehicle by simply turning the wheel so that it would remain safe in all weather conditions. Without the railway vehicle's wheel flange, it is not possible to gain a sufficiently large Y force on the

running wheelset to overcome the friction resistance to the chassis rotation when passing through a curve.

The idea of a wheel without wheel flanges and an uninterrupted rail track requires paradigm shift, in which the wheel profile and the rail profile would be exchanged, see Figure 17. In this concept, the rail thus has wheel flanges and the wheel has the shape of the existing rail head. The system doesn't show natural conicity, but the conicity can be solved due to special wheel and rail profiles.

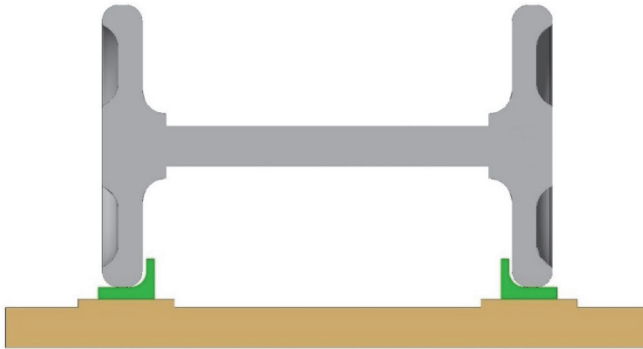


Figure 17. Paradigm shift of railway system

The device was designed on the bogie, which contains movable guiding rollers. Depending on the position of these guiding rollers at the branching point, the vehicle will be led either in the direction of the branch or in a straight direction using a lead-in wedge, see Figure 18. Thanks to the roller system and the lead-in wedge in the switch panel section, the vehicle will be led correctly over an otherwise unguided point at the switch.

The concept of placing the flange on the rail allows the use of the principle of independently rotating wheels instead of common wheelsets, whilst axles with independently rotating wheels are, in this case, naturally stable (in contrast to the conventional arrangement of wheels with wheel flanges). For this reason, it is possible to design curves of very small radii, characteristic for light rail systems or special systems, e.g., lines connecting airport terminals to one another and to other modes of transport. Independently suspended wheels with intelligent rotation control will further allow the design of low-floor vehicles, characteristic for the aforementioned railway systems.

In the next steps, it will be necessary to place a particular emphasis on the contact geometry detail in order to ensure correct vehicle centring when driving, as is the case in conventional railways. If the vehicle – rail system is correctly tuned, we can proceed to the next steps in the resolution of the concept. This concept will also require a great amount of work in the future, not only on the switch itself but also on the vehicle bogies and the control and security systems.

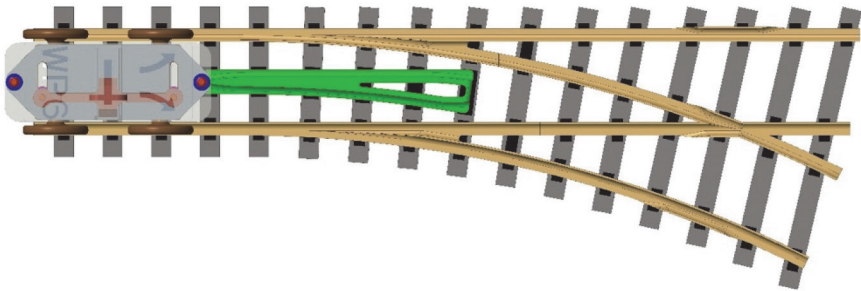


Figure 18. The VBS turnout with a bogie, with the switching mechanism switched into a branching direction

4.3.3. Vehicle Based Switch for Tramways

Another proposal, which was solved in connection with the controlled cornering on vehicles, was inspired by fixed half sets of switches for single switch tongue tram switch panels (see Figure 19). If the fixed half set of switches is used on both sides of the switch panel, then a completely new switch would be obtained. It is necessary to ensure vehicle control at the branching point in an appropriate way, which can be realised either in the same way as in the previous case, using a lead-in wedge, or by means of lateral grooves, into which a guiding roller can be lowered from the device on the vehicle bogie when passing through.

The advantage of this system lies in the possibility of a transitional period. Tramcars equipped with a leading device on such a switch can also be operated on tracks with conventional switches since the wheel and rail profiles remain the same. It is, therefore, possible to gradually rebuild the tram network when transitioning to the new system.

The great advantage, similar to the previous case, is a completely fixed switch with much lower requirements with regard to maintenance work. All direction-change devices are located on the vehicle and can be checked and maintained during vehicle inspections at depots.

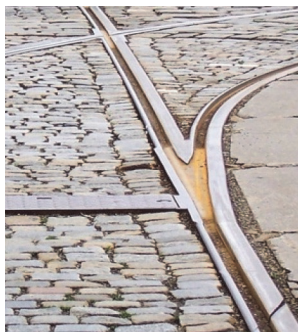


Figure 19. Example of tram turnout with a rigid half set of switch

4.4. The SWOT analysis of the selected concepts

The objective of the SWOT analysis was to gain an overview of the characteristics and properties of individual S&C concepts regarding design, vehicle kinematics (vehicle-track interaction), performance, and safety and maintenance. The goal was also to determine which S&C concepts are to be further developed and to exclude concepts that will no longer be considered. The reason for removing a concept from further research was either non-compliance with the parameters leading to the targets, i.e. worsening of structural properties, safety reduction, or development beyond the project.

A total of 12 experts from the area of railway infrastructure and rolling stock from Austria, the Czech Republic, Slovakia, Spain and the United Kingdom took part in the work. Participating experts were from technical universities, a research institute, a railway administration, an S&C manufacturer, contractors and others. Three experts outside the project took part in the work, and nine experts are members of the S-CODE research teams.

In total, 518 entries were obtained, but a number of them were duplicate. After merging the duplicate entries, a total of 254 entries were obtained, see Figure 20. The assignment of entries according to what they refer to is presented in Figure 21. It is evident that most entries relate to the S&C structural design.

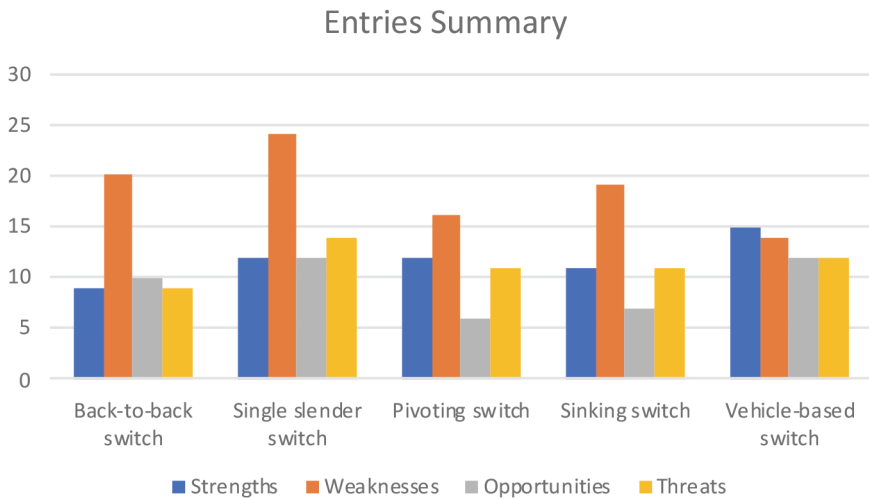


Figure 20. Review of SWOT entries after merging duplicates

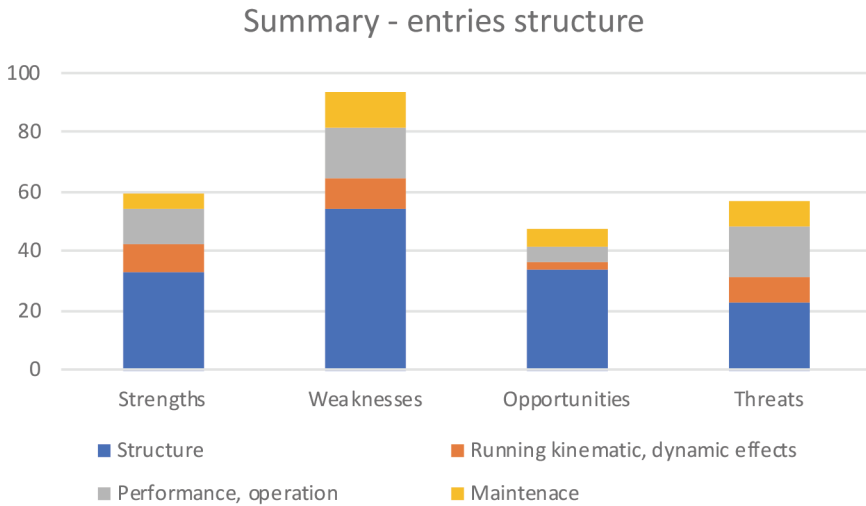


Figure 21. Review of SWOT analysis –structure of entries

The selection of the most important entries is given below.

Back-to-back Bistable switch – the most important entries:

- Strengths: Uninterrupted running surface – minimization of dynamic effects.
- Weaknesses: Transfer of lateral forces in the switching area; Interruption of CWR – thermal expansion of rails.
- Opportunities: Less complexity of wheel-rail contact at switch toes – potential reduction in frequency of switch inspection.
- Threats: Difficult to control dilation and shrinkage of rails near joints.

Pivoting switch – the most important entries:

- Strengths: Moving smaller sections of rail has its benefits both in terms of time to throw and effort required to move.
- Weaknesses: The technology to control dilations and shrinkages must act not only for the S&C operations but also to control undesired longitudinal dilations and shrinkages due to natural thermal variations.
- Opportunities: Installation of movable components made of new high tech materials with increased durability.
- Threats: Increase of dynamic effects caused by negligible wear of movable parts.

Sinking switch – the most important entries:

- Strengths: Perfect locking of switch rail, no possibility to switch the switch rail inadvertently during the passing of vehicles
- Weaknesses: Greater risk of flange climb derailment if the vertical stiffness of the dropping element is too stiff

- Opportunities: Smaller actuators required and a good opportunity for redundancy
- Threats: It is possible that small horizontal movements may also be needed to ensure proper coupling.

Single Slender switch – the most important entries:

Strengths: Simple design, one switch rail - one movable rail only.

Weaknesses: Transfer of lateral forces in switching area; switch rail to touch running rail at either side – geometrical profile of the switch rail to cope with this requirement.

Opportunities: The traditional switch could be kept while changing the crossing and the transition zone (rail between switch and crossing).

Threats: Failure due to rail crack - the entire movable length could be missing.

Vehicle-based switch – the most important entries:

- Strengths: No movable components in the S&C structures
- Weaknesses: Can only be used with compatible stock, so likely only suitable for networks with a single, dedicated fleet
- Opportunities: Potential for eliminating discontinuities through the layout, though this would require a complete rethink of the wheel profile
- Threats: Development of an active steering system for railway vehicles

Based on the SWOT analysis, the following two concepts were excluded from further research:

- pivoting switch – expected increase in dynamic effects due to components wear during the lifespan, reduced durability, impact on safety in comparison with the current S&C concept; the expected benefits can not justify these disadvantages.
- sinking switch – Significant reduction of safety – the risk of flange climbing the wheel.

Substantial benefits can be expected from the vehicle-based switch concept. This concept has never been monitored in the past because of the lack of knowledge and technologies. Vehicle-based switching requires a revolutionary design both in the rolling stock and infrastructure, which would be suitable for research within a separate project. It can be supposed that the development of technologies will allow further deployment of this concept.

4. Conclusions

In the scope of the S-CODE project's research activities, technologies are being sought and developed to contribute to the design of the next-generation S&C structures in both near and more distant future. Completely new suitable design concepts for turnouts have been selected. The vision of how technology will be used in switches and crossings has been defined, especially in the areas of monitoring and diagnostics, and in the field of superstructure design and control command systems. All research activities are intensively directed towards the general objectives set by MAAP Shift2Rail, namely:

- find adaptable methods for the design of low-maintenance switches and crossings structures with self-monitoring system, self-adjustment and self-healing capability, with the aim of reaching 50 % increase in reliability;
- develop concepts, new materials, and construction and maintenance technologies that could lead to a life-cycle cost reduction of up to 30 % in the future;
- increase the service speed and shorten the time required to actuate switches.

The research teams are now preparing demonstrators and evaluating them against these priorities.

Acknowledgements

The research published in this paper was supported by the project S-CODE (Switch and Crossing Optimal Design and Evaluation), which has received funding from the Shift2Rail Joint Undertaking under the European Union's Horizon 2020 research and innovation program under the grant agreement no 730849. Authors extend their thanks for contribution to this work to (in alphabetic order): Ales Haba, Petr Hradil, Jiri Kala, Martin Kohout, Miroslav Komarek, Zdenek Majer, Tomas Marek, Daniela Vukusicova, and Jakub Vagner.

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