S-CODE: Switch and Crossing Optimal Design and Evaluation

Professor Clive Roberts, University of Birmingham

This project has received funding from the Shift2Rail Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement no 730849.

Overview

- Background to the Birmingham Centre for Railway Research and Education
- The new UK Rail Research and Innovation Network (UKRRIN)
- S-CODE an example UK-Czech Republic collaborative project

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Birmingham Centre for Railway Research and Education

Birmingham Centre for Railway Research and Education (BCRRE)

Railway research at Birmingham begun in the 1970s

Nowadays we are a group of over 145 researchers and support staff

2017 Queen’s Anniversary Prize for Higher and Further Education

Lead for the £92m UK Rail Research and Innovation Network

- UKRRIN Centre of Excellence in Digital Systems
- Founding partners:
  - Siemens, Bombardier, SMRT, Unipart, Hitachi, Thales, RSSB, British Steel, Atkins, RIA, AECOM, Pandrol, Progress Rail, Aggregate Industries

UNIVERSITY OF BIRMINGHAM

BCRRE

Birmingham Centre for Railway Research and Education (BCRRE)

Network Rail's Strategic Partner for Data Integration and Management

Strategic partnerships with West Midlands Trains, GTR, CH2M, CRRC, NCHSR

Over 500 students studying Railway Systems

- ~50 UG students BEng/MEng
- ~120 MSc students taught in Birmingham
- ~250 PGCert/PGDip/MSc students taught in Singapore
- ~85 PhD students

UNIVERSITY OF BIRMINGHAM

BCRRE

Birmingham Centre for Railway Research and Education (BCRRE)

International relationships for research and education in:

Many EU countries

Singapore – SMRT (R&E), NTU (R&E)

China – CRRC (R), Beijing Metro (R), Guangzhou Metro (R), Hefei Metro (R), Lutong Freight Railway (R), Beijing Jiaotong University (R&E), Zhejiang Uni (E)

Malaysia – UHTM (E), UTCS (R&E), UiTM (E), HELP (E)

Thailand – SUT (E), Synchrotron Light Research Institute (R)

Saudi Arabia (R&E), Japan (R), USA (R), Brazil (R),


科大學院轉換生計劃

鐵路工程課程招生

與伯明翰大學合作

工程學辦2+2課

克萊夫：助建完善交通系統

全球提供鐵路教育支援

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BCRRE

BCRRE Research Activities

System of systems simulation
Future railway operations and control
Data integration and cybersecurity
Condition monitoring and automation
International benchmarking, safety and system

UKRRIN
UK RAIL RESEARCH AND INNOVATION NETWORK

Power and energy
Aerodynamics
Climate change impact and extreme weather
Computational modelling
Metallurgy and non destructive testing
Geotechnical engineering

BCRRE's Rail EU Project Participation

Shift2Rail (2): S-CODE (S&C), *IN2TRACK* (S&C)

H2020 (3): AUTOSCAN (NDT), RISEN (Infra), E-Lobster (Power)

FP7 (16): IN2RAIL (CM, Ops), RIFLEX (NDT), AUTOMAIN (CM), ON-TIME (Ops), CAPACITY4RAIL (CM, Ops), AEROTRAIN (Aero), WiRailCom (CM), MOSAIC (NDT), MAXBE (NDT), INTERAIL (NDT), INFRAGUIDER (Environ), MOWE-IT (Weather), LivingRail (Electrification), SAFERAIL (NDT), *SUSTRAIL* (CM), *I-Rail* (NDT)

FP6 (4): InteGRail (Data, CM), Innotrack (CM, NDT, Logistics), EURNEX (Networking), WEATHER (Weather)

UK RAIL RESEARCH AND INNOVATION NETWORK

UK Rail Research and Innovation Network (UKRRIN)

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The Queen's Anniversary Prizes
For Higher and Further Education
2017

UNIVERSITY OF BIRMINGHAM

Railway Supply Group Strategy

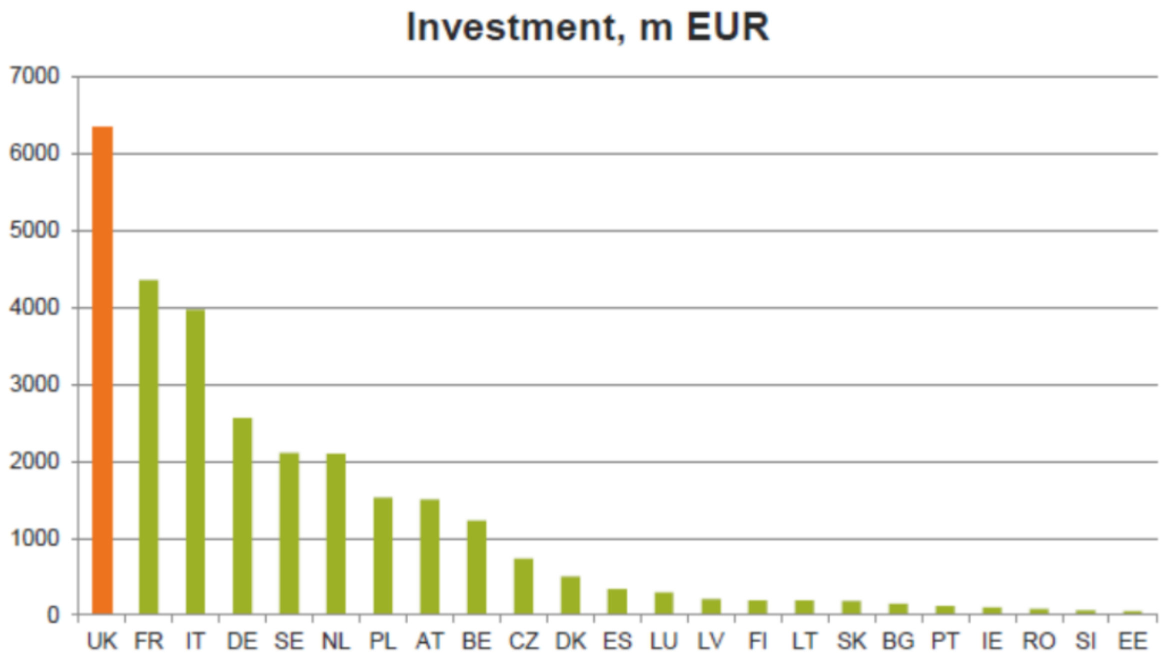
- The Railway Supply Group Strategy, which was launched in February 2016 has the objective of transforming the supply industry making the UK a global leader in rail.
- By 2025, the rail supply industry aims to:
  - More than double export volumes and values
  - Attract the very best UK talent to create a sustainable skills base and to develop new technologies
  - Harness the energy, drive and innovation of SMEs to meet the needs of the global railway market
  - Be a global leader in High Speed Rail
  - Have an entrepreneurial supply chain that innovates to meet customer needs

RSG will prioritise innovation in its five key technology areas across the UK by developing a network of new Centres of Excellence in collaboration with government, universities and business growth incubators.

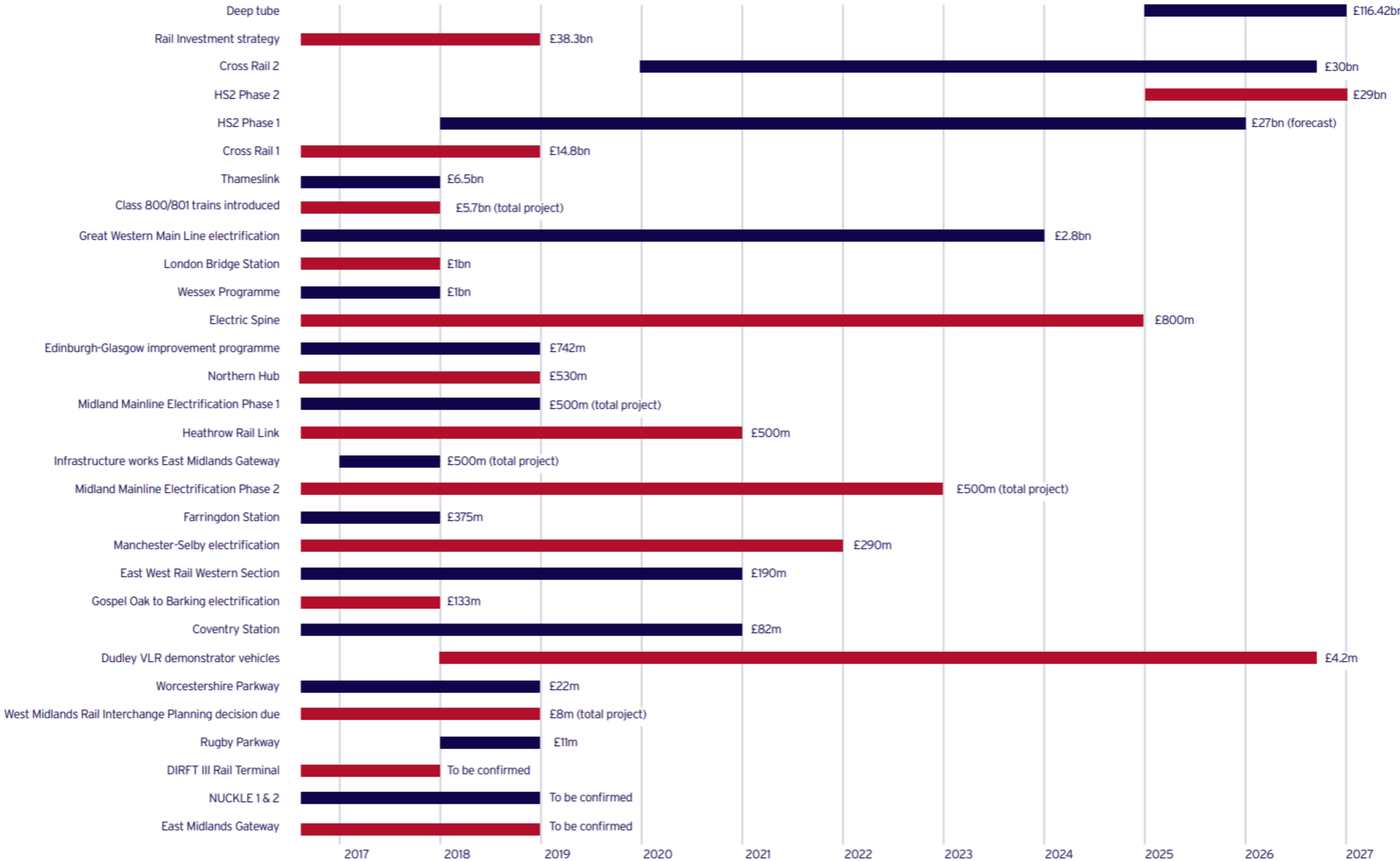
Rail Supply Group

The UK Rail Market

- Largest investment in Europe
- A pipeline of £100 billion of opportunity
- UK is open for international business



UK Rail and Infrastructure Opportunities - pipeline of over £100bn



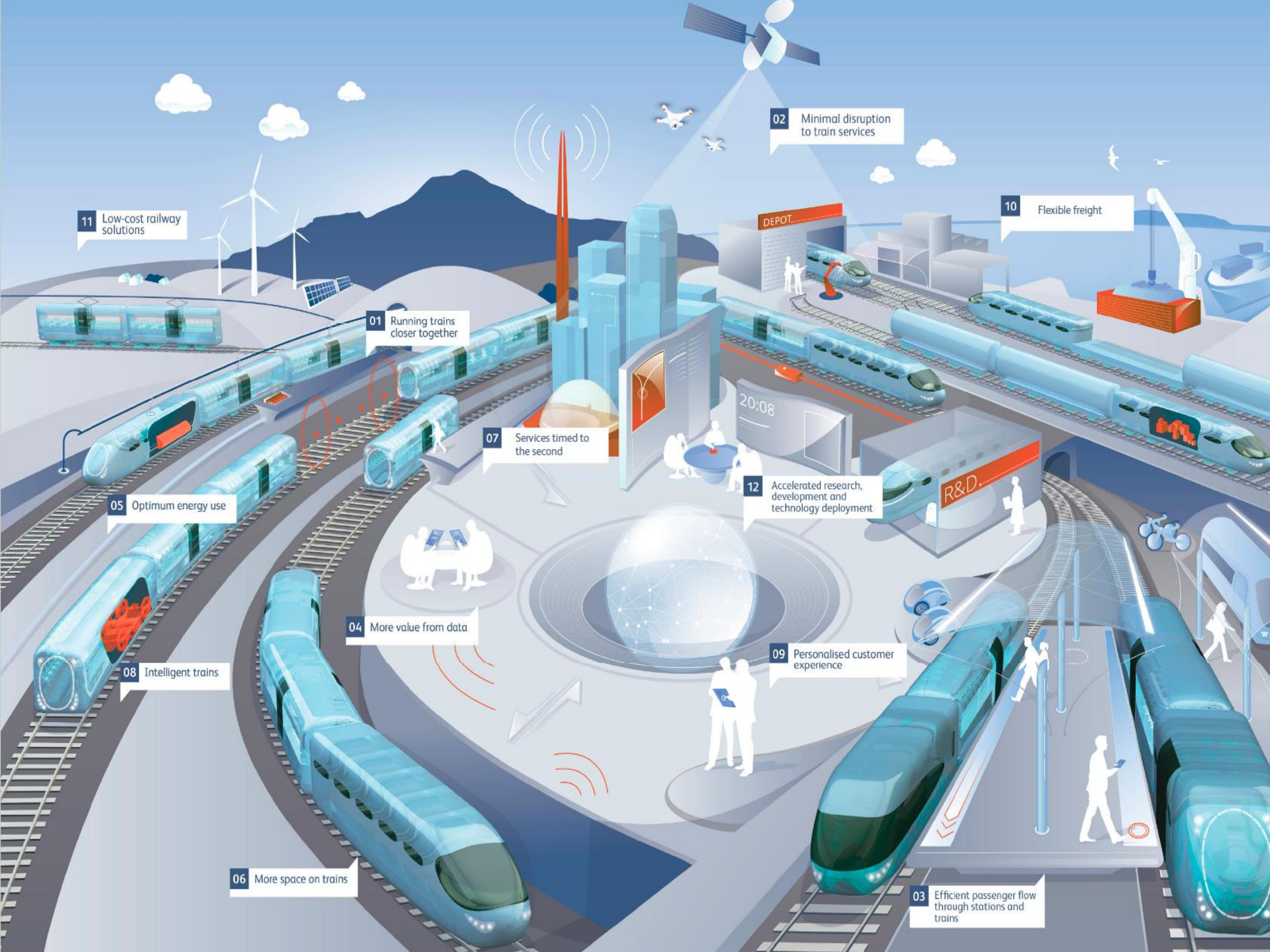
University Selection

UKRRIN
UK RAIL RESEARCH AND INNOVATION NETWORK

- RSG formed a steering group which comprised members of RSG and TLG to select the universities to lead and collaborate in each of the Centres.
- In August 2016 the following universities were selected to develop each of the Centres:
  - **Lead**: University of Birmingham
  - **Digital**: University of Birmingham
  - **Rolling Stock**: University of Huddersfield with Newcastle University and Loughborough University
  - **Infrastructure**: University of Southampton with University of Sheffield, Loughborough University, Heriot Watt University and Nottingham University
  - **Testing**: Network Rail with London Underground, Quinton Rail Technology Centre (Long Marston)

Private Industry Support

SIEMENS
BOMBARDIER
SMRT
RSSB
THALES
UNIPART RAIL
BRITISH STEEL
Railway Industry Association
HITACHI Inspire the Next
ATKINS
AECOM
Progress Rail A Caterpillar Company
PANDROL TRACK SYSTEMS © DELACHAUX GROUP
AGGREGATE INDUSTRIES
NetworkRail
hs2 engine for growth
Digital Railway


02 Minimal disruption to train services
10 Flexible freight
DEPOT
11 Low-cost railway solutions
01 Running trains closer together
20:08
07 Services timed to the second
12 Accelerated research, development and technology deployment
R&D
05 Optimum energy use
04 More value from data
09 Personalised customer experience
08 Intelligent trains
06 More space on trains
03 Efficient passenger flow through stations and trains

UKRRIN Current Position

- Full bid submitted on 16th December 2016
- £64M of private co-investment has now been committed
- £28M of capital funding was requested from HEFCE to fund:
  - Digital Systems - £16.4M
  - Rolling Stock - £10M
  - Infrastructure - £1.7M
  - Testing
- An industry led steering board has been formed and meets monthly
- Launch event at House of Commons on 20th February 2018
- The formal start date is 1st April 2018
- Next phases: Decarbonisation Centre, SME engagement, International, Fundamental Research (PhDs and projects)

Decarbonisation: UK's First Hydrogen Train

UKRRIN

UK RAIL RESEARCH AND INNOVATION NETWORK

Centre of Excellence in Digital Systems

UNIVERSITY OF BIRMINGHAM

PER ARDUA AD ALTA

THE QUEEN'S ANNIVERSARY PRIZES

FOR HIGHER AND FURTHER EDUCATION

2017

Digital Systems Objectives

- Key objectives:
  - Develop global leading expertise in **Future Railway Operations and Control for railway digitisation**
  - Provide much needed **Data Integration and Cybersecurity for the data driven railway and Internet of Railway Things** research capabilities and facilities
  - Developing the next generation of **Smart Monitoring and Autonomous Systems for radically improved sensing and sense-making**
  - Significantly improving processes for **Introducing Innovation for rapid realisation of benefits** into operational railway systems

Digital Systems facilities to be developed

- The key facility is a 3000m^2 building
- This will provide an ‘industry on campus’ capability

Digital Systems facilities to be developed

- Key equipment:
  - Cab simulators
  - Signalling control centre
  - Large data servers (including NR, SMRT data)
  - Large display walls/visualisations
  - Signalling and comms equipment
  - 3D visualisation
  - Cybersecurity test lab
  - Electronic fabrication
  - Technology assets for test

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S2R-OC-IP3-01-2016 – Research into new radical ways of changing trains between tracks

Specific Challenge: Taking into account the expected growth in transport demand and the ever-increasing customer expectations on quality of service, there is a need for ambitious research and a step, yet radical, change in the design and the technology of the track system, in particular the switches and crossing (S&C) sub-system. These systems need to be developed utilising the latest technological advances from others sectors and target maintenance free and degradation free assets. The innovation should lead to significant improvement of capacity, reliability, safety, investment and operating cost of these assets.

Scope: The research and innovation activities should evolve with three interdependent work streams, in line with the Shift2Rail Multi-Annual Action Plan (MAAP):

- Next Generation Control; Monitoring & Sensor Systems:

  The next generation of track and S&C design will incorporate intelligent self-diagnostics systems with the capability to self-adjust, self-correct, self-repair and self-heal within predefined system operating tolerances. The next generation systems will eliminate manual maintenance interventions. The system will have the capability to monitor not only its current state but also its future states and adapt to its environment and external factors.

- Next Generation Design; Materials & Components:

  Smart design and bespoke material science solutions should be considered targeting simplified systems with reduced complexity and fewer components. To progress beyond the current state of the art it will examine technology transfer opportunities from other industries. The wheel-rail interface will be optimised to enable the development of radically new mechanisms for switching a train from one line to another.

- Next Generation Kinematic Systems:

  The next generation S&C design will incorporate a completely new switching function using novel kinematic elements with radically different components and will be designed from a whole system perspective considering mechatronics technology.

This action will be complementary to the actions carried out in S2R-CFM-IP3-01-2016: Research into enhanced track and switch and crossing system. As specified in section 4.2.5 of S2R AWP for 2016, in order to facilitate the contribution to the achievement of S2R objectives, the options regarding 'complementary grants' of the S2R Model Grant Agreement and the provisions therein, including with regard to additional access rights to background and results for the purposes of the complementary grant(s), will be enabled in the corresponding S2R Grant Agreements.

The S2R JU considers that proposals requesting a contribution from the EU of around €5 million would allow this specific challenge to be addressed appropriately. Nonetheless, this does not preclude the submission and selection of proposals requesting other amounts.

Expected Impact: A significant impact is expected from the technologies developed in this research and innovation action including:

- Improvement of capacity – a large improvement in line capacity and improvement in speed through new generation of switches;
- Reliability - all failure modes of current systems to be eliminated with new maintenance free and degradation free systems developed;
- Safety – the new systems must comply with relevant safety standards and address known safety issues which have resulted in past incidents in order to reduce the number and magnitude of incidents;
- Investment costs should be reduced and never increased;
- Significant LCC savings should be possible, thanks to new materials and maintenance.

Type of Action: Research and Innovation Actions

S-CODE partners

- University of Birmingham lead
- Total budget 5M€
- 3 UK partners (all UKRRIN), 3 Czech partners (all Czech Tech Plat), 2 Spanish partners and 1 Austrian partner

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S-CODE Timeline (Proposal)

- Call released - December 2015
- Key tasks
  - Understand call in the work plan
  - Build consortia and write proposal
    - Identity key call area, and TRL
    - At least 3 countries
    - No more that 40% of budget to one country
    - Get individual beneficiaries rates
    - Decide which beneficiary is best to lead overall, and each work package and task
    - Develop high level programme
    - Ensure all work plan issues are addressed
    - Ensure alignment with the Multi-Annual Action Plan (MAAP)
    - Calculate budget
    - Write the proposal – S-CODE is 63 pages
    - Complete on line administrative forms
- Submission 17th March 2016

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S-CODE Timeline (Success)

- Notification of success – June 2016
- Feedback from evaluators and changes suggested (‘Negotiation’)
- Introduction to project officer
- Consortium Agreement developed and signed by all partners
- Kick-off – 1st November 2016
- Mid-term review – 30th April 2018 (18 months)
- End of project – 30th October 2019

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Key S-CODE Outcomes

1. The development and prototyping of a modular whole system switch and crossing architecture that allows subsystems to be changed over the life of the S&C. This will enable innovations to be added as they become available. The architecture and subsystems will be modelled to allow rapid development of further capabilities.
2. The design and prototyping of Next Generation Design components that can be incorporated into the architecture, using new materials and technologies to create a variety of permanent way subsystems.
3. The design and prototyping of a Next Generation Control subsystem that can be incorporated into the architecture, which will include an 'immune system' capable of self- adjustment, self-correction, self-repair and self-heal.
4. The design and prototyping of Next Generation Kinematic subsystem that can be incorporated into the architecture, that includes new actuation and locking philosophies that make use of concepts such as redundancy and 'limp-home' through the use of novel actuators and mechatronic systems.
5. Analysis will be undertaken to quantify the value of these innovations from the perspective of: (i) reliability, (ii) life-cycle cost, and (iii) higher speed switches/train throughput.

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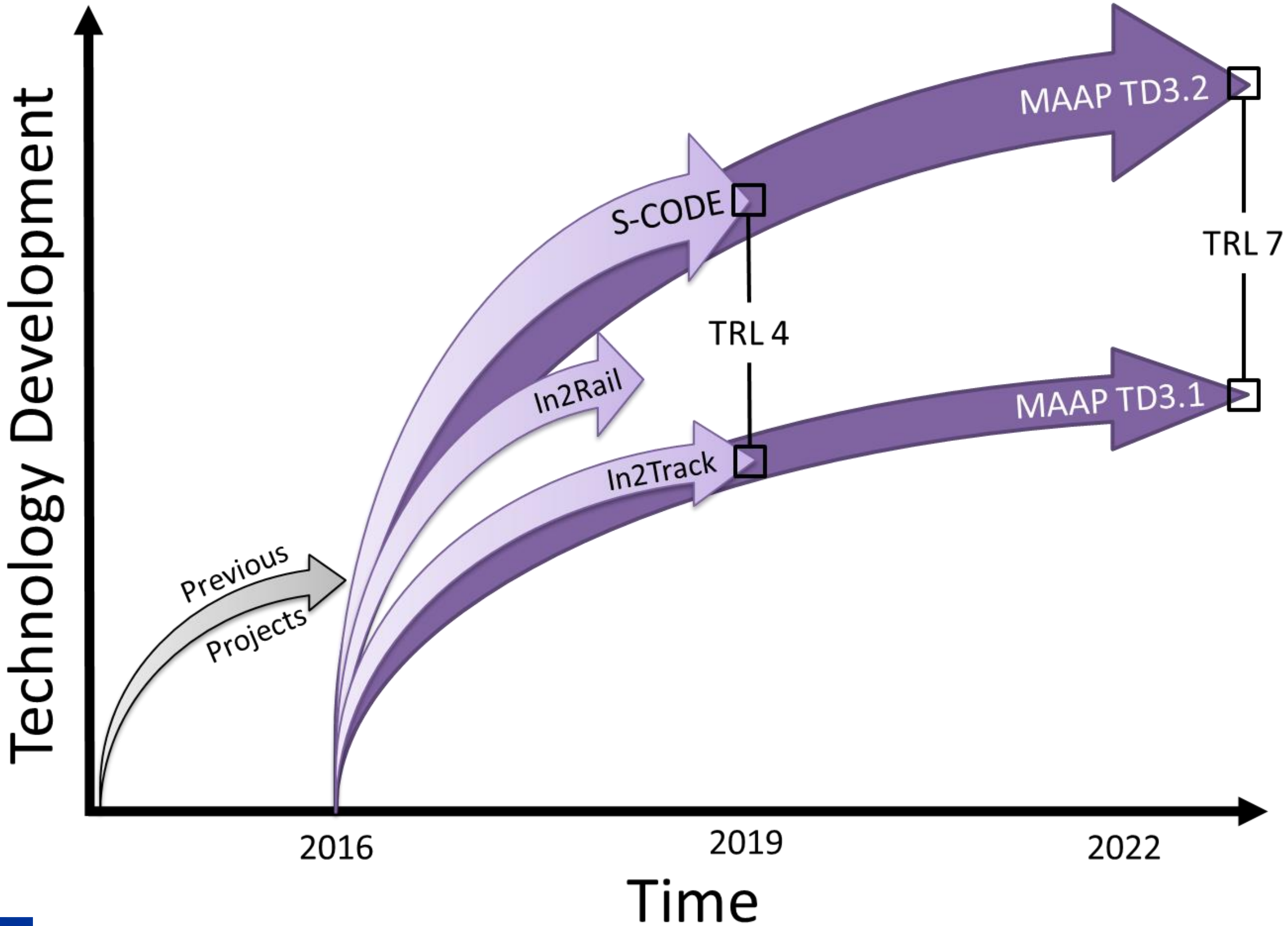
Links between S-CODE, In2Rail and In2Track

- S-CODE works with In2Rail and In2Track
- Draws from previous projects
- Supports delivery of TD3.2
- TRL1-4, but with some higher TRL elements



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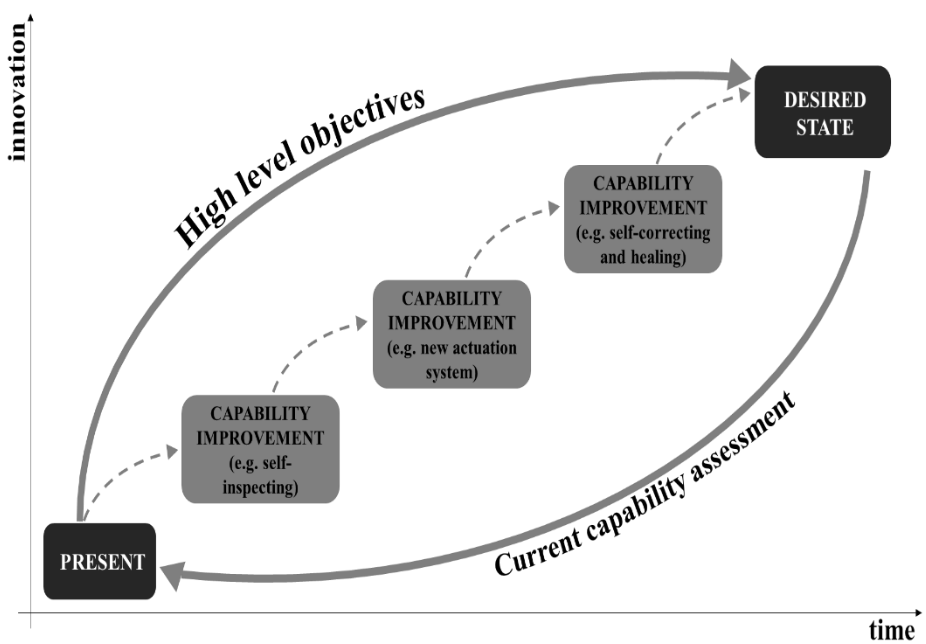
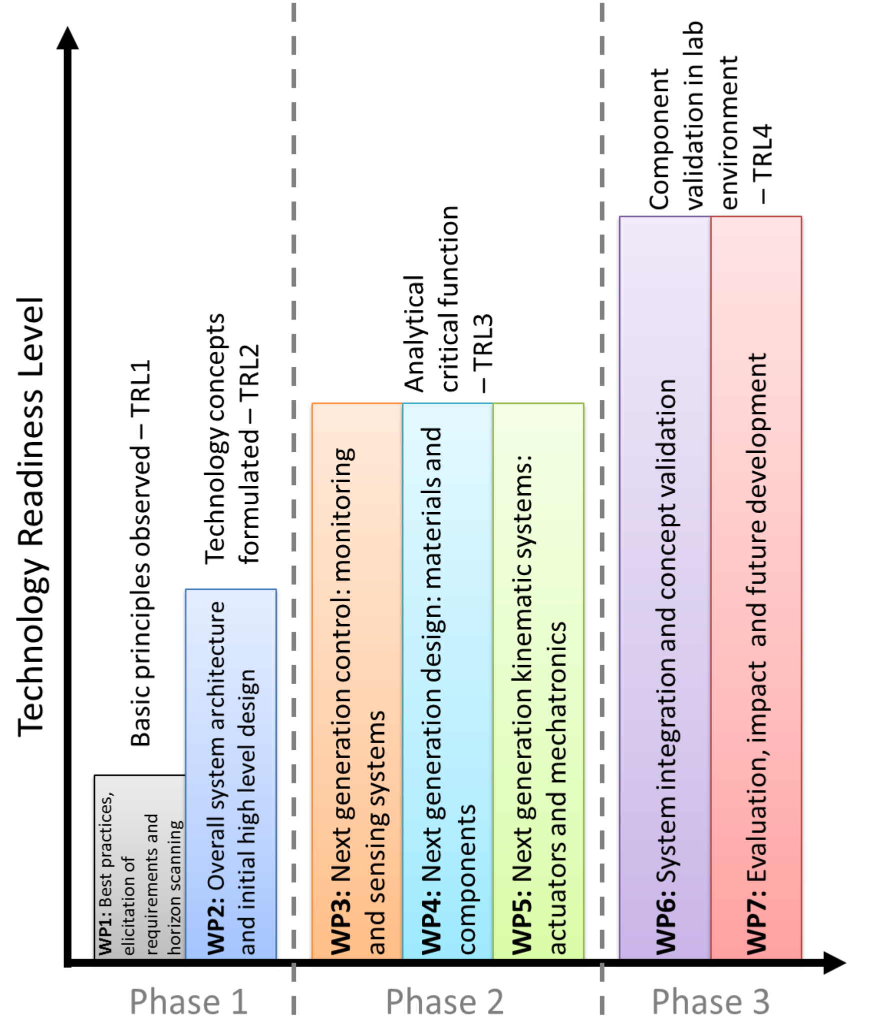
Phases of the project

Phase 1 – Start Nov ’16
- Requirements and initial design

Phase 2 – Start May ’17
- Technical development

Phase 3 – Start Sept ’18
- Demonstration and evaluation





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Innovative approaches in S&C: Switzerland

- **RACK AND PINION SWITCH**

The spring switch is based on the idea of a "cut out" section of track, which acts as a kind of "spring" that is fixed at one point and bends from one end position to the other, along a precisely defined curve.

In the end positions, the system operates like a "closed" track.

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Innovative approaches in S&C: The Netherlands

- **Winterproof Railway Turnout:** This new design turnout is not fitted with horizontal movable tongues, and because of that, snow and ice have no impact on the correct working of the turnout. Therefore, it needs no turnout heating at all.

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Mount Washington Cog Railway

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Dolderbahn Bendy Points

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Flange Bearing Frogs

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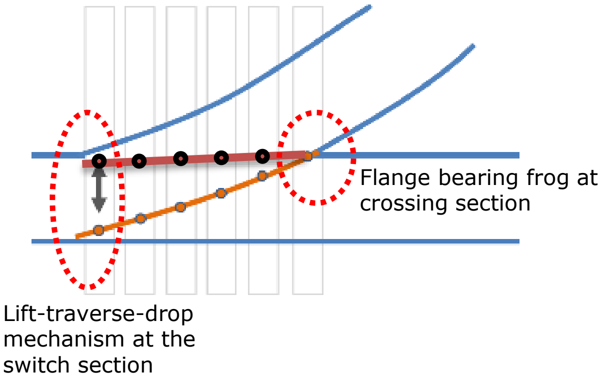
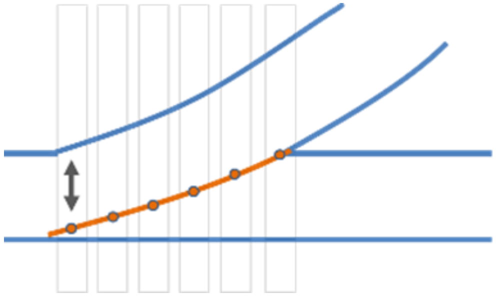
Combined Concepts

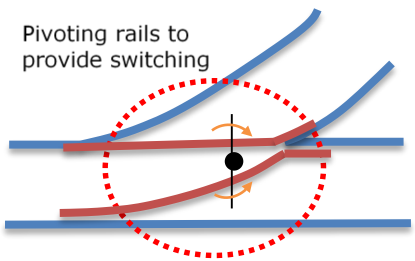
Interesting concepts were combined to make five novel concepts (shown here) that would be modelled as full kinematic systems



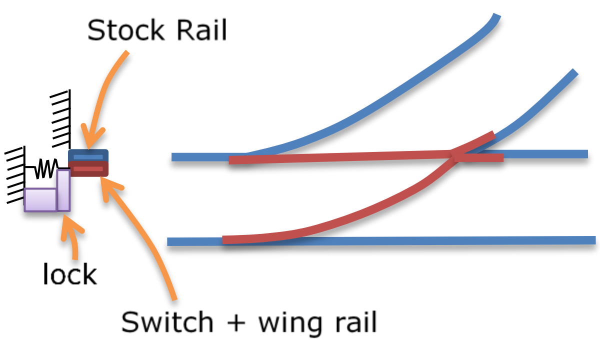
1: **Concept T combined with A1 (at switch section) + E (at nose section)**
Back-to-back bistable switch



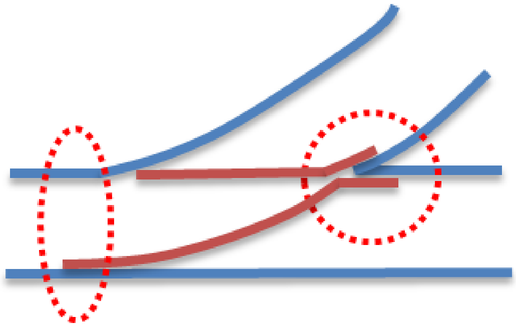
2: **Concept T combined with A2**
Single slender switch



3: **Concept T combined with L**
Pivoting rail switch



4: **Concept T combined with B and V**
Sinking switch



5: **Concept T combined with E**
Vehicle based switching

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S-CODE Innovation Development Maps – WP3

S-Code innovation development map For WP3	TRL 4-7 **More conventional (could build)**	TRL 3-4 **Modelling and simulation**	TRL 2-3 **Conceptual design**	
Actuation monitoring and control	A Power, force, and displacement monitoring of S&C for actuator position control and condition indicators	D Self adjustment of S&C using advanced control system and embedded sensors, condition indicators used to trigger remote inspection and schedule maintenance	G Auto-recalibration of self-adjustment after maintenance. Integration with autonomous inspection to create a detailed assessment of the health of the switch and expected lifetime	**WP5**
Substructure and dynamic impact monitoring	B Accelerometers, microphones and other passive monitoring of S&C for detection of dynamic impacts and substructure degradation	E Embedded accelerometer monitoring of S&C and advanced sensors (e.g. acoustic array or radar). Events used to trigger remote inspection and schedule maintenance	H Combine sensors to isolate fault locations. Integration with autonomous inspection to create a detailed, accurate assessment of the health of the switch and expected lifetime	**WP4**
Autonomous inspection and repair	C Optical cameras, IR cameras, lasers and other NDT inspection techniques to assess the health of the switch	F Drones and/or robots using NDT inspection techniques via remote control to assess the health of the switch and suggest repairs	I Drones and/or robots using NDT inspection techniques autonomously to assess the health of the switch and enact repairs or adjustments	

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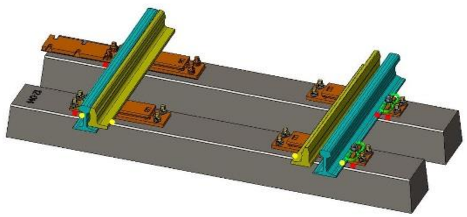
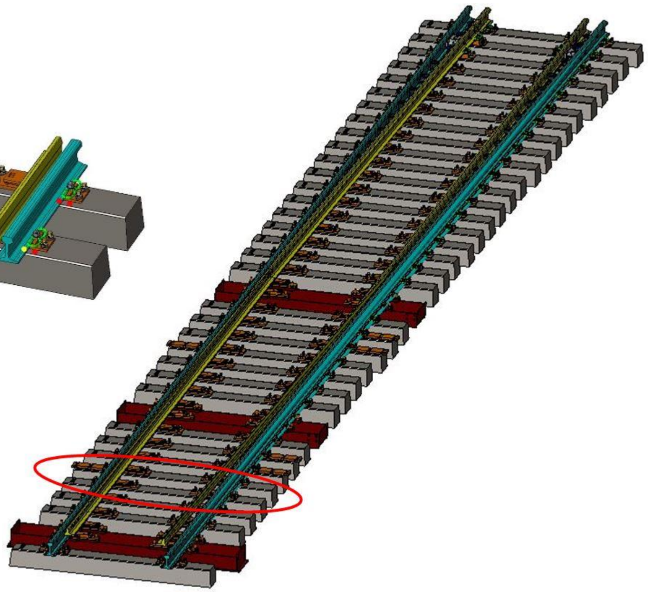
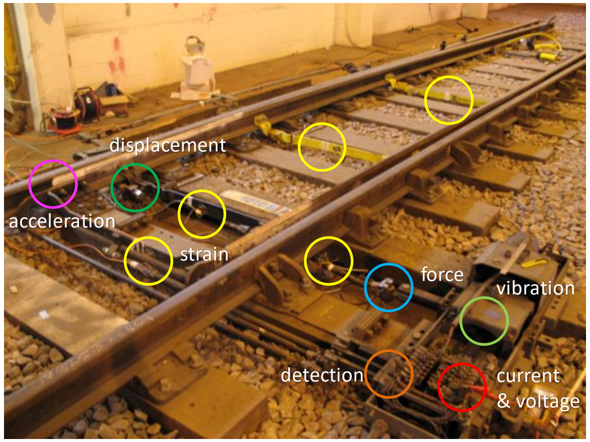
Embedded Sensing for Monitoring and Control

- Sensors embedded in the machine
  - Pressure
  - Displacement
  - Load pins or strain gauges
  - Current and voltage sensors
  - Vibration sensors on the motor
- Sensors embedded in the rails
  - Accelerometers along the S&C
  - Strain gauges in stretcher bars
  - Temperature
  - Smart washers
- Sensors that monitor externally
  - Microphones to listen for defects that generate noise in the machine or the mechanism
  - Cameras to look for obstructions, measure displacement and remote inspection







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Immune System
Self Inspection and Self Repair

- A sensing and control system will allow compensation for degraded functionality using multiple actuators
- Drones and/or robots can perform detailed inspection and correct faults that the main actuator cannot deal with
  - This would allow the system to potentially respond to problems such as obstructions without the need for maintenance teams to visit the S&C.

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S-CODE Innovation Development Maps – WP4

		TRL 4-7 **More conventional**	TRL 3-4 **Modelling and simulation**	TRL 2-3 **Conceptual design**	
Track Stiffness Design	**Composite Bearers**	A: FFU Sleepers; Neo Ballast; USP Bearers;	E: Composite Sleepers with Harvesting Capacity	I: 3D Printing FFU Sleepers; Self Healing Composites	**WP3 WP5**
	Self Healing Concrete	B: High Damping Concrete Bearers and Slabs	F: Self Monitoring Bearers	J: Self Healing Concrete; 3D Printing of Concrete Slabs and Bearers	**WP3**
	Fastening Systems	C: Tunable Stiffness Fasteners (active structure); Adjustable Level Fasteners	G: Energy Harvesting Fasteners; Piezo Fasteners	K: 3D Printing Fasteners	**WP3**
Rail Steel Improvement	**Bainitic Contact**	D: Flashbutt Welding	H: Functional Graded Steel Crossing	L: 3D Printing Bainitic Steel	**WP5**

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S&C Elements and Materials

Elastomeric pad
- Other types of materials

Additive Manufacturing

In-situ (repairing)

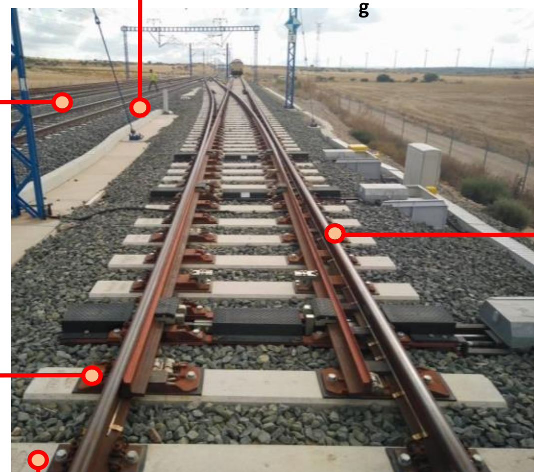
Factories (manufacturing)

Additive Manufacturing
- Powder-bed systems: Direct Metal Laser Sintering
- Powder-fed systems: Laser Cladding
- Laser Engineered Net Shaping (LENS)

- New types of ballast

Ballast

Slab
- Concrete + Reinforcement
  - Self-healing concrete
  - Concrete + geo-polymer
  - Concrete + Reinforcement (fibers)
  - Other types of materials: Composites



Cast Steel

New fastening systems

Laminated Steel
- Carbon-Manganese Steel
- Pearlitic Microalloyed Steel (niobium and vanadium)
- Welding

No welding

- Twinning-Induced Plasticity Steel
- Other types of materials: Composites
- Low-wear Low-friction surfaces (for instance Teflon)
- "Self-healing" Steel
  - Capsule-based self-healing materials: DCPD filled microcapsules
  - Self-healing corrosion protection

Sleepers
- Concrete + Reinforcement
- Wood

- Self-healing concrete
- Concrete + geo-polymer
- Concrete + Reinforcement (fibers)
- Other types of materials: Composites

- Concrete 3D printing

Additive Manufacturing

In-situ (repairing)

Factories (manufacturing)

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S-CODE Innovation Development Maps – WP5

S-Code innovation development map For WP5	TRL 4-7 **More conventional (could build)**	TRL 3-4 **Modelling, simulation or lab demo**	TRL 2-3 **Conceptual design**	
Actuation	Conventional actuators with new mechanisms	New S&C concept development Multiple actuation	Piezoelectric actuator (scaling up) Electro-active polymer based actuators	**WP4**
Locking	New locking mechanisms, active and passive	Magneto-rheological, Dilatant materials based locking mechanism	Electro-restrictive fluid based locking mechanism	**WP4**
Fault-tolerance	Analytical redundancy Hardware Redundancy	Self-inspection by embedded sensing, self-adjustment by using advance control	Highly redundant elements	**WP3**

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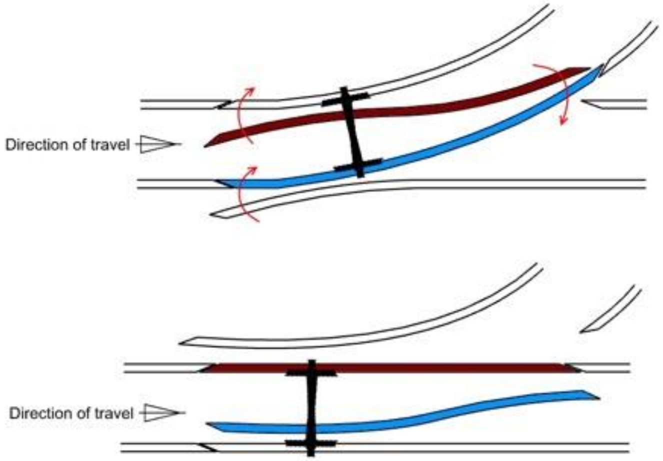
Back-to-back bistable switch

- Comparison of current S&C to Future S&C – High level
- How it will be actuated?
- How it will be locked in place?
- What are the consequences in terms of train passage?



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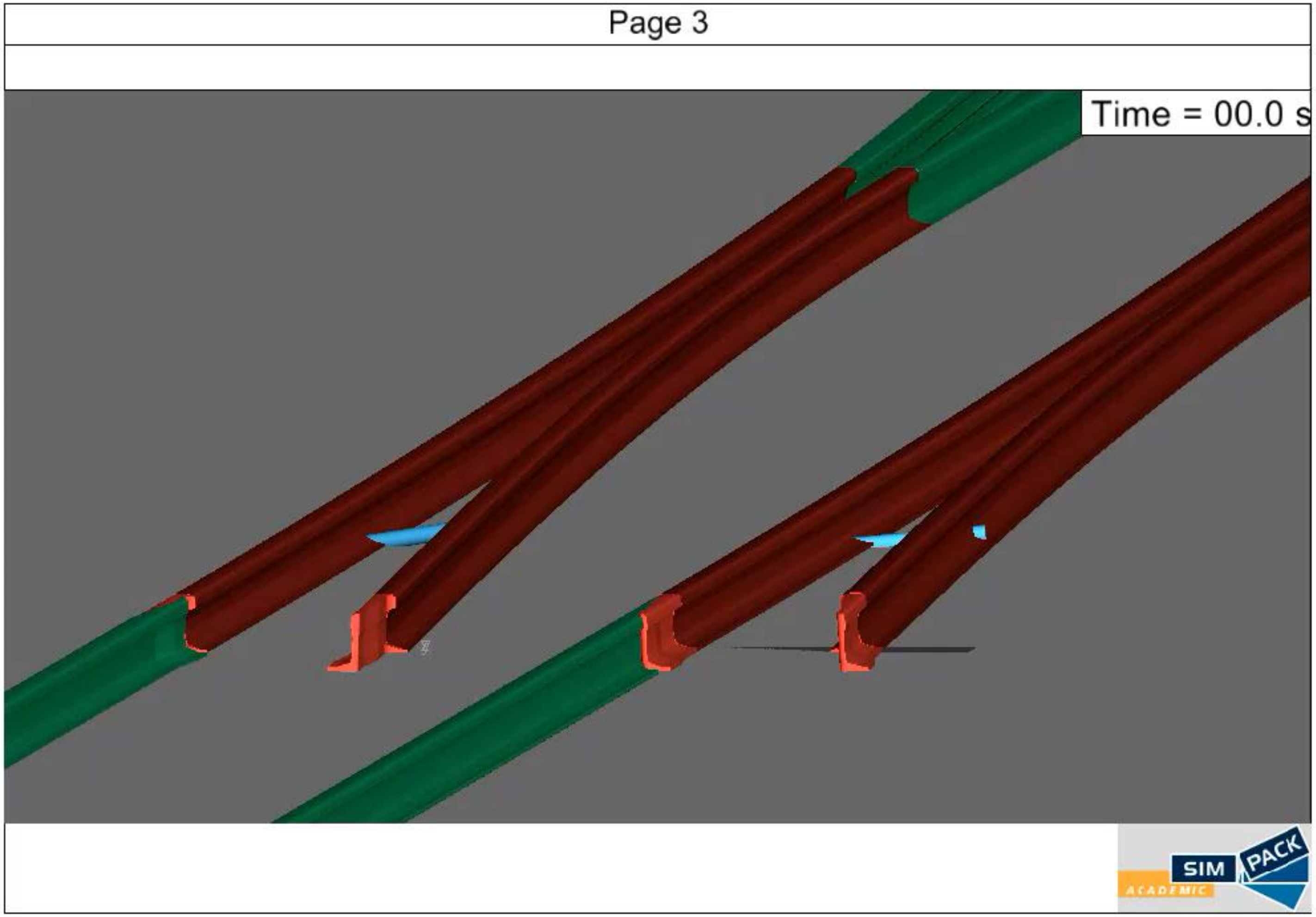
Concept



Potential Condition Monitoring System for the New B2B Concept

- Accelerometer
- Displacement sensor
- Thermal sensor
- Strain gauge
- Force sensor

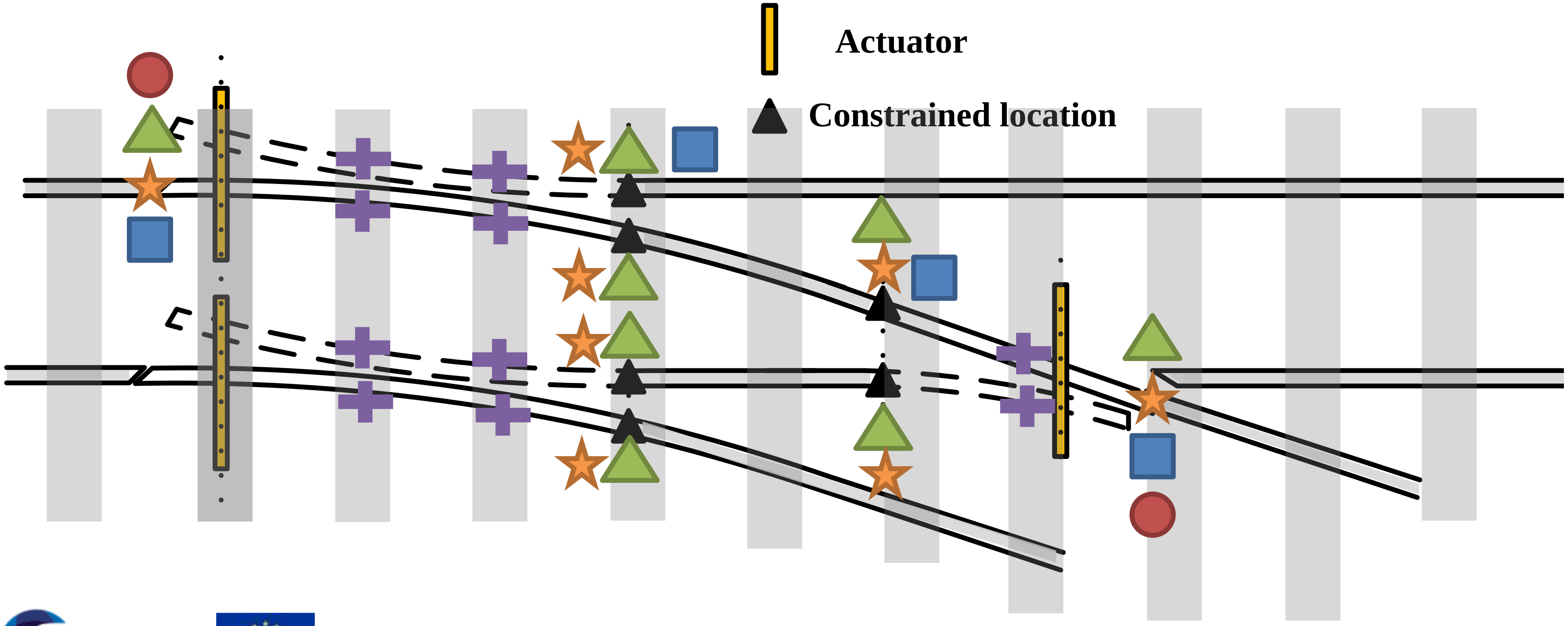
Vertical & lateral accelerometer (Rail foot)

Vertical, lateral, longitudinal displacements

Beginning and end of the free rail section

Contact force, axial force (rail web, rail foot)

Locking force (locking position along free rail section)



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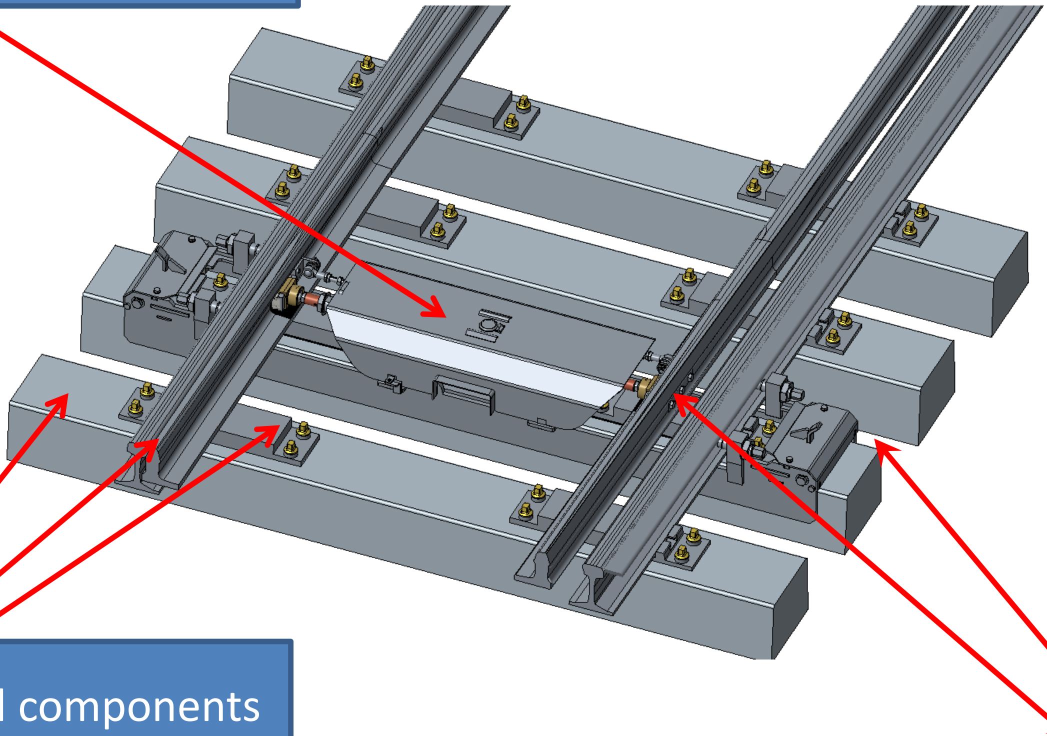
WP6 – Verification and Validation

WP5 Kinematic system and switching mechanism



WP4 Materials and components

WP3 Sensing system

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WP 7 - Three tiers of evaluation

What the project has developed and to what maturity?	Technologies and concepts	TRL Level
What impact the developments will have against MAAP objectives?	Capacity Reliability LCC	RAMS Tools techniques
What standards and industry process would need to be challenged?	Assessment and Standards	Qualitative Evaluation process

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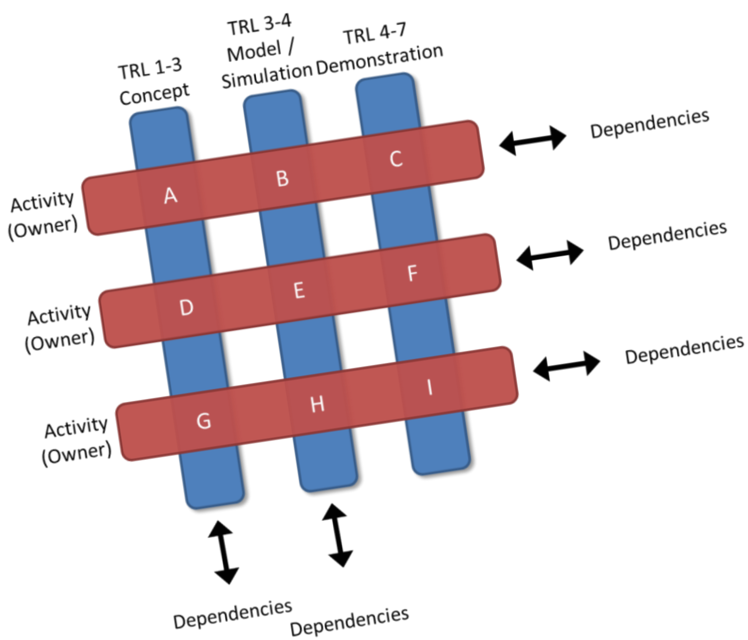
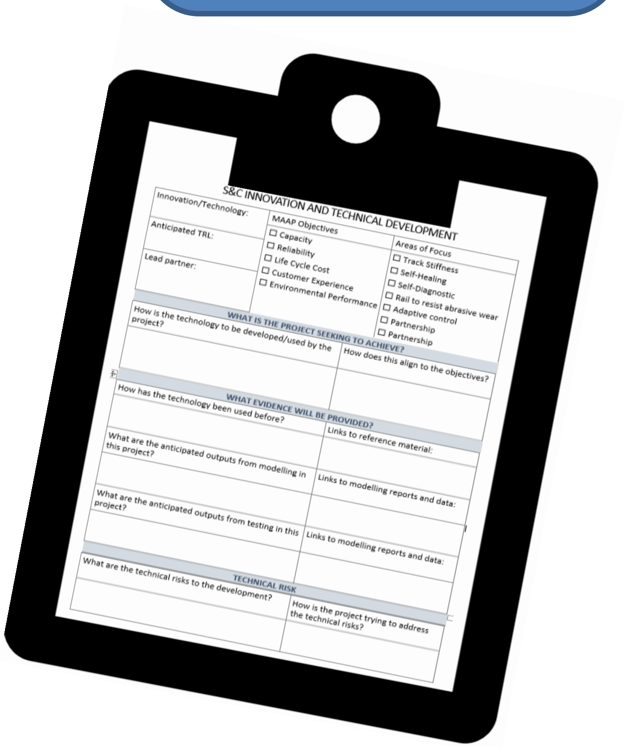
WP 7 – Tier 1 – Developments and TRLs

What the project has developed and to what maturity?

Technologies and concepts

TRL Level





WP 7 – Tier 2 - Impact

What impact the developments will have against MAAP objectives?

Capacity
Reliability
LCC

RAMS Tools techniques

Objective	Parameter	Baseline Model	Improvement delivered
Capacity	• Time to Throw • Mean time to Repair	....	
Reliability	• MTBSAF • Duty Cycles • Life	....	
LCC	• Maintenance costs • Manufacturing costs • Installation costs	....	
Other	• Noise • Power Consumption	....	

FMECA?

Fault Tree Analysis?

Reliability Block Diagram?

LCC Model?

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WP 7 Tier 3 – Standards and Process

What standards and industry process would need to be challenged?

Assessment and Standards

Qualitative Evaluation process

Technology development:					
Operating Parameter	TSI Requirement	EN Requirement	Compliance assessment	Commentary	Future testing needs/capability

-Complies
-Complies with the intent of requirement
-Requires standard change

WP1

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TD3.2 Next Generation Switch & Crossing System Demonstrator

The MAAP outlines the following objectives for TD3.2:

- New methodologies for track switching (radical)
- Reduction in failure modes (less complexity)
- Inherently weather resistant system
- Scalability and applicability across a range of geometries, tonnage and speeds
- Future proofed for mechatronic steering bogies
- Less energy intensive to manufacture
- Reduction in noise and vibration (3db peak noise reduction)
- Improvements in ride quality
- Reduced possession times for installation and maintenance
- Reduction in maintenance costs
- Reduction in manufacturing costs
- Reduction in installation costs
- Increased life expectancy

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Multi Annual Action Plan

The MAAP also makes specific reference to potential areas of focus:

MAAP Objectives

- Reduction in failure modes (less complexity)
- Inherently weather resistant
- scalability and applicability across a range of geometries, tonnage and speeds
- Future proofed for mechatronic steering bogies
- Less energy intensive to manufacture
- noise and vibration (3db peak noise reduction)
- Ride quality
- Reduced possession times
- Maintenance costs
- Manufacturing costs
- Installation costs
- life expectancy

Areas of focus

- Rail steels to resist abrasive wear (Nano technology for metallurgy)
- Track support condition and transition zones
- Reduction in wheel/rail dynamic forces
- Automated manufacture, installation and maintenance
- Signalling philosophy
- Self adjusting
- Self healing
- Adaptive control
- Self diagnostics (real time)

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CODE

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