Designing HS2 for High Reliability – Integration of Operation and Asset Management

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The Need for HS2

Britain is growing

Population of England

- 2008 – 52m
- 2033 – 60m
- 2050 – 70m

Living in City Regions

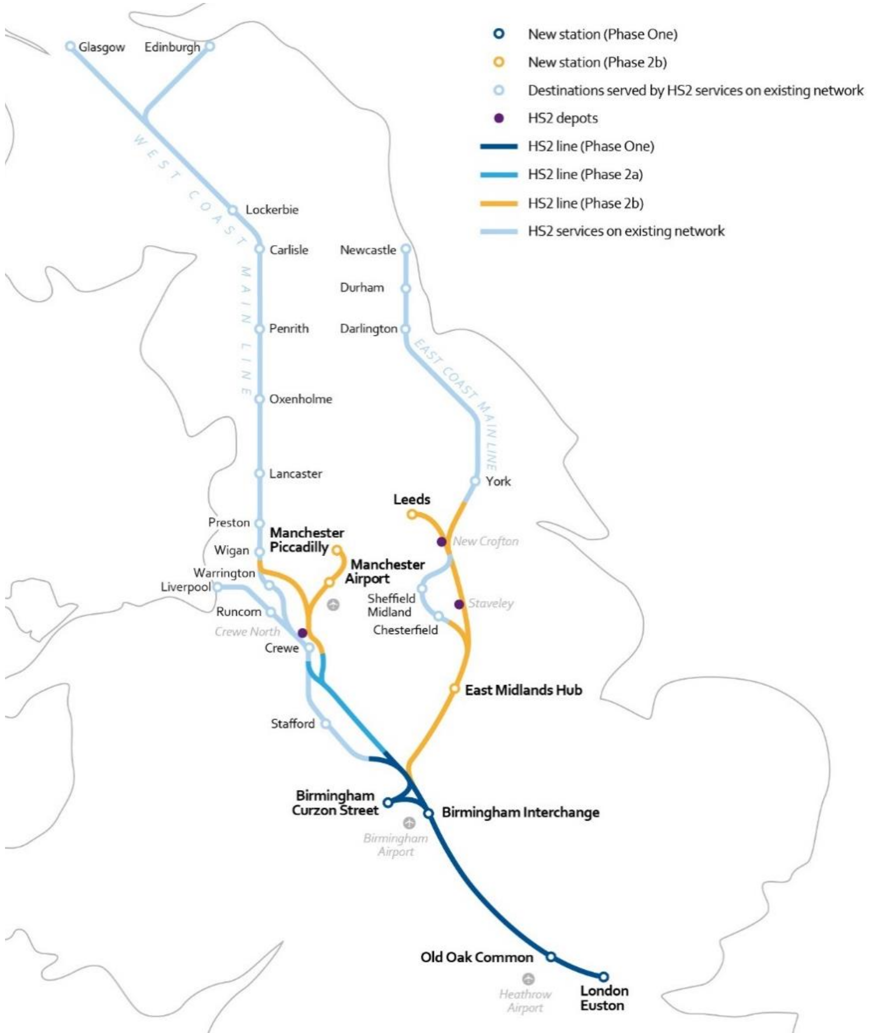
- Today – 41m
- 2050 – 61m

Connectivity, Capacity and Growth

Phase 1 – Birmingham

Phase 2A – Crewe

Phase 2B – Manchester/Leeds



HS2 - 21st century railway

HS2 will deliver a safe, sustainable and reliable system to provide exceptional levels of service to passengers

- An integrated system of systems
- Proven, best in class principles and technology
- High capacity railway, up to 18 trains per hour in both directions

HS2 Design Vision

People Place Time

Good Design is Key (Design Vision)

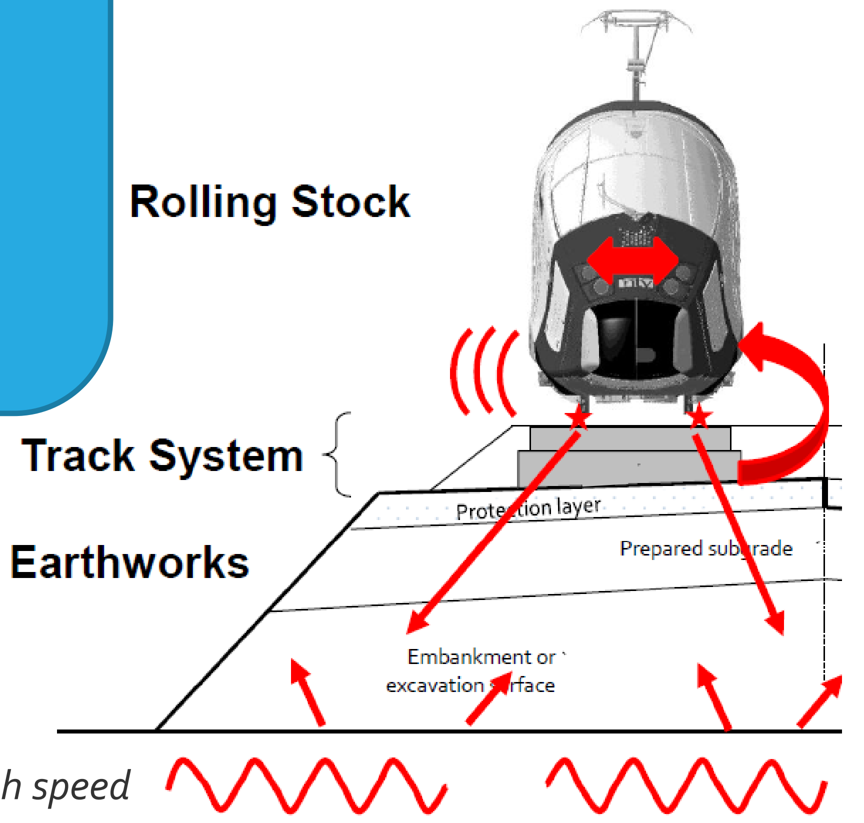
Integrated System Design for High Speeds

High speed trains running at a maximum speed of 360km/h

High capacity railway, up to 18 trains per hour in both directions (>60MGTPA)

Overnight maintenance access: 5 hours Monday – Saturday; 8 hours Sunday

System design to achieve safety and performance requirements, at lowest whole life costs



Required performance for HS2 operating conditions

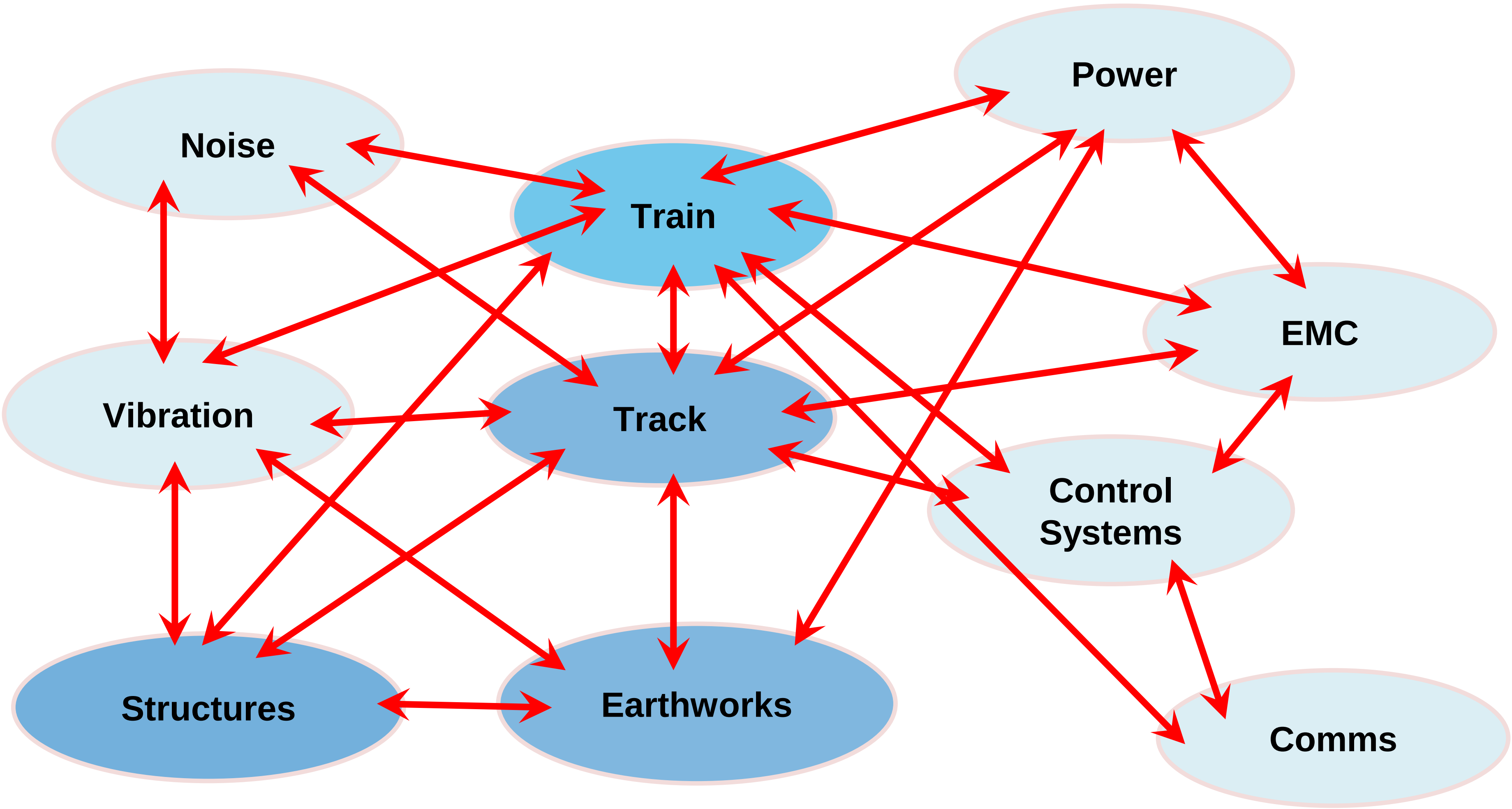
Sponsor's requirements for performance, reliability etc

Minimum Requirement

Delays to passenger services on the Railway shall be less than 30 seconds per train (on the high speed network measured as moving annual average).

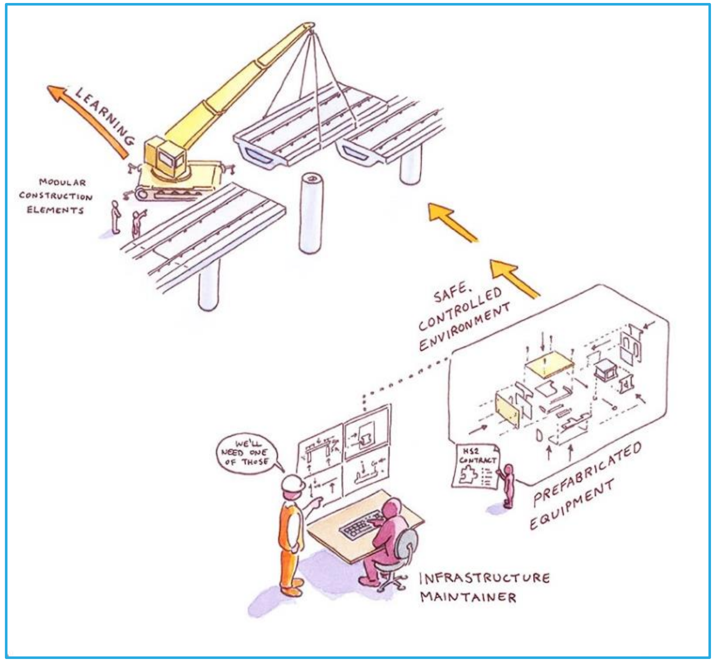
A Complex Technical System…

…with Multiple Interactions



All interfaces need to be identified….

Designed around human capability

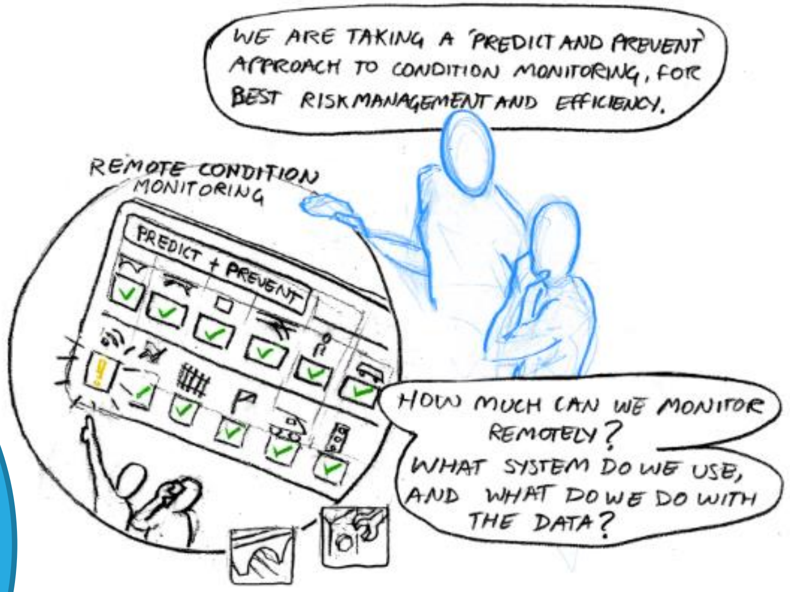


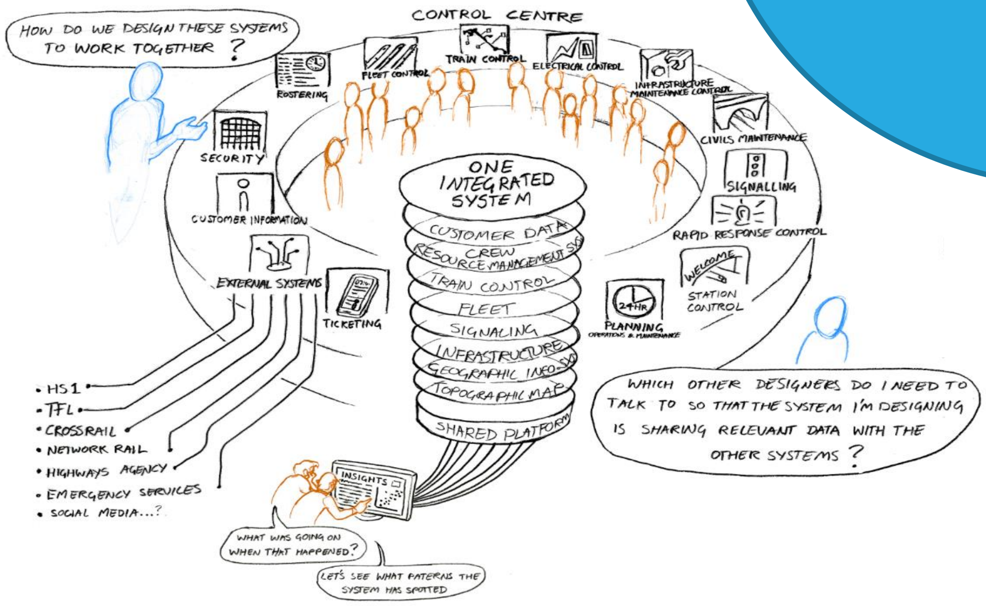
Constructor

Operator

Maintainer

User





Client-led Design and Specification

How do we achieve the required performance for HS2 operating conditions?

- Collaboration with experienced high speed partners and leading research institutions – workshops, investigation and reports
- Incorporate current best practice from HSR around the world…

  … including lessons learned from both high speed and conventional rail
- Identified likely failure modes….

Early design development to inform the technical specifications

- Track system design (inc Trackform)
- Resilient trackform in tunnels at high speeds
- Switches & Crossings
- OCS design
- Tunnel ventilation requirements (civils design)

How do we choose the right trackform?

No standardised method of choosing trackform for HSR

HS2 developed structured evaluation process based on objective evidence

1. Identify Decisions
2. Define Options & Criteria
3. Assess Options
4. Evaluate Decision
5. Implement Decision
   - 5-a. Seek approval for the decision
   - 5-b. Implement the decision

Key Inputs:

- **Technical Performance**
- Environmental Impacts
- Sustainability
- Operational Implications
- Construction Programme
- Capital Costs
- Life Cycle Costs
- Whole life value for money

- Objective evidence
  - Written or published reports, papers or research (not anecdotal)
  - Specific work carried out by consultants on behalf of HS2 with proven technical expertise or high speed operational experience
  - Modelling with appropriate validation

Contributors include

- OBB and TUG, Austria
- Systra and SNCF, France
- JR East and JR West, Japan
- DB, Germany
- Ineco, Spain
- PB/BBRE, UK and Netherlands
- Various UK universities

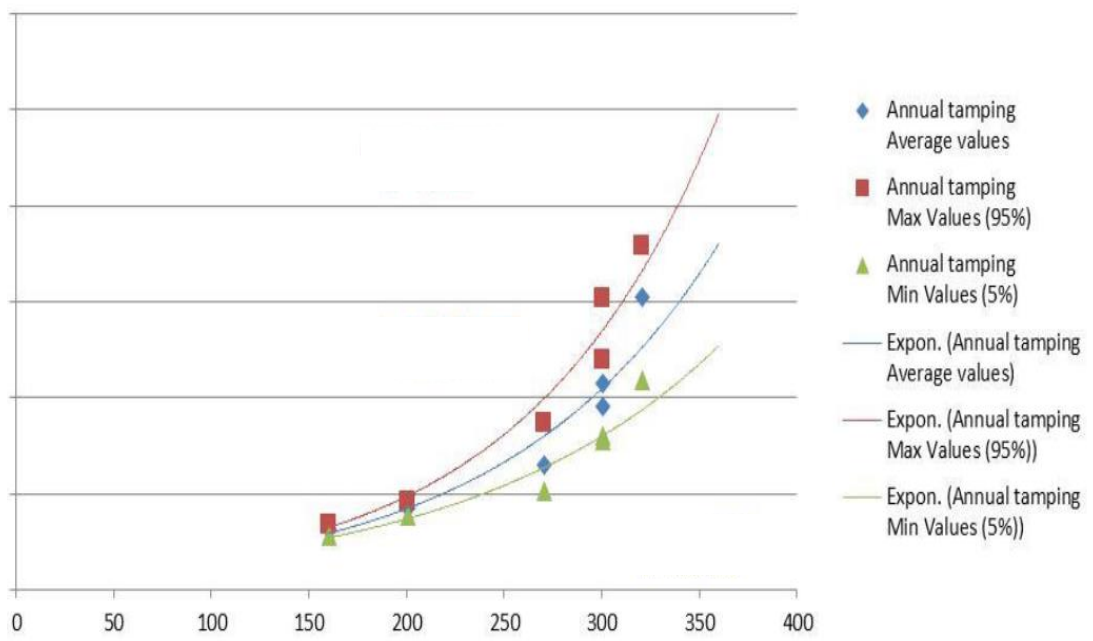
➔ **Sustainable Trackform - ballasted track and/or slab track?**

Assessment of Ballasted Track : Predicted Tamping

- Statistical analysis by Systra/SNCF of all LGV maintenance databases to predict potential tamping effort for HS2 tonnage and speed
- Plotted tamping effort and deterioration rates vs cumulative tonnage at various speeds

- Excluded SDs with S&C, rail expansion joints, bridge approaches etc
- Excluded spot tamping of isolated defects

(km)	160 km/h	200 km/h	220 km/h	230 km/h	270 km/h	300 km/h	320 km/h
LN1	6,8 km				283,6 km	484,2	
LN2		14 km	5,6 km		25,6 km	448,8 km	
LN3	0,8 km	14 km	49,8 km	17,8 km	92,2 km	506 km	
LN4						188,6 km	
LN5	0,6 km					317 km	58 km
LN6			0,8 km			84,6 km	475,8 km

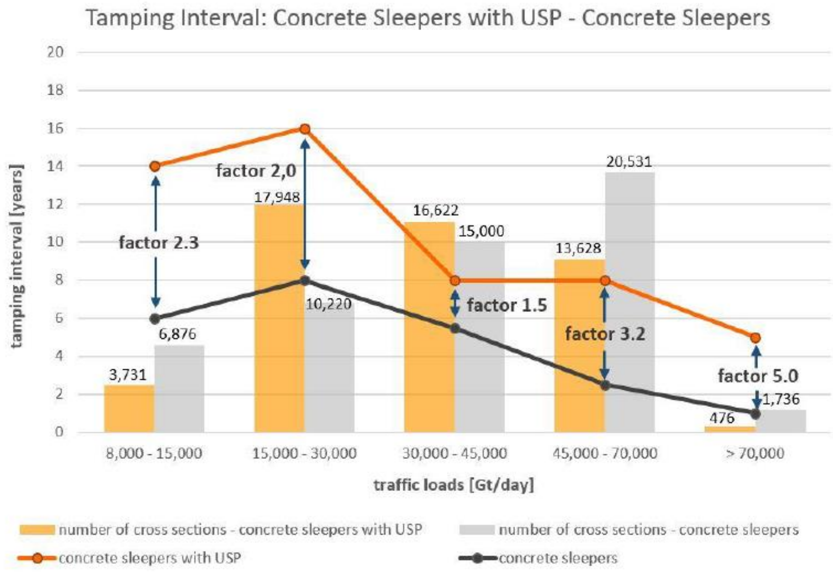


- Predicted tamping further reduced using USPs and bitumen asphalt sub-ballast – although sample size too small

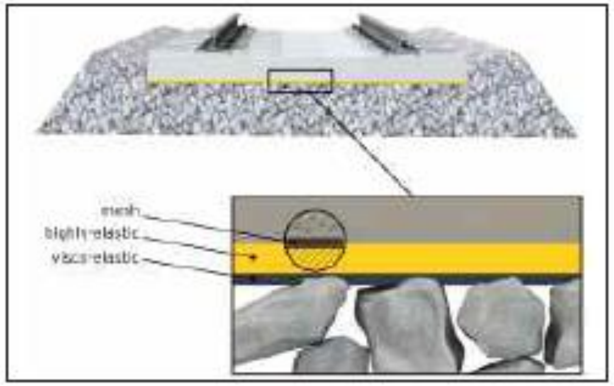
Effect of USPs on Predicted Tamping

- Further evidence of the reduced tamping using USPs and bitumen asphalt sub-ballast required – experience from Austria
- Two key tasks by Technical University of Graz

1. Independent validation of SNCF methodology
2. Propose a reduction factor for USPs and bitumen asphalt based on Austrian experience



Alternative methodology developed by TUG and SBB (Switzerland) and applied to HS2 conditions showed very close correlation



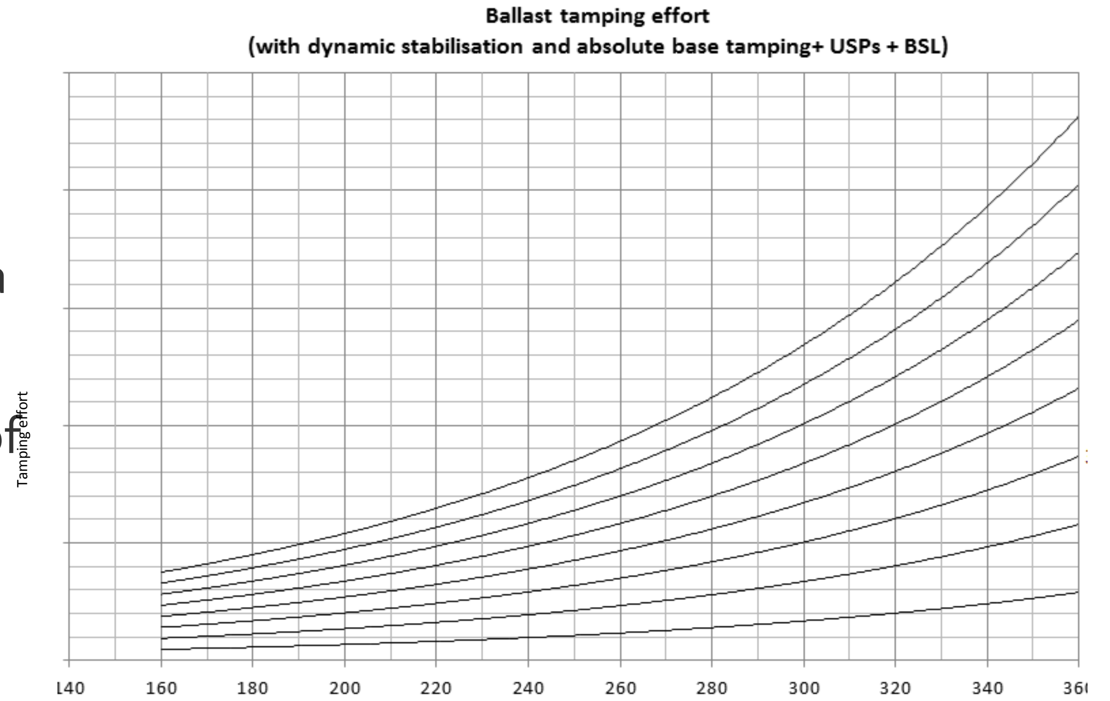
Key input into Trackform decision for Phase 1 (evidence)

Tamping effort vs speed of any given tonnage

(based on the statistical analysis by SNCF and further input by TUG)

- The tamping effort required to maintain ballasted track is a function of tonnage (and speed to a lesser extent)
- Cumulative tonnage is the key input into the degradation of the track system
- The life span of ballast is also a function of the number of tamps…

➔ Higher tonnage = more tamping = lower ballast life = more renewals



400m sets (columns) / 200m Sets (rows)

	0	1	2	3	4	5	6	7	8	9	10
0	9.33	13.1	16.9	20.7	24.5	28.3	32.1	35.9	39.7	43.5	47.3
1	11.2	15	18.8	22.6	26.4	30.2	34	37.8	41.6	45.4	49.2
2	13.1	16.9	20.7	24.5	28.3	32.1	35.9	39.7	43.5	47.3	51.1
3	15	18.8	22.6	26.4	30.2	34	37.8	41.6	45.4	49.2	53
4	16.9	20.7	24.5	28.3	32.1	35.9	39.7	43.5	47.3	51.1	54.9
5	18.8	22.6	26.4	30.2	34	37.8	41.6	45.4	49.2	53	56.8
6	20.7	24.5	28.3	32.1	35.9	39.7	43.5	47.3	51.1	54.9	58.7
7	22.6	26.4	30.2	34	37.8	41.6	45.4	49.2	53	56.8	60.6
8	24.5	28.3	32.1	35.9	39.7	43.5	47.3	51.1	54.9	58.7	62.5

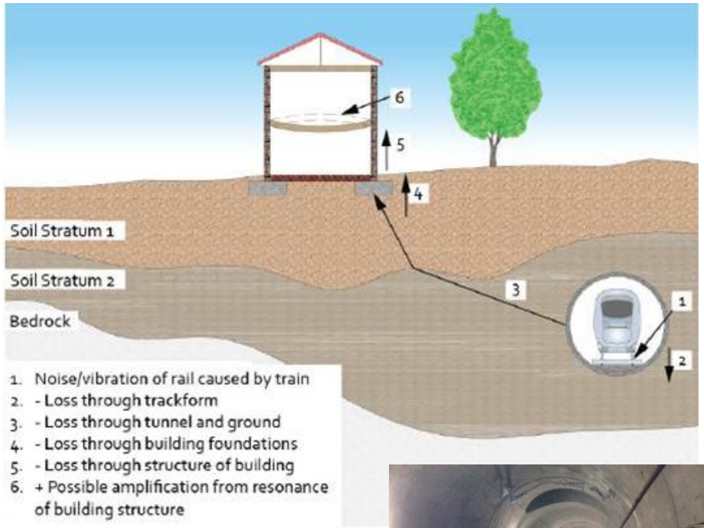
Key input into LCC model and therefore trackform decision

➔ Slab track specified for Phase1 and possibly Phase2A

Resilient track in tunnels at high speeds

Strict commitments on GBN&V made in the Parliamentary Process

- Additional resilient layer tends to lead to 'softer' track
- However… high speed rail requires 'stiffer' track (less rail deflection compared to low speed urban railways)
- Current maximum speeds ≈ 250km/h
- HS2 requires 320km/h in tunnels where vibrations need to be mitigated



- Numerical modelling of 5 different track systems – both booted block and conventional pre-cast/cast-in-situ slab systems
- Determined that a 'stiffer' version of a well known resilient system would meet the Environmental Minimum Requirements
- Enabled a 'acoustic performance specification' to be developed for the ITT for the track in tunnels

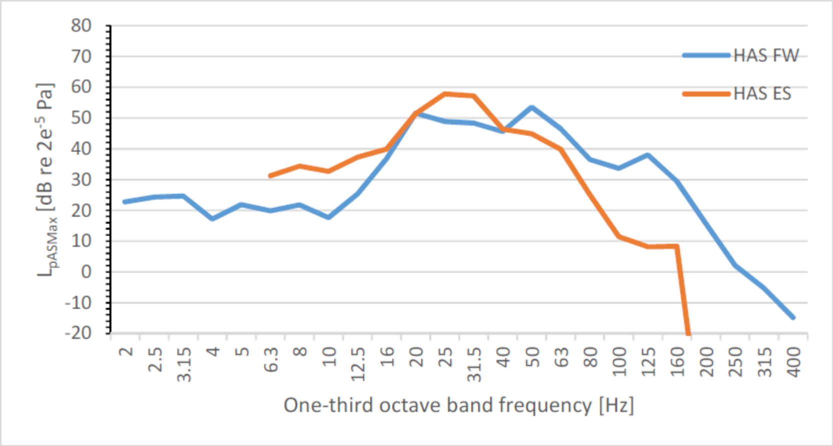


Figure 19: Ground-borne sound spectra predicted with ES and Findwave (FW) models at Horsenden Lane South

Switches & Crossings Design Issues

High Speed Design

- Geometry optimised for high speeds – up to 230kph max diverging speed (450m long crossovers)
- Low jolt at switch toes (double clothoid design)
- High speeds S&C sited on **straight** track alignment
- **Minimum** distance 100m apart for maintenance purposes
- Uniform support platform stiffness and minimum distance away from structures

Low Speed Design (Terminus Stations)

- Improved performance required for UK
- Turnout radius >400m for all operational S&C
  - Significantly reduces switch wear and damage
  - Curved S&C but no cant (increase cant deficiency)
- Optimise wheel/rail interface, including transfer area at crossings

Switches & Crossings (Points Operating Equipment)

POE integral to a highly reliable railway

Potential suppliers to produce accurate and detailed reliability data covering….

- MTBF and MTBSAF (Mean Time Between Service Affecting Failures)
- Number of similar units deployed and details of where and type of operation
- Detailed breakdown of switch failures with categorisation, descriptions, frequency, root cause and remedial action
- Average failure to movement ratio
- Maintenance frequencies and outline maintenance requirements

Need to clearly specify our requirements

How will we manage our asset?

Now that we have designed and built our asset to the highest quality….




HS2 Infrastructure Measurement and Monitoring (IMM) Strategy

Aim

- To identify relevant existing and emerging technologies in:
  - Unattended Measurement Systems (UMS)
  - Dynamic Infrastructure Measurement (DIM)
  - Asset Condition Monitoring (ACM)
- Select IMM candidate technologies by comparing their CAPEX + OPEX against savings in RISKEX and maintenance cost
- Derive an HS2 IMM System to integrate the capabilities of viable IMM candidate technologies into the Asset Management process to achieve the reliability targets

Failure Modes Effects and Criticality Analysis (FMECA)

- 105 HS2 asset failure modes analysed
- Around 70% of these failure modes are detectable in principle at incipient stage using UMS, off-board DIM, or ACM technologies

Severity Rating	Rating Description	Rating Definition	Number of Infrastructure Failure Modes in Severity Category
I	Catastrophic	An infrastructure failure which may cause death or loss of high speed train through derailment, or collision with another train or obstacle	11
II	Critical	An infrastructure failure which may cause severe injury, prevent train movement or a service cancellation through line closure (Immobilising Failure)	33
III	Marginal	An infrastructure failure which may impose a speed restriction, significant reduction in passenger ride quality, or a delay to scheduled arrival time of 5 minutes or longer (Service Failure)	22
IV	Minor	An infrastructure failure which does not affect safety or level of service, but which will result in unscheduled maintenance and/or a delay to scheduled arrival time of less than 5 minutes	39

IMM Use of New Technology

TRL	Original NASA Definition	HS2 IMM Strategy Definition
1	Basic principles observed and reported	Engineering/scientific knowledge underpinning potential IMM application is generated
2	Technology concept and/or application formulated	Practical IMM application identified but speculative. No experimental proof or analysis available to support conjectured use
3	Analytical and experimental proof of concept	IMM application physical principles demonstrated through modelling and simulation
4	Component and/or breadboard validation in a laboratory environment	IMM application component function has been validated in a laboratory environment
5	Component and/or breadboard validation in a relevant environment	IMM application sensor/equipment function has been validated on a test track
6	System/sub-system model or prototype demonstration in an operational environment	IMM application sensor/equipment function has been validated in a high-speed rail environment
7	System prototype demonstration in an operational environment	IMM application fully representative prototype has been demonstrated in a high-speed rail environment
8	System functionally complete and qualified through test and demonstration	IMM application has passed qualification testing and has been demonstrated in a high-speed rail environment
9	System proven through successful mission operations	IMM application proven in use on commercial high-speed rail operations

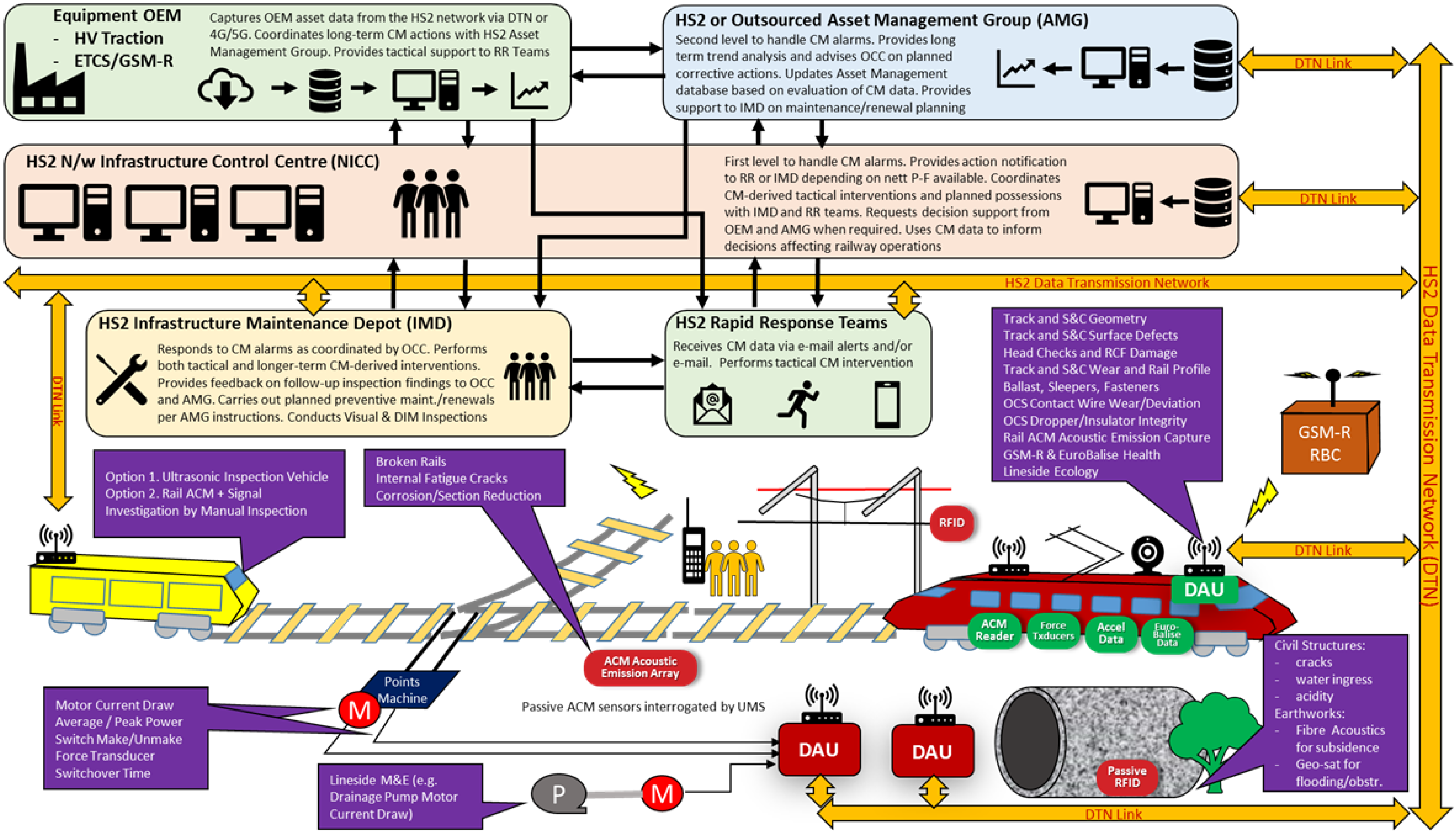
There are 9 Technology Readiness Levels (TRLs) that define the maturity of an innovation at a given point in time

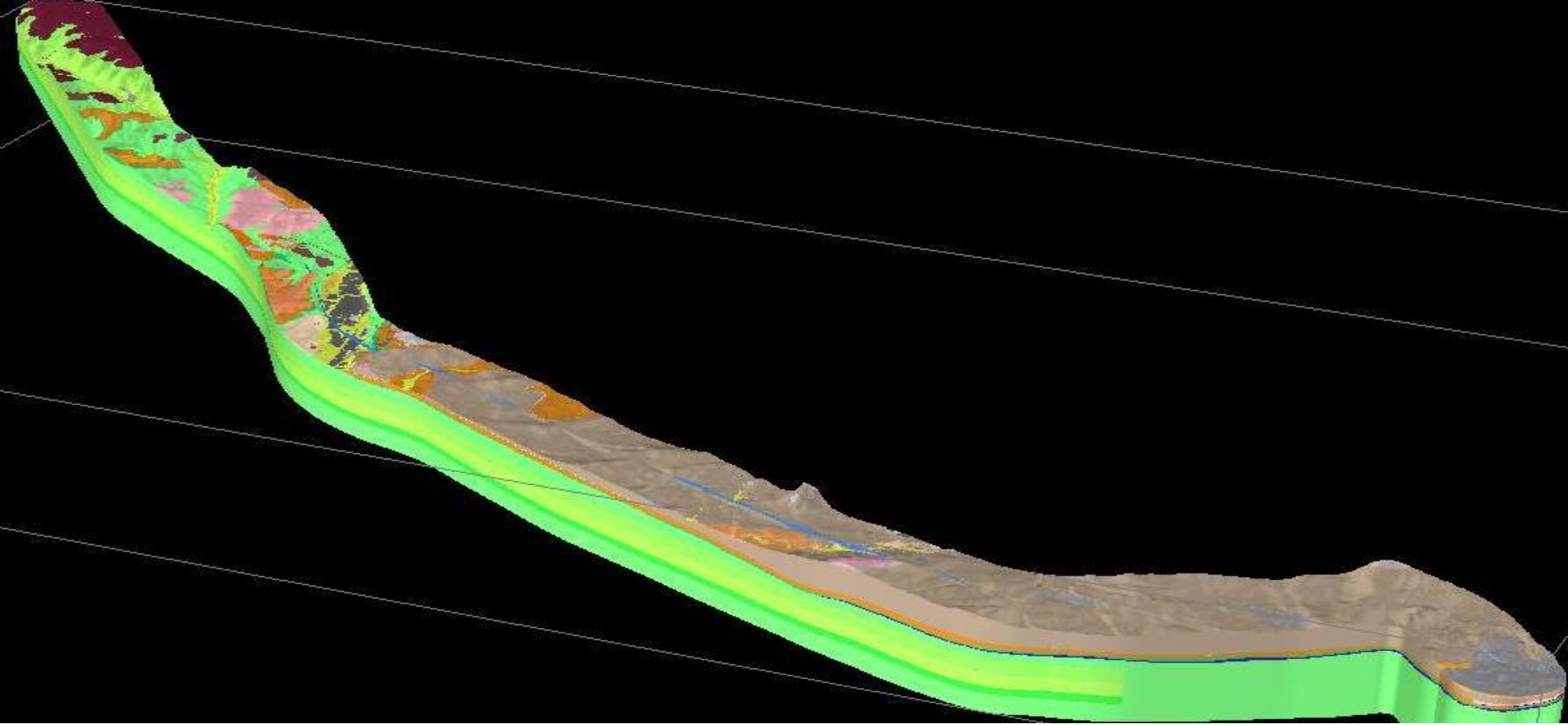
The Technology Scouting activity categorised the potential IMM solutions according to their current (2017) and expected future TRL

Technologies must be capable of reaching a minimum of TRL 8 by the start of HS2 commissioning in 2026 to be considered as potentially viable candidates for inclusion in HS2's IMM System

2026 maturity threshold

HS2 IMM Overview





Applying technology to future maintenance - BIM

Our cornerstone…