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Railway turnout damage prediction and design implications

Speaker: Dr Yann Bezin (IRR Head of Research, Huddersfield, UK)
Content

• Background
  – Key issues with Switches & Crossings in relation to the Wheel-Rail Interface
• Key areas of research by IRR
  – EU/National research projects
• How to address key challenges
  – Research tools
  – Vi-Rail utilisation
  – Validation aspects
• Future work and challenges
  – Challenges and opportunities
Background

**Complexity**
- Large # of parts
- Wide range of possible layout configuration
- Moving parts & exposed mechanisms
- Mechanical interfaces
- Weak structural components

**Non-linearities**
- Rail cross sections (bearing surface)
- Structural stiffness (rail bending stiffness, bearer length & ballast support)
- Rail inclination
- Track curvature
- Cant deficiency
## S&C key components and damages

### Switch Panel

<table>
<thead>
<tr>
<th>Component</th>
<th>Failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast manganese</td>
<td>transverse fatigue crack (foot or nose)</td>
</tr>
<tr>
<td>Casting</td>
<td></td>
</tr>
<tr>
<td>Crossing nose</td>
<td>wear, plastic deformation, shelling and spalling</td>
</tr>
<tr>
<td>Wing rail</td>
<td>wear, plastic deformation, shelling and spalling</td>
</tr>
<tr>
<td>bearers</td>
<td>fatigue cracking, voids</td>
</tr>
<tr>
<td>switch rails</td>
<td>lipping, head checks, squats, wear</td>
</tr>
<tr>
<td>points</td>
<td>all the above + fracture by fatigue</td>
</tr>
<tr>
<td>stock rails</td>
<td>lipping, head checks, squats, wear, spalling</td>
</tr>
<tr>
<td>slide plates</td>
<td>poor movement (high friction) and ceisure</td>
</tr>
<tr>
<td>bearers</td>
<td>fatigue cracking, voids</td>
</tr>
</tbody>
</table>

### Crossing Panel

<table>
<thead>
<tr>
<th>Component</th>
<th>Failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossing Point Operating Equipments</td>
<td>Switches</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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</tr>
</tbody>
</table>
S&C key components and damages

- Spalling of stock rail
- Subsurface initiated fatigue
- Lipping of switch/stock rails

Reference: Capacity4Rail, D131 “Operational failures modes of S&Cs”
S&C key components and damages

Plastic deformation of wing rails

Spalling of crossings

Spalling & plastic deformation of crossing nose

Reference: Capacity4Rail, D131 “Operational failures modes of S&Cs”
Root causes: dynamic W/R Interaction

Poor compliance of W-R geometries

- Harsh interface
- Variable rails shapes
- \( \Rightarrow \) Jumps in contact
- \( \Rightarrow \) Multiple point contact
- \( \Rightarrow \) High normal & surface/subsurface shear stresses

Poor maintenance + support

- Cyclic top/alignment
- Voided/hanging bearers
- Uneven L/R loading
- Differential settlement
Root causes: dynamic W/R Interaction

Poor compliance of W-R geometries

High rail/sleeper accelerations
Ballast void and settlement

Increased Dynamic Forces

High normal & shear stresses
rail wear, fatigue & deformation

Poor maintenance + support

Casting/nose fatigue cracking
Root causes – Influential factors

- **Design** (system level => vehicle-track…)
- **Environmental** (incl. extreme weather)
- **Installation/set-up** (human factor, tolerances…)
- **Maintenance** (mechanised/manual…)
- **Manufacturing** (processes/tolerances/…)
- **Operational** (speed, loading regime, traffic mix, tonnages…)

Reference: D131 Operational failure modes of SCs
Key areas of research & development

Eslöv-Sweden test site:
• Kinematic Gauge Optimisation
• Resilient stiffness

Haste-German test site:
• Crossing nose shape (e.g. MaKüDe)
• Material (built-up)

Simulation software:
• Benchmarking
• KGO optimisation
• Support stiffness variation

Simulation of:
• Derailment analysis
• Switch rail shape optimisation
• Impact of wheel shape
• Under sleeper pads
• Innovative structures

Material
• Higher steel grades

Concept evaluation:
• New switch concepts
• New drive and lock devices

Concepts:
- FP6: Innotrack
- FP7: Sustrail, Rivas, DRail, Capacity4Rail

Towards demonstration of key innovations
Simulation tools – what we need…

Vehicle

☑️ Unsprung mass
☑️ Primary stiffness
☑️ Traction/braking
☑️ PYS and steering

Wheel-Rail

☑️ Variable rail (3D interpolation)
☑️ Variable friction coefficient (switches)
☑️ Non Hertzian multiple contact
☒☑️ Special materials effect on wear and fatigue (Hv)

Track

☑️ Tuned 9dof model
☑️☒ Discrete support model (casting, bearer length/mass, baseplates, variable support, ...) [FlexTrack]
Available simulation technology

- **Vehicle multibody system dynamics**
  - Prediction of vehicle behaviour and WRI forces

- **Vehicle-track interaction dynamics**
  - Prediction of WRI forces based on simplified or detailed track response

- **Wheel-rail contact conditions**
  - WRI forces and contact conditions (normal and tangential)

- **Wear/damage prediction & summation**
  - Based on any of the above
Example key output SUSTRAIL

- Axle kinematic motion
- Vertical wheel motion $\Rightarrow$ dip angle
- 3-dof wheel-track MBS model
- Dynamic $F_{\text{vertical}}$ prediction $\Rightarrow$ P2 force

$$z_w(x) = z_r(x, y) + r_0 - \Delta r(x, y)$$
Contact condition and contact stresses
Example key output SUSTRAIL

- Parametric study: 800+ wheel pairs
  - Prediction of dip angle and P2 force levels

Shape matters!
Take a system approach to design

References:
### Example key activities Capacity4Rail

**Freight vehicle model** – non-linear dry friction Y-series bogies

**Vehicle speed** ($V$) - Non-linear dry friction Y-series bogies

**Crossing geometry**

**Turnout layout**

**Check rail**

<table>
<thead>
<tr>
<th>Switch</th>
<th>Natural</th>
<th>Actual</th>
<th>Lead L2 Toe to nose</th>
<th>Nose across a 1970 interval</th>
<th>Toe to toe</th>
<th>Planing radius</th>
<th>Switch radius</th>
<th>Turnout radius</th>
<th>Length of Planinig P</th>
<th>Length of transition</th>
<th>Length of straight to nose</th>
<th>Turnout Speed /kph</th>
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<tbody>
<tr>
<td>CV</td>
<td>9.25</td>
<td>10.75</td>
<td>25448</td>
<td>5360</td>
<td>56256</td>
<td>287251</td>
<td>245767</td>
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<td>7366</td>
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**Figure:**

- **Crossing 1in~**
- **Lead Lengths**
- **Radii**
- **Length**
- **Turnout Speed /kph**

**Legend:**

- **CV**
- **DV**
- **EV**

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**Diagram:**

- **Crossing 1in~**
- **Lead Lengths**
- **Radii**
- **Length**
- **Turnout Speed /kph**

**Legend:**

- **CV**
- **DV**
- **EV**

**Notation:**

- **ip of natural angle**
- **length of straight to nose**
- **length of transition**
- **length of planing P**
- **lead l2 toe to nose**
- **nose to nose across a 1970 interval**
- **nose to toe**
- **planing radius**
- **switch radius**
- **turnout radius**
- **length of planing P**
- **length of transition**
- **length of straight to nose**
- **turnout speed /kph**
Contact condition and patch shapes

Distance = 30.532m, time = 1.21s, v = 40km/h

freight_P10_benchCEN56V_9-25_20151001.webm
Crossing geometry design and input to simulation

Matlab pre-processed geometry ready for 3D interpolation
Example design geometry evaluation

UK CEN56 vertical HC vs FC

Simulated wheel vertical motion through crossings
Example design geometry evaluation

UK CEN56 vertical HC vs FC

Simulated vertical vertical contact force

Travel Direction

HC

FC
Example design geometry evaluation

UK CEN56 vertical HC vs FC

Predicted surface damage (crack initiation and wear)
Key conflicting requirements

• Engineering design vs cost
  – Highly engineered material specification (at what cost?)
  – Resilient track construction (at what cost)?
  – Standardisation versus customisation?

• Through vs diverging route
  – Traffic mix consideration in design vs generic design!
  – Trade-off in rail shapes and layout geometry optimisation
  – Acute vs Obtuse

• Facing vs trailing move
  – Trade-off in rail shape and layout geometry optimisation

• Wear vs RCF
  – Competing phenomena
Validation Challenges

• Validation of rail damage prediction
  – Based on specific site observation + stochastic data collection
  – Fast and reliable data collection (vehicle inspection vehicles?)

• Material characterisation data and experiments
  – Twin disc rigs for:
    • Wide range of traction and normal pressure
    • Full scale where possible…
    • Replicating S&C ‘harsh’ conditions (high curvature)
    • Replicating S&C materials (cast Mn, EDH, hardened steel e.g. 350HT)
  – Plastic deformation
  – Residual strains in highly stressed contained material

• Full scale testing for close to reality WRI conditions…
Validation Challenges

Centre for Innovation in Rail, University of Huddersfield
Few words of conclusion

• Key damage mechanisms in S&C relate to wheel-rail interface => **heavily strained interface!**
• Key areas of collaborative research in EU are *geometry/shape optimisation* and *improved support stiffness* (upgrade to ballasted & novel track forms)
• Available simulation techniques enable *predicting key damages* (location, intensity and accumulation) and qualitative assessment of different designs
• exchange of *data* and *testing resources* is key to validation as a first step towards innovation selection and evaluation in track
• This is a *system* - consider both sides of the interface!
Thank you for your attention.

Contact: Yann Bezin (y.bezin@hud.ac.uk)

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Software used: Vi-Rail (www.vi-grade.com) and ArgeCare (argecare.com)