Development of new and novel switch and crossing technologies through collaborative European research

INTRODUCTION

It is well understood that S&C causes the highest percentage of failures within the track environment and that for many years, the industry has been progressively enhancing parts of the S&C system to improve performance. Through better means of recording and analysing data we have become more aware of the failure modes and the related design deficiencies of the current systems. This has triggered us to start challenging how we can make S&C better by using a system focused approach as part of R&D.

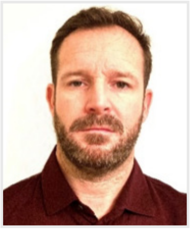
To enable a research programme to deliver its objectives it must have the time, resources, capability and vision to achieve the end goal. The time constraint is an important one. Without time we cannot develop products or systems that achieve the correct maturity for the technology being implemented. This is where Shift2Rail comes in, to help realise our future requirements for rail and provide a programme of individual projects that together provide a shift change in the railway as a whole. The programme unites Europe with a common objective across all disciplines within the railway domain. As part of Shift2Rail, IN2TRACK and IN2TRACK2 were devised as the means to develop and deliver new improved technologies for a future railway. A time horizon of 40 years has been set with designs being developed and demonstrated for use within the next 5 years by enhancement and next generation designs for the future, where radically different methods of switching, supporting, guiding and maintaining track are being advanced. This will help by innovating a system rather than a constituent part over a greater time span. S-CODE has also evolved from Shift2Rail as a vehicle for delivering new innovations within the S&C system.

IN2TRACK2

IN2TRACK2 is one of the innovation projects within the Shift2Rail programme that seeks to improve the performance of the rail system. It is partially funded by the European Union via the Horizon 2020 fund and aims to advance Research and Development in all parts of the rail system. The main objectives for IN2TRACK2 are a 50% improvement in reliability and capacity along with improvements in safety, whilst at the same time reducing lifecycle costs by 50%.

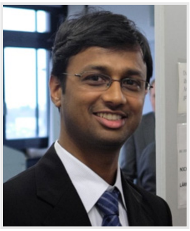
These projects are delivered through consortia of public and private organisations. Shift2Rail brings together operators, infrastructure managers, suppliers and research bodies with the ambition of bringing new and innovative technologies to the market.

AUTHORS



Darren Sharp CEng ICE/FPWI (Permanent Way Consultant), has 30 years' experience within Permanent Way Engineering, covering design, innovation, manufacture, renewals and maintenance. He has worked for British Rail, Scott Wilson, Jarvis, Transport for London and various consultancies. Darren's work has mainly concentrated on London Underground for over 20 years, involved with project engineering management and as the Principal Engineer for S&C. More recently he has worked with New York City Transit and Network Rail Technical Authority.

Roger Dixon is Professor of Control Systems Engineering and Director of Research in the Birmingham Centre for Rail Research and Education (BCRRE), which is part of the School of Engineering at the University of Birmingham. He is a Chartered Engineer with over 25 years of application-focused research experience gained in industry at Alstom and in academia at Lancaster University and Loughborough University. He is a specialist in applied Control Systems, Mechatronics, Condition Monitoring, Fault Detection and Systems Engineering. His team at BCRRE work on research projects in these areas that have a strong focus on rail, but also include application to the road, aerospace, and energy sectors. Roger has published over 150 research papers and has led a number of major research activities in industry and academia. He coordinated a number of work packages in the collaborative European S-CODE project, identifying new switching technologies and was the lead academic and co-inventor of a novel approach to track-switching “REPOINT” – a project which he led from 2010 to 2018.



Dr. Ramakrishnan Ambur is a Research Fellow at the Birmingham Centre for Railway Research and Education. His interests lie in areas of mathematical modelling, system identification, system engineering and control systems. Earlier he worked with projects involving black-box modelling using neural networks, model-predictive control, automotive suspension systems and software-in-the-loop testing for automotive Transmission Control Unit (TCU) testing. Currently he performs multi-body (vehicle) dynamic simulation, railway track dynamics and vehicle-rail interaction related tasks for conventional and novel concepts of switches and crossings.

Phil Winship is a Principal Engineer in the Track and S&C Team, part of the Technical Authority in Network Rail. He has 18 years' railway engineering experience, covering maintenance, track engineering and over 10 years' experience in switch and crossing engineering. Phil joined Network Rail in 2002 on the Track Conversion Course as Railtrack transformed to Network Rail. He then spent 5½ years in track maintenance for the East Midlands before moving to the role of Senior Track Design Engineer within HQ Engineering. In 2010, Phil transferred to Network Rail's S&C Team and in 2018 he joined the Asset Enhancement Team (part of the wider Track and S&C Team) as Principal Engineer. Part of this role involves leading the S&C work of the IN2TRACK2 project, part of the wider Shift2Rail initiative. Phil is a chartered mechanical engineer and a member of the IET and PWI.

Network Rail is a Founding Partner of the Shift2Rail Joint Undertaking and is participating in several of the Shift2Rail projects.

Each Shift2Rail project sits within one of five Innovation Programmes (IPs). IP3 looks specifically at cost efficient, sustainable and reliable high capacity infrastructure, and Network Rail are heavily involved in the IP3 project, IN2TRACK2.

Among other things, Network Rail are responsible for leading and delivering technology prototypes and demonstrators within IN2TRACK2's five main work packages:

- WP1 – Enhanced switch and crossing system demonstrator
- WP2 – Next generation switches and crossings
- WP3 – Optimised track systems
- WP4 – Next generation track
- WP5 – Assessment and improvement of tunnels and bridges

S-CODE

Switch and Crossing Optimal Design and Evaluation (S-CODE) is a completed project within the Shift2Rail Joint Undertaking (JU) under the European Commission's Horizon2020 research and innovation program. It was a "complementary project" of IP3 carried out by partners who were not part of the Shift2Rail JU and led by University of Birmingham. Other than incremental evolution of the S&C system over that last 120 years, very little has changed in terms of its operating principle and design, and this project explored new technologies and concepts to help provide a shift change in S&C design.

The overall aim of S-CODE was to investigate, develop, validate, demonstrate and evaluate radically new concepts for switches and crossings (S&C) that have the potential to lead to increases in capacity, reliability and safety, while reducing investment and operating costs. In this project, radically new S&C concepts and improved subsystems with technology readiness levels up to four (TRL4) were developed by a consortium of nine organisations, which will be taken further by IN2TRACK2.

The development map shown in Figure 1 describes the evolution of technology and shows how other projects such as In2Rail combine to meet the objectives of the Joint Undertaking (JU) and the Multi Annual Action Plan (MAAP) including any potential Technology Demonstrators (TD). Technology readiness levels are described in Figure 2.

S&C CONCEPTS FOR THE FUTURE

At the outset, instead of forecasting the future, a backcasting approach was used. Backcasting is a process whereby a desirable future is defined, and then by working backwards, it is possible to identify the workstreams that connect that specified future with the present. It is because of this, future S&C can be envisioned without being masked by constraints known to us, and then tracked back to today, thereby laying an innovation and R&D roadmap to achieve them. Operational concepts were evolved that are radically innovative using backcasting along with system engineering inspired methods.

The S-CODE project carried out an in-depth concept evaluation of various technologies to understand and assess the potential for these to be developed for the next generation S&C requirements. A ranking process was undertaken as part of the evaluation process as shown in Figure 3. This evaluation considered many options. Those that scored as having the greatest potential were identified as items that can be taken further beyond the concept stage.

As an outcome of the above process there were a handful of S&C concepts filtered methodically out of around 100 ideas (Figure 4). One explored concept was the Back-to-back bistable S&C (Figure 5a) which actuates the switch rails and crossing nose in a specially designed trajectory. With an expansion joint type layout, it aims to transfer the vehicle loads between the stock and switch rails as smoothly as possible. The second concept, Single slender S&C (Figure 5b) was also analysed for its kinematics, actuation and strength among others. This concept aims to use only one switch rail to steer the vehicle but was then only adopted for the crossing.

A third concept Vehicle-based, switching (Figure 5c) was proposed where the vehicle steers itself through the tracks with mechatronic system. It is a game changing concept which requires redesign of the vehicle bogie as well as the infrastructure, which needs intensive research on its own.

In a relative scale, if the conventional S&C is considered a baseline scenario, the back-to-back S&C offers a step change to the design, the single slender S&C is an enhancement (although used in some mining and rural railways) and the vehicle-based S&C is a fundamentally different concept.

To begin with, the novel concepts should be further evaluated for their feasibility against the known but solvable constraints and their compatibility with other subsystems. The rigorous development stages in future projects will include failproof safety examinations before the concept becomes a reality. The project then considered what componentry or associated technology advances could be developed to potentially feed into these concept solutions. This resulted in a large number of demonstrators being developed by the project, some of which were considered for taking forward in IN2TRACK2 WP2 (next generation S&C).

THE TECHNOLOGY PATH

The path to achieve S&C redesign consists of many subsystems which need to be improved. Some of them were developed during the course of S-CODE project and these have been grouped thematically in Table 1.

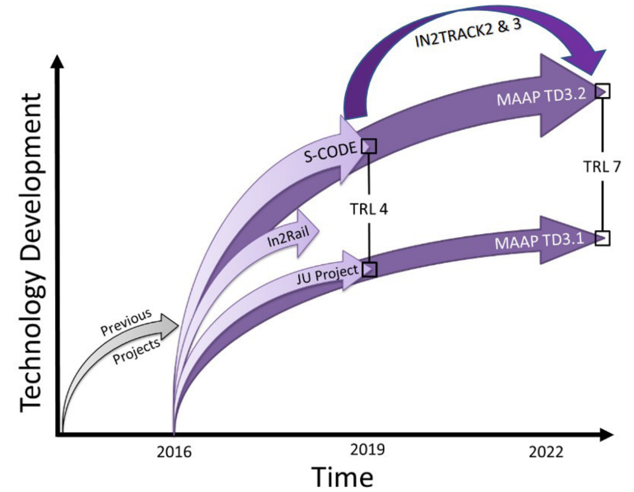


Figure 1: Timeline of projects.

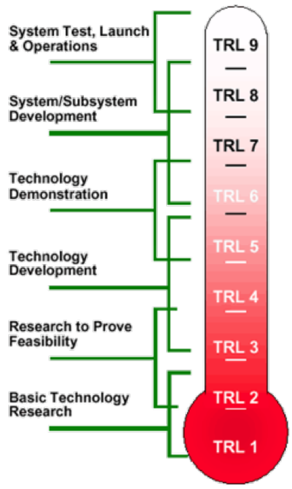


Figure 2: Technology Readiness Levels.

	Concept Selection Matrix	Weighting	Existing S&C	Concept A	Concept B	Concept C	Concept D	Concept E	Concept F	Concept G	Concept H	Concept I	Concept J	Concept K	Concept L	Concept M	Concept N	Concept O	Concept P	Concept Q	Concept R	Concept S	Concept T	Concept U	Concept V
Design	Radically different	0.105	0	4.75	4.90	4.95	5.70	2.25	4.35	1.90	2.80	5.55	4.75	5.05	4.40	5.00	6.85	6.80	5.10	5.45	7.00	6.50	6.05	5.80	5.85
	Versatile and scaleable (can be adapted to various situations)	0.073	5	5.30	5.90	4.25	2.85	6.20	4.75	5.65	5.40	4.95	6.30	4.45	5.80	4.55	3.90	6.00	5.75	5.15	5.35	5.80	5.25	6.35	5.70
	Retrofitting	0.009	10	5.80	6.25	4.15	3.50	8.15	5.90	7.50	6.80	3.55	6.35	4.80	6.55	5.25	2.80	4.10	5.95	4.55	4.05	4.20	5.95	6.75	6.20
	Modularity	0.076	5	5.70	4.90	4.20	3.10	6.05	4.75	5.35	5.20	5.20	6.05	4.80	5.80	4.85	4.20	4.80	5.45	5.35	6.85	5.25	5.60	6.80	6.40
	Allows track continuity	0.073	5	5.15	7.20	5.30	4.75	6.20	5.45	6.70	6.55	4.60	6.25	4.85	5.70	6.35	7.15	4.95	4.85	5.30	4.05	5.80	5.80	6.65	6.05
Manufacturing	Existing machinery/process can be used?	0.015	10	7.58	6.90	6.05	5.40	8.65	6.75	8.65	8.15	5.65	7.40	6.05	7.30	7.55	4.05	5.30	7.30	7.70	5.00	4.50	6.75	5.75	6.15
Maintenance	Easy maintenance	0.07	5	5.15	4.30	3.60	2.65	5.60	4.10	4.70	4.30	4.60	4.40	3.75	4.50	4.25	3.20	4.35	4.50	5.05	2.85	3.15	4.90	4.35	4.10
	Allows maintenance to be done offsite	0.038	5	5.75	4.90	3.55	2.70	4.75	4.60	4.70	4.35	5.10	5.55	4.65	5.45	4.45	3.35	6.45	4.95	4.80	5.50	6.60	5.30	5.20	5.30
Logistics	Deployability	0.073	5	5.05	5.15	3.05	2.30	5.50	4.75	5.30	4.90	4.10	4.95	4.40	5.00	4.45	2.70	4.55	4.60	4.55	4.60	4.15	4.60	5.40	5.10
	Plug and Play?	0.073	5	5.35	5.45	4.25	3.75	5.80	4.60	5.00	4.95	4.10	5.25	4.50	4.80	4.30	3.80	4.55	5.05	5.15	4.60	4.75	5.00	5.25	5.05
Operation	Energy efficiency	0.015	5	4.20	5.45	2.60	3.35	5.65	5.75	4.50	3.95	6.45	4.50	4.90	4.30	4.85	3.45	5.35	5.10	5.20	2.75	4.45	4.10	5.15	5.75
	Speed of switching	0.044	5	5.10	5.25	3.05	3.00	5.30	5.35	4.65	4.80	5.55	4.80	4.80	4.40	4.65	3.20	5.55	5.15	5.35	3.60	5.05	4.05	5.35	5.45
	Improvement in loading?	0.056	5	5.85	5.40	5.40	3.65	6.35	4.70	6.70	6.30	4.70	6.55	4.60	5.85	6.10	4.60	5.35	4.75	5.05	4.20	4.85	5.65	5.60	5.70
	Weather resistance	0.067	5	5.05	5.95	4.75	4.20	5.35	4.75	4.75	4.30	5.50	4.60	4.70	4.30	4.45	4.05	6.85	5.25	5.55	4.00	6.05	4.50	4.85	4.00
Safety	Risk of derailment can be reduced	0.082	5	5.80	5.65	5.85	5.25	4.75	5.15	5.85	5.70	4.75	5.75	4.90	5.45	5.15	4.15	3.90	4.90	3.20	5.35	3.60	5.55	5.45	5.20
	Allows safe run-through	0.032	5	2.95	3.90	2.70	2.60	5.15	4.50	4.95	4.60	5.60	3.50	3.65	3.00	3.65	3.50	6.35	3.95	3.80	3.10	5.85	3.90	4.70	5.70
	Reduction of Out Of Correspondence	0.067	5	5.50	5.65	4.65	4.15	5.20	5.20	4.70	4.50	6.25	4.05	4.60	4.30	5.00	4.30	5.05	5.10	4.85	3.90	5.30	4.95	5.25	5.30
Other	Time to market	0.015	10	6.40	6.60	6.15	5.65	7.90	5.55	8.40	7.40	3.85	6.75	4.95	5.60	6.00	3.35	3.10	5.35	5.45	3.85	3.35	4.95	4.65	4.50
	Cost	0.018	5	4.75	5.00	3.35	3.15	5.85	4.60	4.85	4.30	2.50	4.10	3.45	4.70	4.10	2.70	1.85	4.45	4.00	2.65	2.50	4.50	3.80	3.65

Figure 3. Concept Evaluation from S-CODE.

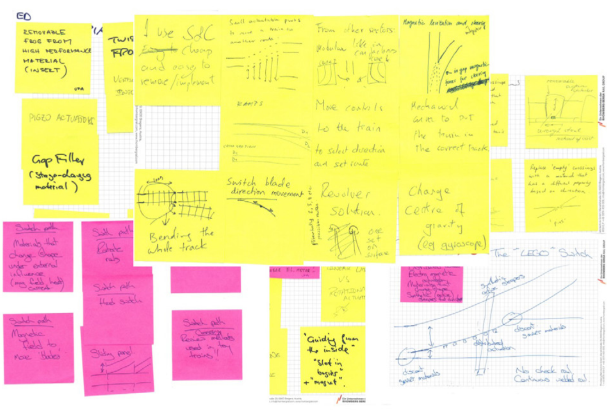


Figure 4: Over 100 ideas.

Work stream	Demonstrable S-CODE Outcomes
Actuation monitoring and control	Condition monitoring of points movement using conventional technology and model-based analysis
	Feedback controller with fault-tolerant scheme
Autonomous inspection and repair	Acoustic inspection and monitoring of S&C
	Autonomous inspection using drones
Substructure and dynamic impact monitoring	Condition monitoring of S&C using dynamic response
Track stiffness design	Application of composite sleepers and bearers
	Neoballast
	Optimising the properties of concrete bearers and track structure
	Tuneable stiffness fasteners (active structure)
Rail steel improvement	Functionally graded steel crossing
Actuation	Maglev actuator
	High redundancy actuator
Locking	Lock using materials with changeable properties
	Novel locking mechanism using magnets
Fault tolerance	High redundancy actuator
	Feedback controller with fault-tolerant scheme

Table 1: Demonstrable outputs from S-CODE classified into work streams.

NEXT GENERATION CONTROL, MONITORING AND SENSOR SYSTEMS

Among the mechatronic technologies developed, there are three strands to this workstream the project has examined which have been taken through to technology demonstrators.

1) *The optimal position of sensors in infrastructure for capturing dynamic response under the passage of vehicles.* S-CODE also explored the opportunity to embed sensors to examine the crossing nose stress under the load of a passing vehicle, as shown in Figure 6.

2) *The mathematical process by which the dynamic response 'signatures' of S&C can be obtained and analysed and changes in dynamic response detected.* Condition monitoring could be done based on it, which was demonstrated to detect faults in the switch actuation mechanism. In parallel, machine learning techniques were used to develop an algorithm which identifies the parameters of the vehicle components passing through track.

3) *Low-cost hardware solutions for capturing and processing the data.* A data acquisition system was developed to record data from the sensors mounted at infrastructure. In parallel, a handheld rail profile scanning device, as shown in Figure 7, was also developed to capture any surface defects on rail head.

MATERIALS FOR NEXT GENERATION INFRASTRUCTURE

Research on materials for rail steel have augmented the current state-of-art metallurgical advances in other IN2TRACK workstreams. On the support structure level, Neoballast was developed and tested on a real track. These are ballast stones covered with recycled rubber materials and a special adhesive to bind with the stone which are shown in Figure 8. They provide improved noise and vibration behaviour and are suitable for tracks in urban environments and at the transition to tunnels portals.

Fibre reinforced foamed urethane composite bearers and their ability to be 3D printed were researched to better understand how this technology can serve us in the future. Self-healing concrete bearers were also developed which, by including rubber, could provide higher damping and self-heal crack formations.

INTEGRATING THE TECHNOLOGIES

From the bottom up, it is essential to bring the concepts and technologies together to help establish the whole system benefits. Many technologies were designed to work together in different combinations and permutations. With the help of maps drawn between the different concepts and technologies, compatibility with each other and amongst themselves was evaluated.

For reasons of brevity, an extract of this evaluation is shown in Figure 9, where only those outcomes from one of the work packages of S-CODE are combined. This helps to evaluate conceptual or functional compatibility and synergy between the technologies.

Physical integration can be evaluated by tools such as BIM (Building Information Modelling). This tool taken from the construction industry serves to identify design clashes. In one of the examples such as depicted in Figure 10, it was attempted to integrate magnetic locking and

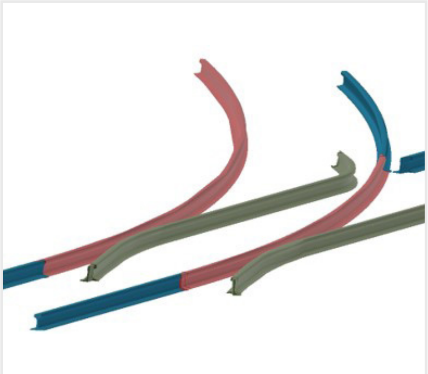


Figure 5a: Back-to-back bistable S&C.

back-to-back bistable S&C. As can be seen,

the method identified a design clash. BIM not only is used for physical structure planning, but also lays the network of information such as supply chain of components together in different levels.

After the evaluation described above, three different technologies were integrated in the form of a demonstrator to show the ability to bring them together. An active tuneable fastener was conceptualised which employs piezoelectric materials within a replaceable cartridge, with an aim to change the railpad stiffness. It is integrated within within the Fibre-reinforced Foamed Urethane (FFU) composite bearers as shown in Figure 11 and with the provision to assemble the magnetic lock above them. There are no issues from the construction point of view, though concerns of structural rigidity, electromagnetic compatibility among others should be analysed in future tests.

EVALUATING THE OUTCOMES

A lifecycle cost analysis of all outcomes of the S-CODE project estimated that most of them would offer potential improvement against today's conventional S&C concept and technologies. An 80 year time horizon was envisioned as can be seen in Figure 12, where only those technologies concerning the support structure are presented. Because the scope of the project is within low TRLs, it is a challenge to project quantitative improvements into the future until more detailed cost benefit analysis can be obtained.
Using an impact scoring tool, the technologies were linked to the S&C concepts. The impact scoring evaluates the confidence with which the corresponding technology offers a benefit to S&C over current conventional technologies. Most of the developments offer potential benefits to capacity, reliability and maintainability, but there is less opportunity to deliver improvements to safety, environmental performance and customer experience. This impact score for each technology was used to tune the lifecycle cost analysis. This provided a better steer as to which technologies offer the most potential.

The S-CODE project ceased at the end of October 2019. The outputs from the project varied from computer model concepts to physical scale model examples. A total of 18 demonstrator outputs, most of which are at or near TRL3/4 stage were showcased at the final S-CODE dissemination event at University of Birmingham to illustrate the technology developments that had been achieved by the project.

HOW THESE TECHNOLOGIES WILL BE USED WITHIN IN2TRACK2

Further work is planned to evaluate the potential benefit of progressing each of the demonstrators within IN2TRACK2, WP2 (next generation S&C). Table 2 lists the demonstrators that were developed by the S-CODE project and their relevance within the In2Track different work packages (WPs). Many of these are at very early TRL stage and will require some significant further development to achieve the TRL5/6 required in some tasks in WP2 next generation S&C.

The S-CODE project initially assessed the various options for developing a solution for the next generation S&C, however the project did not take these concepts forward as a whole system approach. The S-CODE project set to work developing possible solutions for subcomponents of a switch and crossing unit that had the potential to be adopted as part of a next generation switch and crossing solution.

In 2019, RSSB provided a report evaluating the outputs of S-CODE. D7.1 S-CODE Evaluation was reviewed as part of IN2TRACK2 to define which demonstrators are viable for inclusion within WP2. Life Cycle Cost (LCC) modelling was also undertaken as part of RSSB's report. Figure 12 details the LCC of combined technologies of the support structure.

The result of the evaluation scoring exercise by RSSB was continued through to model demonstrators for proof of concept. These demonstrators and the results evaluations were presented at the S-CODE final events meeting in October 2019 held at the University of Birmingham.

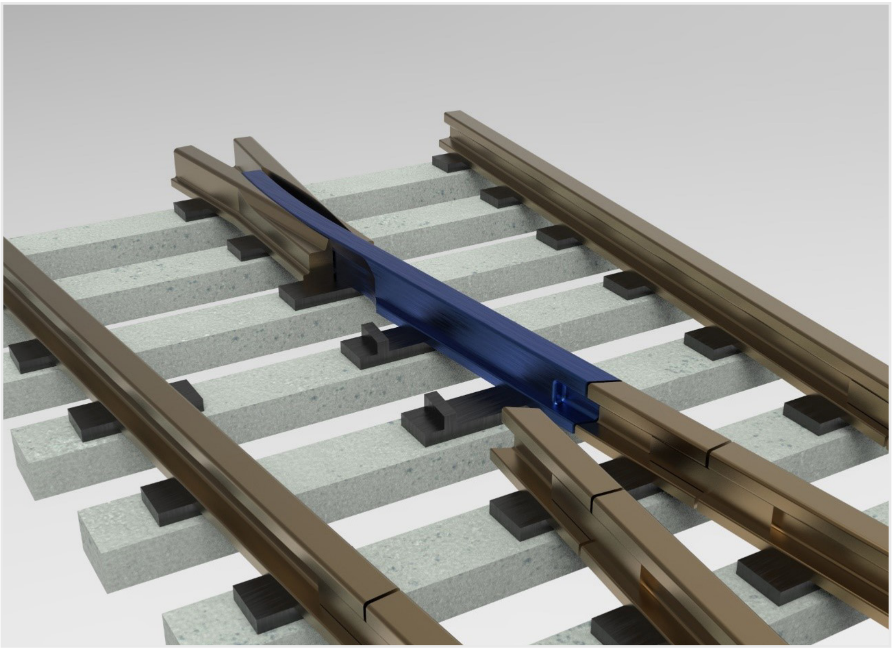


Figure 5b: Single slender S&C.

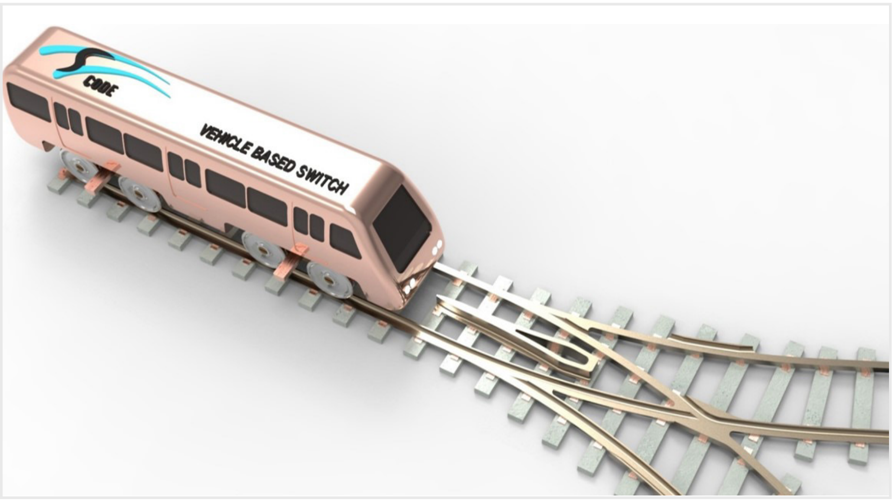


Figure 5c: Vehicle based S&C.

NEXT GENERATION S&C WORKSHOP

Building on the work completed in the S-CODE project, on 11 March 2020 the Network Rail Technical Authority team hosted an IN2TRACK2 next generation switches and crossings workshop in London Paddington. Many industry partners from the Shift2Rail programme attended, including; Trafikverket (Swedish Transport Administration), RSSB, Cranfield University, WSP, Schwihag, Hitachi, Aecom, University of Birmingham, University of Southampton and Chalmers University.
The key objective for the workshop was to begin exploration of new S&C concepts to deliver a step change in performance. The key areas explored include; innovative S&C systems including actuation and control, sub-structure and support, autonomous inspection, innovative methods for maintenance and repair, materials, design and manufacturing to optimise asset performance. The workshop was also used to establish the most feasible next generation S&C sub-system concepts from S-CODE to take forward for further work into IN2TRACK2.

S-CODE CONCEPTS AND OUTPUTS

S-CODE concepts were evaluated and further discussed within the workshop, weighting each concept in order of importance.
The following key was decided to categorise concepts:

- DE- Design Enabler
- IT- Inspection Tool
- M- Material

The design enablers and smart materials were largely the topic of conversation. Discussing concepts 1-4 raised questions over how the raw data would be processed. Stating that the data captured would only be beneficial if it was analysed and translated into useful information; is it sensing fatigue and movement to help predict a potential failure?

Something that is self-powered such as photovoltaics, without the need for expensive cabling, was a common theme throughout, suggesting the concept could act as a health monitor to predict failure within the asset.

Embedded condition monitoring systems were also discussed and the capability to capture the boundaries within S&C. The following requirements were outlined concluding the analysis:

- Fit for purpose to serve intended duty cycle
- No human intervention
- Autonomously repaired and inspected
- Improved safety levels beyond state of the art
- Pro-active asset management from a system approach
- Capture potential risks and manage ownership of asset

Having analysed outputs from S-CODE it was recognised that we need to maintain two new designs; 1) for integrating with legacy systems and 2) an alternative for new construction projects. Sub-system specifics and components include a stable support structure (supporting the rails), use of high-performance materials (graphene, piezoelectric, self-healing concrete) and wireless condition monitoring with AI and self-diagnostics.

WORKSHOP CONCLUSION AND THE PATH TO IMPLEMENTATION

To optimise installation and maintenance efficiency, enhance control over degradation and improve environmental performance, the next generation S&C will feature a stable support structure. This includes ballast-free structures and re-engineered ballast using high performance materials such as steels, concretes, elastomers and engineered composites.

A combination of these technologies will ensure a step change in performance, of which will form a radical outcome when all combined. The kinematic devices may move the rails

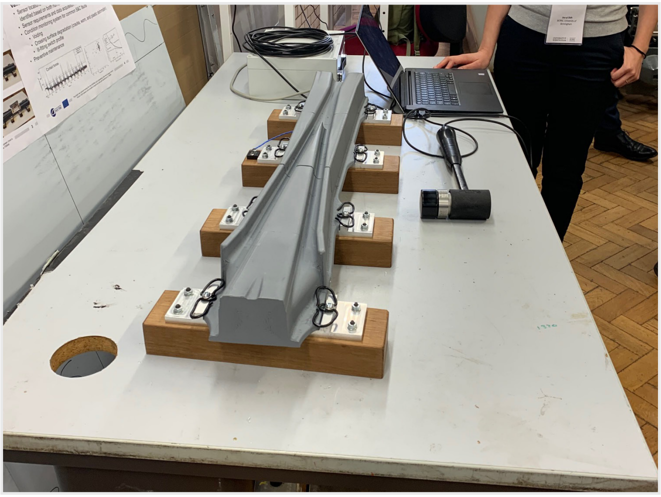


Figure 6: Demonstration of embedded sensors within crossing nose.

Figure 7: Handheld rail profile scanner.

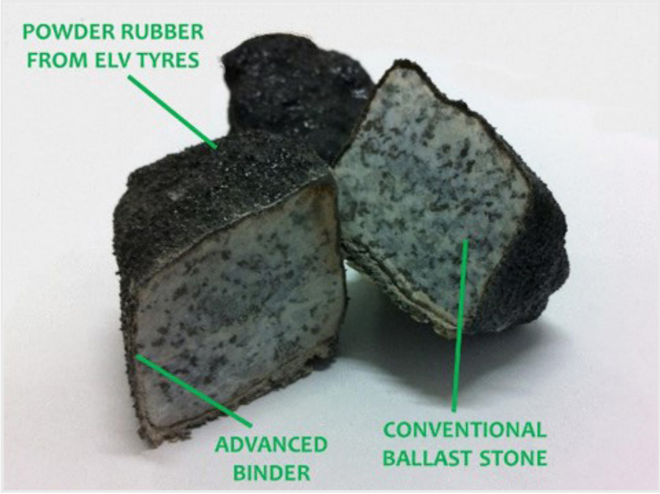


Figure 8: Neoballast and its cross-section.

Key	
I	Independent technologies
A	Alternate technologies
C	Complementary technologies
N	Technologies not compatible

		WP3 Acoustic Inspection and monitoring S&C	WP3 Autonomous inspection using drones	WP3 Condition monitoring of points movement using conventional technology and model-based analysis	WP3 Condition monitoring of switch and crossing using dynamic response	WP3 Feedback controller with fault tolerant scheme
WP3	Acoustic Inspection and monitoring S&C		C	C	C	I
WP3	Autonomous inspection using drones	C		I	C	I
WP3	Condition monitoring of points movement using conventional technology and model-based analysis	C	I		C	C
WP3	Condition monitoring of switch and crossing using dynamic response	C	C	C		I
WP3	Feedback controller with fault tolerant scheme	I	I	C	I	

Figure 9: An extract from evaluation of integrating the outputs from S-CODE.

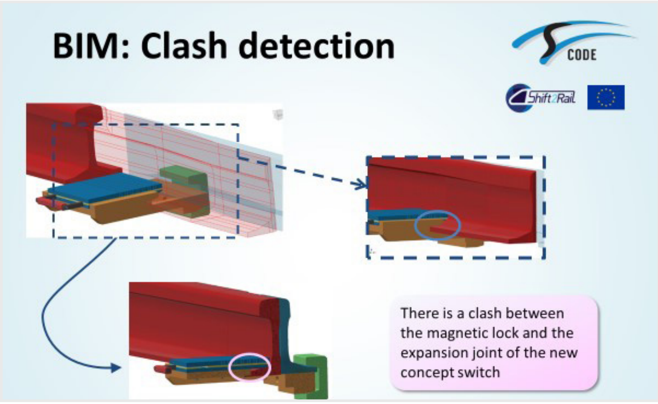


Figure 10: Applying BIM in railway context.

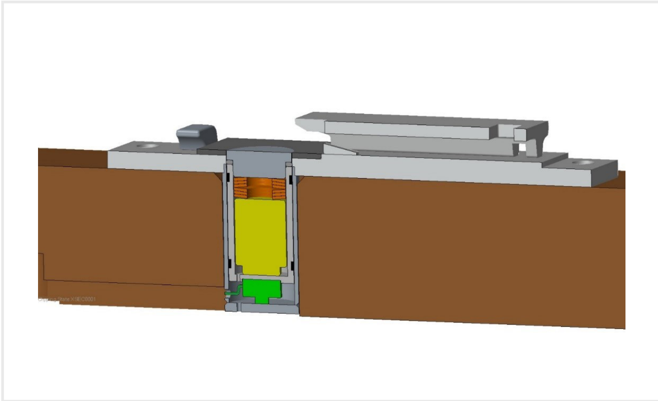


Figure 11: Demonstrating synergy of three different technological outputs.

in a different manner than today if a more suitable way of track switching is discovered. When combining the stable support structure, novel kinematics, imbedded sensing systems, fault tolerant control, self-healing materials, machine and behavioural learning using the outputs initiated from S-CODE will all systematically help to create a higher performing S&C design.

The work currently being undertaken on this within IN2TRACK2 will form the remit for IN2TRACK3 to enable integrated technology demonstrators to be produced, tested and evaluated. The initial trials are expected to take place in 2021 and 2022 using virtual and physical technology demonstrators.

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ACRONYMS

JU: Joint Undertaking – The governing board of the Shift2Rail committee members.

MAAP: Multi Annual Action Plan - The MAAP is a planning document which identifies the concrete actions, milestones and deliverables to be undertaken collaboratively by the Shift2Rail JU for the period 2015-2024.

TD: Technology Demonstrator – a physical or virtual model to demonstrate the new technology being introduced.

TRL: Technology Readiness Level – A scale from 1 to 9 used to describe the assessed technical maturity of offerings to support various programmes.

WP: Work Package - split into various packages for IN2TRACK2.

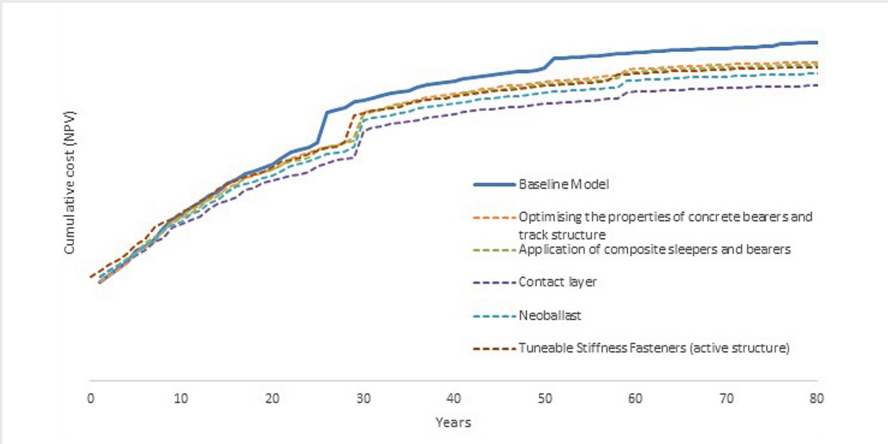

Figure 12: Lifecycle costs of technologies concerning the support structure.

No.	Title	Use within IN2TRACK2	Relevant IN2TRACK2 Sub Task or WP	High	Medium	Low
1	DAQ "S-box"	Data Acquisition of multiple sensor inputs. Elements of this being used within multiple monitoring devices	2.1.2 & 4.1.3	DE		
4	Sensor placement (3D printed model, embedded)	Principle being widely embedded across S&C and Plain Line	2.2.1 & 4.5.1	DE		
5	Handheld scanner, optical scanner and scanner using drones	Handheld scanner being progressed for S&C and Drone surveys	2.2.2		IT	
8	Condition monitoring (software demonstrator)	Elements of this being used within S&C RCM. Extension of existing technology	2.2.2, 2.4.1, 4.4.3 & 4.5.1	IT		
9	Fault tolerant control system (software demonstrator)	Principle being applied to new points machine	2.2.3 & 2.4.1	IT		
10	Contact layer	Principle of additive manufacturing being applied across all high wearing components eg crossings and rails	All WPs	M		
11	Neoballast	To be considered for ballasted designs	All WPs	M		
12	Self-healing, high-damping concrete bearers	Was agreed to be further explored for NG S&C	2.3.3	M		
13	FFU composite bearers	Already being used	N/A		N/A	
14	3D-printed Bearer	To be considered for NG bearers and sleepers	2.3.1, 2.3.3, WP3 and WP4	M		
15	Vehicle based switch	Not being deployed	N/A		N/A	
16+17	Back to back bistable switch (simulation+physical model)	Being considered for NG switch kinematic system	2.4.1		TBA	
19	Single slender switch	Not being deployed	N/A		N/A	
21	Maglev actuator	Not being deployed	N/A		N/A	
23	Locking based on MR fluid	Not being deployed	N/A		N/A	
24	Hardware-in-the-loop simulation (using high redundancy actuator)	Principle being applied to new points machine	2.2.3 & 2.4.1		TBA	
25	Section of switch part (Innovative rail fastening, Magnetic locking)	Not being deployed	N/A		N/A	
26	BIM	Elements of this being used within Digital Twin	2.1.2 & 4.1.3	IT		

Table 2: S-CODE output scoring for IN2TRACK2 Next Generation S&C.

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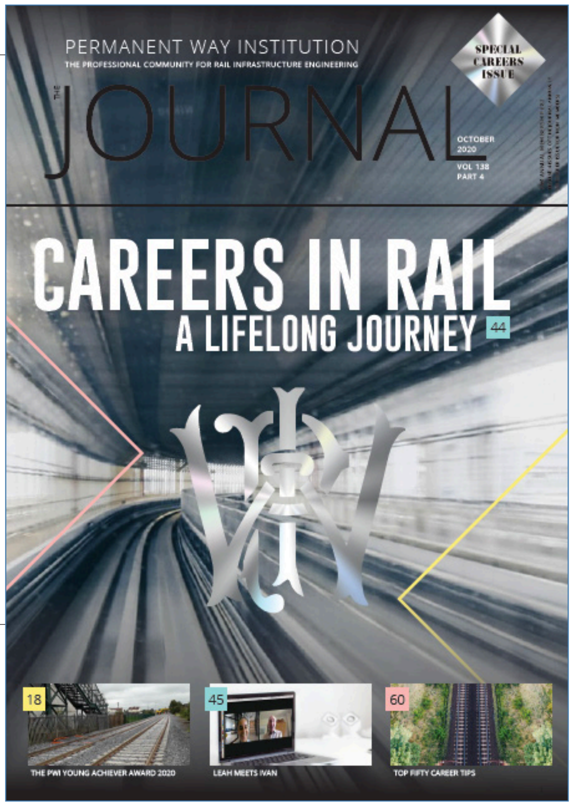

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