Institution: University of Huddersfield

Unit of Assessment: UoA12 (Engineering)

Title of case study: Understanding Rail Freight Vehicle Performance to Reduce the Likelihood of Derailment

Period when the underpinning research was undertaken: 2012–2019

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Dr Phil Shackleton	Principal Enterprise Fellow	2012–Present
Simon Iwnicki	Director	2012–Present
Paul Allen	Associate Director	2012–Present
Yann Bezin	Head of Research	2012–Present
Paul Molyneux-Berry	Principal Research Fellow	2012–2018
David Crosbee	Principal Enterprise Fellow	2012–Present
Aniruddha Kaushal	Research Assistant	2013-2016

Period when the claimed impact occurred: 2017–2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

The outputs of this University of Huddersfield research have enabled the UK rail freight industry to reduce the derailment risk for freight wagons by up to 50% via the provision of new metrics. The metrics utilised existing railway sensor infrastructure and were relevant for more than 90% of the wagons in the UK.

The research informed industry action to assuage safety concerns raised by the regulator, which was then able to remove “risk of freight derailment” from its critical issue list. Findings were included in a national standard to prevent future risk from new vehicle designs.

A new derailment risk for was identified for repurposed wagons. Otherwise redundant coal wagons are now to be modified to carry aggregates, with improved safety, savings of up to £175m over replacement rolling stock and greater network utilisation. Beneficiaries include freight operating companies (such as Freightliner), the Rail Safety and Standards Board (RSSB) and Network Rail.

2. Underpinning research

The loading of a rail freight vehicle invariably leads to a degree of imbalance. This can result in increased derailment risk, and in recent years has been identified as a causal or contributory factor in a number of derailments. The imbalance is a consequence of factors such as unevenly loaded or distributed shipping containers, loading practices for bulk products, or uneven unloading, such as discharging ballast from one side of a maintenance wagon. The number of derailment incidents, combined with the risk of future imbalance-driven derailments, caused the Office of Rail and Road (ORR) to take regulatory action and call for an industry-wide response to address the issue in 2014 **[5.1]**. The research described in this case study was key to enabling the industry response.

The work described below was carried out by the Institute of Railway Research (IRR) at the University of Huddersfield (UoH). It was led by Dr Phil Shackleton (Principal Enterprise Fellow at UoH since 2012), who worked with Simon Iwnicki (Director since 2012), Paul Allen (Associate Director since 2012), Yann Bezin (Head of Research since 2012), Paul Molyneux-Berry (Principal Research Fellow, 2012 to 2018), David Crosbee (Principal Enterprise Fellow since 2012) and Aniruddha Kaushal (Research Assistant, 2013 to 2016). The impact was underpinned

by the contribution of UoH to three collaborative European Union research projects, SUSTRAIL **[3.1, 3.2]**, Spectrum **[3.3]** and D-Rail **[3.4]**. In these projects, the IRR team investigated the performance of a range of freight vehicle suspension systems. Their research modelled different suspension mechanisms and simulated freight vehicle–track interactions. It focused on:

- Incremental improvements of conventional running gear (wheel, bogie, suspension and brake combinations) to permit higher speed freight (2013–15) **[3.1, 3.2]**
- The development of novel running gear concepts to exploit opportunities in the shipment of low density, high value goods (not carried by rail at the time) (2016) **[3.3]**
- The most significant factors contributing to the likelihood of derailment and the derailment resistance of freight vehicles when exposed to those factors (2013) **[3.4]**

The research outputs were used to develop an improved understanding of freight suspension behaviour and the factors that influence it, and to develop a modelling methodology to investigate and quantify variation in risk performance.

Multiple research projects were undertaken for the Rail Safety and Standards Board (RSSB) (2017–19). These created a holistic approach to managing the risk posed by derailment mechanisms caused by the "imbalanced loading" of freight wagons **[3.5, 3.6]**, across a system with multiple duty-holders. The methodology described above was implemented to study examples representative of the most common wagon types in the GB fleet, covering well over 90% of those in use, and ran 6,000 use cases to maximise its relevance and utility.

The outcomes from the research can be summarised as follows:
[a] An in-depth understanding of how imbalanced loading affects derailment resistance. This redefined operational limits for imbalanced loading. Previously, imbalances in the longitudinal and lateral directions were considered in isolation, while the revised limit more accurately accounts for the combined influence of longitudinal and lateral imbalances. This provided the justification for more optimal controls, with greater operational flexibility where possible, and more stringent limits where necessary.
[b] A metric was developed that replaced the traditional pass/fail limit with an analogue quantification of the derailment risk posed by a given vehicle imbalance. This enabled the identification of the most "at-risk" wagons on the network and for the efficacy of the industry's risk mitigations to be quantified and trended over time.
[c] Fundamental relationships between derailment metrics were proven. This gave confidence in using convenient proxies, such as established laboratory tests to assess derailment risk, as opposed to more direct but complex methods, such as on-track tests.
[d] Some freight vehicle types were found to have a low tolerance to imbalanced loading. This meant they could pose an increased risk if "re-purposed" for a load, other than that for which they were originally intended. For example, a coal wagon partially filled with an equal (maximum) weight of aggregate can generate significant imbalance, whereas the same wagon filled to the top with coal cannot.

3. References to the research

The following outputs provide reference to the body of research and are predominantly 2* or higher, being either peer-reviewed journal articles, high-quality peer-reviewed conference papers or high-quality technical reports endorsed by industry. Authors at the University of Huddersfield at the time of publication are highlighted in bold.

[3.1] S.D. Iwnicki, S. Stichel, A. Orlova & M. Hecht (2015) Dynamics of railway freight vehicles, Vehicle System Dynamics, 53:7, 995–1033, https://doi.org/10.1080/00423114.2015.1037773
[3.2] S.D. Iwnicki, **Y. Bezin**, A. Orlova, P-A. Johnsson, S. Stichel, H. Schelle (2013) The 'SUSTRAIL' high speed freight vehicle: Simulation of novel running gear design, 23rd Symposium of the International Association for Vehicle System Dynamics (IAVSD 2013): Qingdao, China [can be supplied on request]
[3.3] P. Shackleton, **Y. Bezin**, **D. Crosbee**, **P. Molyneux-Berry**, & **A. Kaushal** (2016) Development of a new running gear for the Spectrum intermodal vehicle, 24th Symposium of

the International Association for Vehicle System Dynamics, IAVSD 2015 (pp. 1461–1470). CRC Press/Balkema. https://doi.org/10.1201/b21185-153 [can be supplied on request]

[3.4] P. Allen, **P. Shackleton**, **D. Crosbee** (2013) Influence of vehicle parameters on derailment In D-RAIL D3.2 - Analysis and mitigation of derailment, assessment and commercial impact (pp. 19–72), D-RAIL Consortium, http://d-rail-project.eu/IMG/pdf/DR-D32-F3-Analysis_mitigation_derailment-assessment_commercial_impact.pdf

[3.5] P. Shackleton (2018) Simulating Offset Loading of Container Wagons on Twisted Track (Report), RSSB, https://www.sparkrail.org/Lists/Records/DispForm.aspx?ID=25630 [can be supplied on request]

[3.6] P. Shackleton (2019) Imbalanced loading of bulk wagons (Report), RSSB/University of Huddersfield Strategic Partnership, IRR/110/192/iss2 https://www.sparkrail.org/Lists/Records/DispForm.aspx?ID=26257 [can be supplied on request]

4. Details of the impact

Additional cross references **[a, b, etc.]** refer to the relevant outcomes in Section 2.

The impact presented in this case study contributed to an improved understanding of the derailment risk posed by imbalanced wagons by the rail industry, and led to a consequent improvement in risk management. The key beneficiary groups were freight operating companies, Her Majesty's Inspector of Railways and the Rail Safety and Standards Board.

The impact can be divided into four subheadings:

1. Enabling industry response to a critical issue
2. Reduction in derailment risk
3. Commercial benefits
4. Contribution to standards

Enabling Industry Response to a Critical Issue

In 2014 the Office of Rail and Road (ORR) took regulatory action and called for an industry-wide response **[5.1]** to address the issue of freight derailments, which reached an all-time high of 14 that year. A cross-industry group was created, which commissioned research **[3.5, 3.6]** described in this case study and then applied the findings.

Collectively, the research findings **[3.5, 3.6]** were critical in helping industry provide a satisfactory response, by informing and justifying stakeholder mitigations. Such mitigations included re-orientating imbalanced containers to minimise vehicle imbalance when loaded **[5.3]**, or providing targets so loading operators of bulk products knew where to "aim" the load, such as a painted line down the middle of a flat wagon or ensuring the peak of loaded aggregate "does not exceed 250mm from the [wagon] midline" **[5.9]**. As a result of risk-mitigation processes introduced across the industry, the incidence of freight imbalances dropped dramatically, with "monthly longitudinal imbalances reducing from 70 to 3 events" (2018–20) **[5.4]**. As a result, in May 2020 ORR removed freight derailments from their top five concerns **[5.8]**. The ORR confirmed the significance of the changes: "Phil Shackleton's work [..] provided [..] the incontrovertible evidence, a measurement system and thresholds to allow the freight industry to act on this matter", and "This has had a great positive impact. It has led to a change [in] the way in which the industry addresses this concern and has facilitated a step-change in the industry's attitude to derailment risk", adding "It has been an exemplar of how academia can work hand in hand with industry stakeholders to solve a complex problem" HM Chief Inspector of Railways, ORR **[5.6].**

Reduction in Derailment Risk

Derailment risk from imbalanced loading was reduced by up to 50% **[5.2, 5.3]** as the industry applied the relationship between imbalance and derailment risk **[a]** identified by the research **[3.5, 3.6]**. Freight operating companies have been able to make informed changes to their operating policies and procedures and thus substantially reduce derailment risk from imbalance,

as industry representatives testify: “For Freightliner, we believe this has allowed us to take action to reduce the risk of derailment by between 30-50%, and managing this risk using the outputs and tools of Phil Shackleton’s work is now in our DNA” Professional Head of Traction & Rolling Stock Engineering, Freightliner **[5.2]** (2020).

“The industry’s approach to freight loading has transformed as a direct result of the work that Phil’s team did to formally identify and for the first time quantify the relationship between derailment risk and combined lateral and longitudinal load imbalances for rail freight wagons, and enabled a derailment risk reduction of 49%, despite a traffic uplift of at least 25% since 2018” Chair, Cross Industry Freight Derailment Prevention Group **[5.3].**

The research utilised existing, in-situ sensor and data acquisition technology to quantify the risk factor from offset loads for any freight wagon, train or wagon contents **[5.4]** using UoH metrics **[3.5, 3.6]** to quantify acceptable levels **[b]**. The data generated by this approach has enabled freight operators to monitor the ongoing effects of the resulting risk-mitigation strategies, using regular reports from Network Rail that quantify the risk of derailment and how it has trended over time **[5.4]**. Although the risk cannot be completely eliminated, recorded instances of excessive imbalance have reduced by 95% since 2018, when records were first made available to the industry **[5.3, 5.4].** The historic average cost of a derailment was estimated at over £800k and the justified annual safety spend for the industry was £1m per year. There is an expectation from the regulator that, following the mitigations enabled by the IRR research and undertaken by the industry, these costs will have fallen, but at this time a new calculation has not been made. A Senior Engineer at Network Rail indicated that:

“Without the work that Phil Shackleton at the University of Huddersfield did to confirm the link between longitudinal and transverse offset loads and derailment risk, it is highly likely that freight operators would still lack the information they needed to confirm the need for change” **[5.4]**.

Commercial Benefits

The research also led to the prevention of a new derailment risk. It was planned to repurpose redundant coal wagons to carry denser aggregates. The research identified that the wagon type was sensitive to imbalanced loading, which would not normally be possible when fully loaded ‘to the top’ with coal. However, more dense aggregates, which would not fill the wagon volume, could potentially introduce significant imbalance **[d]**. The research indicated that shortening the wagons to reduce the load volume to match the new payload density **[3.6]** would avoid the need to scrap them. The modification minimised the imbalance and hence, the derailment risk. The shorter wagons also meant there could be more wagons in a train, bringing increased operational efficiency **[5.3]** (as freight trains are length limited in the UK). The Cross-Industry Freight Derailment Prevention Group (XIFDPG) commented on activity since 2018:

“Put simply, this has […] saved costs and extended asset life - by finding a use for approximately 2500 redundant coal wagons (the market for coal has collapsed). It costs up to £50k to repurpose each of these coal wagons and this avoids having to buy a new aggregates wagon at £120k. If the whole fleet ends up getting repurposed, this alone will have saved the industry nearly £175m. This process has started, with 500 already complete or underway to my knowledge” **[5.3]**. To date the industry has expended £25m on the 500 wagons, producing assets worth £60m at a net saving of £35m.

The research findings were exploited in a number of commercial projects for freight operators including GB Railfreight, Freightliner, VTG, Network Rail, DRS and DB Cargo, as a result of their membership of the XIFDPG **[5.7]**. The projects **[3.5, 3.6]** allowed the operators to better understand the imbalances from specific payloads and then develop strategies and operational rules to reduce imbalance-driven derailment risk **[5.2, 5.3]**. The letter from XIFDPG confirms: “[The] model has proven equally effective in both container and bulk wagon loading and has provided the owners of the UK’s freight wagons with the confidence to make financial decisions about their rolling stock…” **[5.3]**. Where imbalance could not be avoided, one operator “re-

allocated a fleet of aggregate wagons… to a problematic flow based on their superior predicted tolerance to imbalanced loads, using Phil's model" **[5.3]**.

Contribution to Industry Standards and Best Practice
The imbalance limit **[a] [3.5]** was used to define new acceptance test conditions in the relevant national standard (GMRT2141 i4 **[5.5]**) owned by the Rail Safety and Standards Board (RSSB); instead of measuring only the Tare (unloaded) and fully loaded behaviour of the vehicles, a number of representative use cases must now be considered. This ensures that new vehicle designs do not introduce greater risk to the network.

"Phil Shackleton's quantification of the problem was vital to us being able to publish effective guidance for designing wagon suspension to handle the impact of offset loads and to minimise the likelihood of derailment" Director of Standards, RSSB (2020) **[5.5]**.

The National Freight Safety Group produced a new Code of Practice (CoP), which is now used as a reference point for its 11 members **[5.9] [3.6]** and is freely available to download for wider use. A General Manager at Aggregate Industries wrote: "The guidelines in these sections were informed by the findings [..] and provide operators with practical rules which may be applied on a daily basis as part of ongoing, industry wide, management of derailment risk". He continued, "This work has addressed risk areas which had not previously been clearly qualified and practices to mitigate them had not been identified" **[5.10]** (2020).

The CoP also led to a change in practice across the industry. The same General Manager said: "Further to the publication of the CoP a number of toolbox (local training) talks were produced by Aggregate Industries to support the communication of those key practices to relevant operators. These [were] made available within RSSB's SPARK [cross-industry system]". The CoP and toolbox talks were shared with 90%+ of the construction materials sector and "widely communicated" to relevant staff. He concluded, "As a consequence of the CoP, and supporting research, day to day loading practices are better informed, and the derailment risks from imbalanced bulk wagons has been reduced" **[5.10]**.

5. Sources to corroborate the impact

[5.1] Health and safety regulatory action following recent freight derailments. Letter from HM Chief Inspector of Railways, ORR to rail freight stakeholders, Evidence of Need. http://hud.ac/ict
[5.2] Risk reduction, industry change of behaviour. *Source*: Professional Head of T&RS Engineering, Freightliner, Letter of Support
[5.3] Derailment risk reduction and repurposing wagons. *Source*: Chair XIFDWG, Letter of Support
[5.4] Using UoH research to measure offset freight loads Gotcha reports and trending. *Source*: Senior Engineer ME, Network Rail, Letter of Support
[5.5] Importance of the research in enabling effective guidance on wagon loading *Source:* Director of Standards, RSSB
[5.6] Importance of research on enabling industry response to ORR. *Source*: HM Chief Inspector of Railways, ORR, Letter of Support
[5.7] Membership of the XIFDPG http://hud.ac/h9e
[5.8] Derailment Project – Movement to Business as Usual Report, National Freight Safety Group (NFSG), May 2020 http://hud.ac/h9d
[5.9] National Rail Safety Group – Code of Practice. Huddersfield is mentioned on pp.15/16 http://hud.acv/h9c
[5.10] Aggregate Industries – Evidence of changes in industry practice. *Source:* General Manager, Aggregate Industries