Monitoring of switches & crossings (turnouts) and tracks

Elias Kassa, Amund Skavhaug
Norwegian University of Science and Technology
Amir M. Kaynia
NGI
Outline

• Background
• Analysis of turnout failure statistics
• Location of hotspots using GPR
• Monitoring of switches & crossings
• Field testing
• Future development
• Summary
BACKGROUND
## Turnout populations

<table>
<thead>
<tr>
<th>Countries</th>
<th>Track (km)</th>
<th>S&amp;C population</th>
<th>S&amp;C units per track kilometre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>6,500</td>
<td>12,200</td>
<td>1.88</td>
</tr>
<tr>
<td>Italy</td>
<td>27,100</td>
<td>42,700</td>
<td>1.58</td>
</tr>
<tr>
<td>Netherlands</td>
<td>6,500</td>
<td>7,800</td>
<td>1.20</td>
</tr>
<tr>
<td>UK</td>
<td>31,100</td>
<td>25,800</td>
<td>0.83</td>
</tr>
<tr>
<td>Sweden</td>
<td>14,900</td>
<td>12,000</td>
<td>0.81</td>
</tr>
<tr>
<td>France</td>
<td>65,100</td>
<td>25,600</td>
<td>0.40</td>
</tr>
</tbody>
</table>

- Belgium – 1.88 units/km
- Sweden – 0.81 units/km < 5% of infrastructure
- France – 0.40 units/km
- In Sweden over 12% of track maintenance and 25% of track renewals are spent on S&Cs

- Network Rail is using about 17% of the track maintenance budget and ca. 25% of the track renewal budget in Switches and Crossings
- In addition, cost for disruption and delays in train operation are very high
Failure hierarchy for a turnout unit

Turnout
- To guide the train in the main route
- Primary: to guide the train to diverging route
  - Line blocked
  - Wheel derailment
  - Speed restriction
    - Rail mechanical damage
    - Stretcher bar damage
    - Switching rail failure
    - Switch machine failure
    - Sleeper and fastenings failure

Product
  - Function
    - Failure mode
      - Failure cause
        - Failure mechanism
WP1.1 – Turnout failure classification

- Failure may be classified based on failing components

Failure cause/mechanisms in rail failure
- Rolling contact fatigue
- Wear
- Rail head deformation
- Rail head cracks
- Rail web cracks
- Transverse & Longitudinal rail foot cracks

Switch rail breakage

Fracture

Plastic deformation

Wear

RCF on stock rail

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Failure classification by components

- Failure may be classified based on failing components

<table>
<thead>
<tr>
<th>Components</th>
<th>Failure causes/mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail</td>
<td>Wear, rolling contact fatigue, plastic deformation, rail head cracks, rail foot fractures, rail web cracks</td>
</tr>
<tr>
<td>Stretcher bar</td>
<td>Stretcher bar bracket breakage</td>
</tr>
<tr>
<td>Switching machine</td>
<td>Too much or too little power, unable to close the switch rail against the stock rail</td>
</tr>
<tr>
<td>Sliding chair and rollers</td>
<td>Dry slide chair, rusty slide table or fully contaminated lubrication which blocks the movement of switch rail from sliding</td>
</tr>
<tr>
<td>Fastening system</td>
<td>Missing bolts, damaged rail pad, broken base plate</td>
</tr>
<tr>
<td>Sleeper</td>
<td>Rail seat deterioration, flexural cracking at the sleeper centre, and transverse cracking at the fastening bolt</td>
</tr>
</tbody>
</table>
Failure data analysis: failure data from the UK

- Example of failure data analysis based on the failed components

### Failed Components

<table>
<thead>
<tr>
<th>Failed Components</th>
<th>Total Number</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switch rail</td>
<td>1113</td>
<td>45.3</td>
</tr>
<tr>
<td>Slide chair</td>
<td>747</td>
<td>30.4</td>
</tr>
<tr>
<td>Ballast</td>
<td>194</td>
<td>7.9</td>
</tr>
<tr>
<td>Schiweg Roller</td>
<td>138</td>
<td>5.6</td>
</tr>
<tr>
<td>Stretcher bar</td>
<td>111</td>
<td>4.5</td>
</tr>
<tr>
<td>Stock rail</td>
<td>71</td>
<td>2.9</td>
</tr>
<tr>
<td>Crossing</td>
<td>33</td>
<td>1.3</td>
</tr>
<tr>
<td>Fishplate</td>
<td>24</td>
<td>1.0</td>
</tr>
<tr>
<td>Back Drive</td>
<td>18</td>
<td>0.7</td>
</tr>
<tr>
<td>Sleeper</td>
<td>5</td>
<td>0.2</td>
</tr>
<tr>
<td>Spacer Block</td>
<td>4</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>2458</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

**Frequency (%)**

[Bar chart showing frequency of each component]
Failure data analysis, Cont’d

- Data assessment based on possible failure causes (mechanisms)
Failure classification by severity

- Severity level is one way of failure classification method to categorise the criticality of the effects on the function of item or component

<table>
<thead>
<tr>
<th>Severity level</th>
<th>Criticality nature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category I - Catastrophic</td>
<td>A failure which may cause death or total system loss</td>
</tr>
<tr>
<td>Category II - Critical</td>
<td>A failure which may cause severe injury, major property damage, or major system damage</td>
</tr>
<tr>
<td>Category III - Marginal</td>
<td>A failure which may cause minor injury, minor property damage, or minor system damage which will result in delay or loss of availability or speed restriction</td>
</tr>
<tr>
<td>Category IV - Minor</td>
<td>A failure not serious enough to cause injury, property damage, or system damage, but which will result in unscheduled maintenance or repair</td>
</tr>
</tbody>
</table>
# Failure data analysis, Cont’d

- **Data assessment based on rectification**

<table>
<thead>
<tr>
<th>Rectification</th>
<th>Total Number</th>
<th>Frequency %</th>
<th>Failed Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>De-iced</td>
<td>559</td>
<td>22.7</td>
<td>Switch rail, Slide chairs, Schiwag Roller, Back drive, Stretcher bar</td>
</tr>
<tr>
<td>Lubricated</td>
<td>445</td>
<td>18.1</td>
<td>Slide chairs, Schiwag Roller</td>
</tr>
<tr>
<td>Removed obstacle</td>
<td>427</td>
<td>17.4</td>
<td>Switch rail, Slide chairs, Stretcher bar, Back drive</td>
</tr>
<tr>
<td>Replaced/Renewed</td>
<td>243</td>
<td>9.9</td>
<td>Stretcher bar, Slide chairs (broken), Crossing (nose crack), Fish plate, Switch rail, Stock rail, Sleeper, Space block, Ballast</td>
</tr>
<tr>
<td>Lift &amp; Pack</td>
<td>190</td>
<td>7.7</td>
<td>Ballast</td>
</tr>
<tr>
<td>Grind</td>
<td>167</td>
<td>6.8</td>
<td>Switch rail, Stock rail, Rail weld</td>
</tr>
<tr>
<td>Adjusted</td>
<td>143</td>
<td>5.8</td>
<td>Schiwag Roller, Switch rail, Stretcher bar, Back drive, Slide chairs, Ballast</td>
</tr>
<tr>
<td>Cleaned</td>
<td>136</td>
<td>5.5</td>
<td>Slide chairs, Switch rail, Schiwag Roller</td>
</tr>
<tr>
<td>Weld repair</td>
<td>71</td>
<td>2.9</td>
<td>Switch rail, Stock rail, Crossing</td>
</tr>
<tr>
<td>Tightened</td>
<td>70</td>
<td>2.9</td>
<td>Slide chairs, Stretcher bar (nuts), Back drive, Fish plate</td>
</tr>
<tr>
<td>Gauged</td>
<td>7</td>
<td>0.3</td>
<td>Track gauge</td>
</tr>
</tbody>
</table>

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LOCATION OF HOTSPOTS
WP1.2 – Location of Hotspots
Ballast monitoring using GPR

- This is part of the WP1 – FIND: to identify locations of hotspots on the ballast structure
- To map the ballast with Ground Penetrating Radar

Notice changes in:
- Aggregate size
- Layer thickness
- Depth to rock
- Water distribution in ballast
- Determining degree of ballast fouling
- Locating hidden objects/utilities
- Detecting ballast anomalies
Water infiltration monitoring

Water infiltration monitored with GPR (3d-Radar antenna type)

Water is spread in on the ballast in great quantities
GPR measurements
MONITORING OF SWITCHES, CROSSINGS
WP1.3 – Monitoring of switches, crossings and tracks

• This study addresses use of smart sensor technology for health monitoring of turnouts to determine the real-time condition of the infrastructure

• A key part of this work is to find and identify risks in railway track and S&C assets before they fail

• The objectives will be achieved through a combination of numerical simulation and remote monitoring of rail vibrations
Approach

• Detection of Acceleration Sensitive Areas of a Rail Using Dynamic Analysis
• Development of wireless sensor for monitoring of switches, crossings and track
Dynamic Analysis

MBS code Gensys

Wheel-rail forces
Contact points

Loading platform

FE tool ABAQUS

wheel-rail contact force and contact location

Rigid Body

Load Platform

accelerations at rail head, rail web and rail foot

Test Point in rail

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Rail sampling points

Along the track

Cross section

Across the rail

The rail acceleration time-history

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System Architecture

Sensor infrastructure for remote monitoring

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Key demands

Some of the key demands of the remote monitoring:

– a system which is cheap, reliable and easy-to-install
– system should provide real-time information and continuous monitoring
– should be inbuilt and allow high integration into the already existing infrastructure
– should be low battery-powered and wireless
Wireless sensor hardware

- Digital accelerometer
  - continuously monitor vibrations on train passage
  - wake-up on threshold
  - sampling on 3200 Hz
  - capable to measure on 3-axis
  - sensing range ±0.5, 1, 2, 4g
  - sensitivity resolution 1024LSB/g

- Power supply
  - Nanopower Buck-Boost
  - High efficient up to 90%

- Temperature sensor
  - ±0.5°C maximum accuracy
Requested structure

Rail casings

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Gateway

- Future type – GSM-R
- Current types - GSM, WIFI, Ethernet
- Responsibility of GW
  - Starting communication
  - Datalog server

RF Power
Old GW 12.5 mW in 360°
New GW 500 mW in 36°
Webserver

- DB with all data
- Post-processing
- Showing the vibration graphs/nod/event
- Showing the power consumption graph/nod
- Showing the temperature graph/nod
- Command page (easily to reprogram nods)
- Links to download RAW data
Tests (Lab and Field)
FIELD TESTING
Field testing at Tommerup, Denmark
Can it be wireless??
Field testing at Tommerup, Denmark

Sensors at the switch heel

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Sensors on the sleeper and on the rail web
Trains passing over the sensors
Installation and testing
System test in Munich, Germany with new and old casings

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Accelerations at the sleeper: Reference and DestinationRail sensor

Vertical, longitudinal and lateral accelerations

**Vertical acceleration of the reference sensor**
Validation – Comparison of sleeper acceleration with reference sensor

[Graphs showing comparison of sleeper acceleration with reference sensor]
Comparison - rail web acceleration

[Graph 1: DESTinationRAIL sensor vs reference sensor]

[Graph 2: DESTinationRAIL sensor vs reference sensor]

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Preliminary data assessment healthy and faulty train passage
Future development

• **Data processing and trend recognition** (is the turnout healthy?)

• Software updates (leading to lower consumption)
  – Increase RF transfer rates 19,2kbps -> 150 - 400kbps
  – Optimizing data handling (buffers)
  – Data compression & encryption (Sensor-Gateway)

• Hardware updates
  – Sensor - optimizations for lower costs & consumptions, enhance functionality
  – Sensor - investigate possibility of battery-less modules
  – Gateway - GSM-R version

• Advanced websites & data storage
  – graphs, possibility to change settings, GPS coordinates & maps, user roles
  – Smartphone app for creating sensor infrastructure in field
Summary

- Failure risk in turnouts has been assessed based on occurrence of failures.
- Two failure mechanisms are identified to critically affect the turnout primary operation: switch obstruction and dry chair.
- Such kind of failure risk evaluation may support health monitoring of turnouts.
- The field testing revealed possibilities and drawbacks of the 4g accelerometer.
Summary, cont’d

• Good matching of the output characteristics for sleeper acceleration with the reference sensors
• The sensor has less precise clock and need to be looked
• The sensor is being developed with increased acceleration magnitude and more sensors will be deployed at once
  – Sensor - optimizations for lower costs & consumptions, enhance functionality
  – Sensor - investigate possibility of battery-less modules
  – Gateway - GSM-R version