Comparison of Options for Dynamic Response Analysis of Axle Bearings

Tribo-sensing and Condition Monitoring - The Journey to Net Zero

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Phil Shackleton & Adam Bevan – Institute of Railway Research, University of Huddersfield
Pete Gowan – Rail Safety and Standards Board
Contents

• Background
• Review of DRA monitoring systems
• Potential benefits and use case definition
• Cost benefit analysis and results
• Conclusions
• Bearings are typically inspected, overhauled or replaced at pre-defined intervals
  o However, unexpected in-service failures can occur due to several mechanisms, such as fatigue, lack of lubrication, contamination, incorrect handling/fitting or overloading......

• Monitoring of axle bearings can support the early detection of bearing defects
  o Reducing the incidence of unexpected failures and support the extension of intervals for routine overhaul and inspection activities

• Existing monitoring technology typically offers two distinct approaches: Track-side or On-vehicle systems
  o Each approach has different strengths, weaknesses, deployment considerations, implementation costs and potential benefits

• Further research required to review the available condition monitoring technologies and quantify the potential benefits and costs
Review of DRA monitoring systems

- Commercially available Track-side and On-vehicle monitoring systems can provide actionable information relating to the condition of freight vehicle axle bearings
  - However, On-vehicle systems must be self-powered and feature wireless communications, as such connectivity is not currently available on the vehicle
- Track-side systems tend to use acoustic measurements, while On-vehicle systems tend to use vibration measurements
- On-vehicle systems are installed close to the bearing allowing frequent monitoring with high signal-to-noise ratio data
  - Frequency of measurements for a track-side system related to how often the vehicle passes a monitoring station
- DRA is insensitive to lubrication failure, which can lead to rapid bearing degradation
  - Thermal monitoring (as currently provided via Hot Axle Box Detectors) is more suitable
  - Thermal monitoring can be incorporated into DRA systems; however, On-vehicle systems not capable of safety-critical real-time alarms (as required to protect from rapid bearing degradation as provided by HABDs)
Potential benefits and use case definition

Safety benefits:
• Catastrophic bearing failure can lead to derailment
  o HABDs are effective at mitigating catastrophic bearing failures, however a small number of catastrophic failures do occur which could be reduced

Maintenance benefits:
• Diagnose potential failures earlier than the existing inspection processes
  o Allowing corrective action to be taken earlier - improved scheduling and planning
• Extension of intervals for routine bearing overhaul and inspection
  o Reduced risk of introducing bearing problems from maintenance interventions
• Improved identification of actual bearing that has failed
• Potential detection of other wheelset-related defects and aligning of maintenance intervals can also result in significant cost savings

Operational benefits:
• Reduction in disruption from HABD false alarms (no fault found) and subsequent actions
• Reduce the occurrence of positive HABD alerts, with the fault detected and repaired before it would have been detected by HABD
Definition of use cases

1. ‘Do-minimal’ – existing use of HABD alerts and bearing maintenance policies, but progression based on current industry direction

2. ‘Track-side’ - a number of track-side systems are deployed over several years across the GB rail network, aiming to cover 80% of freight traffic

3. ‘On-vehicle’ - freight vehicles are fitted with wireless, self-powered axlebox mounted sensors. Rollout is gradual, initially retrofitting existing vehicles then fitting new stock at the time of manufacture

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Variant</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do Minimum</td>
<td>Core</td>
<td>Base line scenario</td>
</tr>
<tr>
<td>Track-side</td>
<td>Core</td>
<td>Core Track-side DRA scenario with nominal parameters</td>
</tr>
<tr>
<td></td>
<td>Monitoring System (MS1)</td>
<td>Track-side core with reduced monitoring system hardware renewal costs</td>
</tr>
<tr>
<td></td>
<td>External benefit (US1)</td>
<td>Track-side core with added up-side benefits from passenger vehicle bearing maintenance</td>
</tr>
<tr>
<td>On-vehicle</td>
<td>Core</td>
<td>Core On-vehicle DRA scenario with nominal parameters</td>
</tr>
<tr>
<td></td>
<td>Monitoring System (MS1)</td>
<td>On-vehicle core with monitoring system hardware cost reductions representing volume price breaks and periodic technological improvements</td>
</tr>
<tr>
<td></td>
<td>Monitoring System (MS2)</td>
<td>On-vehicle Monitoring System (MS1) with reduction in sensor volume from one sensor per axle to one sensor per axle</td>
</tr>
</tbody>
</table>
Identify the potential impact and benefits from introducing DRA bearing monitoring system in the areas of:
- Safety
- Operations
- Maintenance (infrastructure and freight maintainers)

Quantify the costs associated with these impacts/benefits and differences between adopting Track-side or On-vehicle systems

Process follows the DfT TAG guidelines
- Cost determined as accurately as possible and associated uncertainty estimated (spread of costs in each area)

Costs are totalled for each scenario over 40-years
- Calculation of cumulative benefit versus cost ratios (BCR)
- Costs presented in relation to key stakeholders and beneficiaries
Key assumptions

- Level of safety provided will not be less than current situation
- Current costs as is, based on available data and established strategies
- Replacement of life expired HABDs and new HABDs expected to have improved performance
- Monitoring systems are gradually rolled out up to the envisaged maximum required for 100% cover
- Routine maintenance costs gradually reduce to 50%, reflecting the potential doubling of bearing life based on user experience
  - No action happens in year one from DRA outputs – still looking at data, digesting and planning
- Frequent measurements and identification of pending failures reduces effects of HABD detected failures
Current cost landscape

Routine bearing inspection and replacement costs make up a large proportion of current costs (>60%)
Cost of an undetected bearing failures leading to a derailment are also significant (>30%)
### CBA results – Track-side BCR

<table>
<thead>
<tr>
<th>Scenario</th>
<th>BCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track-side (-)</td>
<td>0.954</td>
</tr>
<tr>
<td>Track-side</td>
<td>1.362</td>
</tr>
<tr>
<td>Track-side (+)</td>
<td>1.922</td>
</tr>
<tr>
<td>Track-side MS1 (-)</td>
<td>0.994</td>
</tr>
<tr>
<td>Track-side MS1</td>
<td>1.419</td>
</tr>
<tr>
<td>Track-side MS1 (+)</td>
<td>2.003</td>
</tr>
<tr>
<td>Track-side US1 (-)</td>
<td>1.250</td>
</tr>
<tr>
<td>Track-side US1</td>
<td>1.990</td>
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<tr>
<td>Track-side US1 (+)</td>
<td>3.006</td>
</tr>
</tbody>
</table>

![Graph showing cumulative benefits and costs over years](image-url)
## CBA results – On-vehicle BCR

<table>
<thead>
<tr>
<th>Scenario</th>
<th>BCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-vehicle (-)</td>
<td>0.149</td>
</tr>
<tr>
<td>On-vehicle</td>
<td>0.230</td>
</tr>
<tr>
<td>On-vehicle (+)</td>
<td>0.361</td>
</tr>
<tr>
<td>On-vehicle MS1</td>
<td>0.587</td>
</tr>
<tr>
<td>On-vehicle MS1 (-)</td>
<td>0.868</td>
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<tr>
<td>On-vehicle MS1 (+)</td>
<td>1.283</td>
</tr>
<tr>
<td>On-vehicle MS2</td>
<td>0.880</td>
</tr>
<tr>
<td>On-vehicle MS2 (-)</td>
<td>1.293</td>
</tr>
<tr>
<td>On-vehicle MS2 (+)</td>
<td>1.893</td>
</tr>
</tbody>
</table>

![Graph showing cumulative benefit/cumulative cost over years with different scenarios highlighted.]
CBA results – Observations

• Monitoring system costs were predictably the greatest increase in cost compared to the baseline scenario
  o Costs of On-vehicle sensor deployment was significantly greater than Track-side systems, due to the large number of sensors required for fleet coverage and assumed lifespan of current technology

• Track-side scenario was found to deliver greater value for money
  o Greatest value for money was calculated for variant which included the anticipated benefits to bearing maintenance for the passenger vehicle sector

• Variations of the On-vehicle scenario showed that with technological improvements, to reduce sensor cost and increase longevity, the overall BCR was close to the core Track-side scenario
CBA results – Cumulative net benefits (40-years)

<table>
<thead>
<tr>
<th>Cost owner</th>
<th>Scenario</th>
<th>Total Costs (£M)</th>
<th>Total Benefits (£M)</th>
<th>Net Benefit (£M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight owner/maintainer</td>
<td>Track-side</td>
<td>25.6</td>
<td>47.1</td>
<td>21.4</td>
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<tr>
<td></td>
<td>On-vehicle</td>
<td>65.2</td>
<td>39.6</td>
<td>-25.7</td>
</tr>
<tr>
<td>Infrastructure manager</td>
<td>Track-side</td>
<td>25.5</td>
<td>13.1</td>
<td>-12.4</td>
</tr>
<tr>
<td></td>
<td>On-vehicle</td>
<td>0.0</td>
<td>8.4</td>
<td>8.4</td>
</tr>
<tr>
<td>Society</td>
<td>Track-side</td>
<td>0.0</td>
<td>9.5</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td>On-vehicle</td>
<td>0.0</td>
<td>8.6</td>
<td>8.6</td>
</tr>
<tr>
<td>Passenger owner/maintainer</td>
<td>Track-side</td>
<td>0.0</td>
<td>32.2</td>
<td>32.2</td>
</tr>
<tr>
<td></td>
<td>On-vehicle</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

- Freight owner/maintainer realises a significant total benefit
  - Due to extension of routine bearing overhaul and inspection intervals and reduction in bearing replacement

- Track-side scenario results in a net benefit to freight, while On-vehicle case leads to a net deficit
  - Due to additional costs associated with the monitoring system

- Both scenarios provide a total benefit for infrastructure manager due to a reduction in undetected bearing failures
  - Track-side scenario results in a deficit due to monitoring system cost

- Differences between the On-vehicle and Track-side scenarios is a result of the slower rate of fleet coverage for the On-vehicle monitoring systems

- Additional benefit for the passenger vehicle is only realised in the Track-side scenario
Conclusion

• CBA indicates that Track-side DRA monitoring system is highly likely to deliver greater benefit than an equivalent On-vehicle system for the monitoring of freight vehicle axle bearings

• Defects can be detected while they pose no significant risk to safety by taking intermittent measurements over a long period of time, providing maintenance and operational savings

• Track-side monitoring capability can also be exploited by the passenger vehicle maintenance sector

• Disparity in the costs incurred by the infrastructure Manager and benefits realised by Vehicle Owners/Maintainers could be redressed through track access charging, or similar mechanisms

• Implementation areas for future consideration include:
  o Data flow to end users (e.g., data as a service)
  o Hybrid implementation (e.g., Track-side and On-vehicle) and future transitions
  o Next generation ‘smart’ wagons (e.g. adoption of digital automatic coupling)
Questions?
Q&A slides
CBA cost breakdown – 1
CBA cost breakdown – 2