High Speed Rail Design Challenges
Designing for High Reliability

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Design and Construction of HSR

Some of the issues that need to be considered:

• Business Need and Operational Requirements
• Standards and Specifications
• Route Alignment
• Rail Systems Design including Trackform
• Civil Engineering Structures

Gap between current technology and experience, and what is required to meet the operational requirements...

i.e. asset performance and reliability
A Complex Technical System... ...with Multiple Interactions

All interfaces need to be identified... and specified and designed
How do we achieve the required performance?

Client-led specification and design

Collaboration with high speed partners and research institutions

• Workshops, investigation and reports
• Incorporate current best practice and lessons from around the world (HS and conventional rail)
• Identify likely failure modes to inform design
• Knowledge transfer
• Research and Innovation

Systemic and structured approach to .....
Improving the performance of the infrastructure

Better reliability and resilience

Demanding operating conditions and high reliability targets at lower costs may require relaxing standards or new technology.

Proven Technology

Benefit

Risk

Research and Innovation

Universities

Theory/Model

Lab Testing

Industry

In-situ Trials

Operations

Better reliability and resilience
Beware the Vagaries of Computing/Modelling

Can we believe everything we are told?

‘Our model tells us we can reduce ballast depths... reduce transition lengths... save millions with...!’

Various managers/engineers from industry

What is the answer to the ‘Ultimate Question of Life, the Universe and Everything’?

Deep Thought....

Important that industry has closer and more dynamic relationships with the Academia...

• To understand the capabilities and limitations of computers/modelling
• To facilitate access to the operational railway for validation and introduction of new technology
Specifying and designing for a successful outcome...

Operational Strategy
Requirements

Technical Specifications
Constraints
Appropriate to the UK

Design
Client-led early designs, research and innovation

Construction
High Availability
Low Maintainability
Asset Management
Infrastructure Monitoring

Quality
Asset behaves as designed

Operations
Customer Satisfaction
Reliable
Business Case
Reputation

Asset behaves as designed

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Track Requirements - High Speed (vs conventional?)

- Dedicated passenger only railway (if possible!)
- Good vehicle-track Interaction (classic-compatible trains)
- **Track alignment** suitable for high speed operations
- **Trackform**: Optimised track stiffness and elasticity inc rail deflection
- **Consistent support platform** – earthworks, tunnels, bridges
- Track-bridge interaction design
- Very strict tolerances for geometry, dimensions and wheel-rail profiles, during both construction and maintenance
- Critical-track velocity and geodynamics analysis
- Control of noise and vibrations

**Focus on integrated system design**

Application can be different
- System (Components)
- Alignment
- Tolerances, accuracy
- Quality

Ya canna change the laws of physics!
High Speed Track Alignment

The design of the track geometry alignment should aim for good vehicle dynamic behaviour

• Lower forces on the track and higher passenger comfort
• Long, flat geometrical elements to limit the number of changes of direction

Produce appropriate Track Alignment Standard

• Cognisant of and consistent with other HS standards although tailored for UK requirements and constraints
• Balance between the physical and environmental constraints, costs and a sustainable railway with high passenger satisfaction
• Optimum design is not found in the TSI...
• Ultimate objective is to design a safe, reliable and efficient railway
Track Alignment Modelling

Combined Horizontal and Vertical Curves

• Both the horizontal and vertical components of high speed track alignment must be considered together due to passenger comfort, buildability and maintainability issues.

• Most high speed Infrastructure Managers place some restriction on the use of **vertical/horizontal transition curves** in combination.

• UK topography and population density makes for a challenging high speed alignment design.

• Relaxations to certain parameters can help achieve more efficient and cost-effective designs.

• IRR, Huddersfield modelled various geometrical combinations (car accelerations and WRI behaviour).

• HS2 analysed outputs and relaxed HS2 requirements for desirable vertical curves (2.25%g).
High Speed Route Alignment

Iterative process of developing a high speed route alignment

- Starting point and destination(s)
- Appropriate Track Alignment Standard
- Use the DTM to scheme various route options

Consider environmental, topographical constraints

- Several main corridors are found using best terrain and landmarks/population centres
- From these multiple options along each corridor are developed
- As information comes to light, options are adjusted or dropped
- Sifts carried out to decide the most economical with least environmental impacts, within engineering standards
Track System Design for High Speeds

Achieve required performance for specified operating conditions
• Maximum design speed, gross cumulative tonnage etc

Mechanical behaviour and performance of track enhanced as the speed increases to cope with:
• Higher dynamic loads and vibrations (lead to fatigue and wear)
• Higher stresses on the track bed and support platform/structures
• Higher specification components to improve load transmission
• Optimise elasticity (vertical, horizontal and longitudinal)
• Special trackwork – S&C and Rail Expansion Devices

Trackform is a key strategic decision for HSR
Choosing the Right Trackform?

No standardised method of choosing trackform for HSR

Structured evaluation process based on objective evidence

Key Inputs:

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

Sustainable Trackform: ballasted track and/or slab track?
Ballast Track – Optimisation

- Rails – rail head profile, metallurgy
- Fastenings (soft rail pad)
- Sleepers – size, shape
- Under Sleeper Pads (stiff pad)
- Ballast (stabilised in layers)
- Bitumen asphalt sub-ballast
Slab Track: Engineered Design

Suited to higher speeds and tonnage due to engineered design

- Engineered design for loading and speed (new EN standard)
- Can be modelled using proprietary packages
- Controlled stiffness and rail deflection
- 60+ year design life with minimal maintenance but will last longer
- Fewer risks due to codified design process
- Inherently more stable under loading

Slab track usually consists of:

- Track slab, rails and fastenings
- Base slab (hydraulic bound layer)
- Founded on Protection Layer
Slab Track Systems – High Speed Rail

• Designs evolved over many years in service
**HSR Switches & Crossings**

- Different geometries for high speed and low speed turnouts
- Swing nose crossings eliminate impact forces
- Uniform track stiffness through S&C
- Uniform support platform stiffness
- Minimum distance away from bridges

**S&C: High performance and low maintenance**
High Speed Switches & Crossings

Double clothoid design
- Geometry optimised for high speeds
- Low jolt at switch toes
- Sited on straight track, minimum distance apart, 100m, for ballasted track
- 450m long crossovers toe-to-toe (230km/h)
Acoustic Performance Design

Commitment to minimise ground borne noise in buildings above HS2 tunnels and airborne noise in open route

Tunnels and urban locations
• GBN performance specified
• Measure and demonstrate performance

Open Route
• Track system contributes to overall noise levels
• Certain noise mitigation measures for track may be specified
The Hybrid Bill track alignment was in OSGB36 grid which does not take into consideration curvature of the earth. Over approx 170km from London to Birmingham this creates a difference in length of some 50m.

The Snake projection is a method for projecting the curved surface of the Earth onto a flat plane and is designed specifically for long linear sinuous routes such as rail. Each projection is tailored for the target project.

This forms a unified grid system for the whole project which removes the need for further corrections.

Developed by University College London.

Alternative would be to use 27 overlapping, consecutive grids between London and Birmingham.
Earthworks for High Speed Rail

- High speed earthworks utilise a layered stiffness approach
- Consistent approach worldwide

![Diagram showing layered stiffness approach in ballasted and slab tracks with modulus values.]
Earthworks for High Speed Rail

- High speed earthworks utilise a layered stiffness approach
- Consistent approach worldwide
- Very slight difference between slab and ballast trackforms

DB site tests in 1970s
Technical Performance – Ballast (hardspots, transitions)

Other implications for ballast

- Hardspots such as culverts, viaducts, undertrack crossings
- Slab-ballast transitions
  - Performance risks at higher speeds (F320, G250, HS2 360?)
Slab Track on Earthworks

- Track slab and HBL/CBL
- Re-profile of the Protection layer where canted
- Track drainage (central drains)
- Predicted ground movements—when to install the track
- Manage on-going settlement and heave
Slab Track on Bridges and Viaducts

- Special requirements for slab track on bridges/viaducts
- Cast-in-situ Intermediate Layer
- Track to bridge connection details
- Track-Bridge interaction analysis
- Rail Expansion Devices and comp plates
Slab Track in Tunnels

- Design and construction of
  - resilient track system to mitigate vibrations where required
  - suitable for high speeds (320km/h)
  - Standard slab track in other tunnels
- Track drainage and connections to tunnel drainage
- Gauging and aerodynamics
- Design of specialist plant and equipment
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 with appropriate Readiness Levels (TRLs)

• 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

- 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

<table>
<thead>
<tr>
<th>Severity Rating</th>
<th>Rating Description</th>
<th>Rating Definition</th>
<th>Number of Infrastructure Failure Modes in Severity Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Catastrophic</td>
<td>An infrastructure failure which may cause death or loss of high speed train through derailment, or collision with another train or obstacle</td>
<td>11</td>
</tr>
<tr>
<td>II</td>
<td>Critical</td>
<td>An infrastructure failure which may cause severe injury, prevent train movement or a service cancellation through line closure (Immobilising Failure)</td>
<td>33</td>
</tr>
<tr>
<td>III</td>
<td>Marginal</td>
<td>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)</td>
<td>22</td>
</tr>
<tr>
<td>IV</td>
<td>Minor</td>
<td>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</td>
<td>39</td>
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Reliability
Our cornerstone

- Performance
- Customer Satisfaction
- Reputation
- Business Case
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