Institution: University of Huddersfield

Unit of Assessment: 12 (Engineering)

Title of case study: Optimization of Railway Wheel Profile Design and Maintenance

Period when the underpinning research was undertaken: 2013–2020

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:
Adam Bevan	Professor, Head of Enterprise	2012–Present
Paul Allen	Professor, Associate Director	2012–Present
Julian Stow	Associate Director	2012–Present
David Crosbee	Principal Enterprise Fellow	2012–Present
Paul Molyneux-Berry	Principal Enterprise Fellow	2012–2018
Yousif Muhamedsalih	Research Fellow	2012–Present
Antonio Antrado	Research Fellow	2012–2016

Period when the claimed impact occurred: 2013–2020

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

1. Summary of the impact

The interface between the wheel and rail is critical for train operation, and maintenance of wheels and track is one of the largest areas of cost in the rail sector. A significant challenge is transitioning between tram and heavy rail networks. Standard wheel profiles can cause damage and increase the vehicle derailment risk. The tram-train wheel profile developed through this research has been instrumental in the opening of the award-winning tram-train route in Sheffield, with more than ten other transport authorities planning similar services.

Research into the optimization of wheelset maintenance resulted in significant revisions to national standards and guidance to operators and generated operational and cost benefits. The tools and techniques developed were trialled by Alstom, the French rolling stock manufacturer, increasing wheelset maintenance (re-profiling) intervals by up to 43%. A number of the tools have been incorporated into commercial systems, such as the Alstom ‘Trainscanner’ and MRX Technologies’ ‘Surface Crack Measurement’ device.

2. Underpinning research

The shape of the cross-section of a railway wheel can significantly influence the dynamic performance of the wheelset (consisting of the axle and the wheels), as well as the physical properties such as contract stress, creep forces and wear. An incompatible wheel-rail profile combination can be the source of problems such as high rates of wear, cracking of the wheel-rail surface through excessive cyclic stresses (known as rolling contact fatigue (RCF)) and wheelset instability. These problems can result in reduced wheel-rail life, increased maintenance costs and, in some cases, increased derailment risk. Rail vehicle wheelsets are regularly maintained to ensure their safe operation and prolong their life. This is achieved through measurements to inspect roundness, profile shape and surface damage. If necessary, wheels are re-profiled on a lathe to preserve the optimal wheel profile shape and remove any surface damage.

The research described below was undertaken at the Institute of Railway Research (IRR) based at the University of Huddersfield (UoH). It was led by Adam Bevan (Professor, at IRR since 2012). Other members of the team, who all joined IRR in 2012 and are still there, except where indicated, were Julian Stow (Assistant Director), Principal Research Fellows David Crosbee and

Paul Molyneux-Berry (left 2018), and Research Fellows Yousif Muhamedsalih and Antonio Antrado (left 2016).

The research included the development of wheel damage models using a combination of detailed vehicle dynamic simulations and bespoke computer models. These models were then applied to the development and assessment of new wheel profiles and the design of wheelset maintenance optimization activities, with the aim of extending wheel-rail life and reducing whole-life costs.

Development of Wheel Damage Models

Research carried out by Bevan and Molyneux-Berry has developed and validated computer models to predict the rate of wear and RCF damage on railway wheels. These models were used to improve the understanding of the main wheel damage mechanisms, the rates at which they occur and the optimum maintenance regimes [3.1]. Wheel maintenance and observation data was reviewed from over 90% of all UK passenger vehicle fleets to determine the main drivers for maintenance, identify the frequency of the different wheel damage mechanisms and to provide validation data for the computer models that were developed during the research. These models were subsequently incorporated into the industry-recognized Vehicle-Track Interaction Strategic Model (VTISM) to support whole system cost modelling [3.2].

Design of Optimal Wheel Profiles

A common and serious cause of wheel-rail deterioration is RCF damage, which if left unattended can result in premature fracture of the surface material with catastrophic consequences, as observed during the Hatfield train crash in October 2000. To better understand how RCF could be reduced, the computer modelling tools [3.1, 3.2] were used to assess the performance of current and new wheel profiles designed by the researchers. A new 'track friendly' wheel profile shape, designed to reduce the wheel-rail forces that cause RCF damage, was developed and has since been adopted as one of the standardized profiles used in the UK.

A tram-train is a vehicle that operates on two very different railway infrastructures – as a tram on light-rail infrastructure and as a conventional train on heavy-rail infrastructure. The wheel profile needed for safe running on a street and a heavy-rail network are different, which causes a problem for rail vehicles that can transition between the two. Existing wheel designs caused a significant risk of derailment of the vehicle and increase in damage to the track. A combination of vehicle dynamic simulations and bespoke software was used to create a wheel profile design for use on a tram-train vehicle which was optimized to provide safe running and minimized wheel-rail damage. This resulted in a new wheel profile for GB tram-train operations that was successful on both railway infrastructures [3.5].

Optimization of Wheelset Maintenance

Research into wheelset maintenance, undertaken by Bevan, provided a better understanding of the factors that influence the degradation of wheels and the scheduling of maintenance activities. The development of computer models [3.1, 3.2] and wheelset management tools, to calculate and interpret wheel condition, supported the optimization of wheelset maintenance and renewal activities and an examination of the cost benefits [3.2, 3.4]. Techniques and guidance (developed by the researchers and published by the Rail Safety and Standards Board) to help fleet maintainers better understand wheel degradation and solutions to extend life and reduce costs, were also developed. In particular, Stow and Muhamedsalih investigated the use of Economic Tyre Turning (ETT), a technique not previously permitted in the UK, that minimizes the amount of metal that is removed from railway wheels during planned maintenance [3.4, 3.6]. The technique was proven, through application of computer models [3.1] and field trials on the Alstom Class 390 fleet, to improve maintenance efficiency and reduce costs without compromising safety.

The review of wheelset maintenance on UK passenger vehicle fleets [3.1] identified that to reduce inspection times and optimize wheel re-profiling, a fast and repeatable method of quantifying damage (both surface and near-surface) on railway wheels was needed. Research

into novel automated non-destructive testing (NDT) technologies and tools for monitoring wheel condition was undertaken to address this. This included the use of magnetic flux techniques for the detection of wheel surface damage [3.3]. Tools for calculating and trending wheel profile parameters from laser scanned data were developed.

3. References to the research

Included below is a list of the relevant journal papers which evidence some of the underpinning research described in this case study. Three of the research outputs listed below [3.1, 3.5 and 3.6] have been awarded prizes by the Institution of Mechanical Engineers (IMechE) Railway Division for their contribution and achievements in the field of Railway Engineering.

1. Bevan, A., Molyneux-Berry, P., Eickhoff, B. and Burstow, M. (2013) '**Development and validation of a wheel wear and rolling contact fatigue damage model**', Wear, Vol. 307, pp. 100–111. https://doi.org/10.1016/j.wear.2013.08.004
2. Bevan, A., Molyneux-Berry, P., Mills, S., Rhodes, A. and Ling, D. (2013) '**Optimisation of wheelset maintenance using whole system cost modelling**' Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, Vol. 227, pp. 504–608, ISSN 0954-4097, https://doi.org/10.1177/0954409713484712
3. Bevan, A. and Klecha, S. (2016) '**Use of magnetic flux techniques to detect wheel tread damage**' Proceedings of the ICE - Transport, Vol. 169, pp. 330–338. ISSN 0965-092X, https://doi.org/10.1680/jtran.16.00025 [can be supplied on request]
4. Andrade, A. and Stow, J. (2017) '**Assessing the potential cost savings of introducing the maintenance option of Economic Tyre Turning in Great Britain railway wheelsets'** Reliability Engineering and System Safety, Vol. 168, pp. 317–325. ISSN 0951-8320, https://doi.org/10.1016/j.ress.2017.05.033
5. Crosbee, D., Allen, P. and Carroll, R. (2017) '**Analysis of design and performance of tram-train profiles for dual-operation running**', Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, Vol. 231, pp. 578–597. ISSN 0954-4097, https://doi.org/10.1177/0954409716679448
6. Muhamedsalih, Y., Stow, J. & Bevan, A. (2018) '**Use of railway wheel wear and damage predictions tools to improve maintenance efficiency through the use of Economic Tyre Turning (ETT)**', Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, Vol. 233,1 pp.103-117. https://doi.org/10.1177/0954409718781127

4. Details of the impact

The research findings have led to impact on the UK rail and tram networks for passengers and operators. Government policy on tram-train transportation systems and national railway standards were influenced.

The impacts can be summarized under three main headings:
1. Improvements to public transport in Sheffield and plans to replicate the model
2. Enabling the use of a cost-effective wheel maintenance procedure
3. Commercial exploitation by train operators

Improvements to Public Transport in Sheffield and Plans to Replicate the Model

The research [3.5], undertaken as part of a £125m Department of Transport tram-train pilot study, developed a tram-train wheel profile that was subsequently tested on the Sheffield tram-train scheme operated by Stagecoach. Stagecoach stated that "without this work and the identification of a wheel profile that would allow dual operation of a tram on both a street network and a heavy network, it is highly unlikely that Network Rail would have allowed street trams to operate on its network" [5.1].

The economic benefits from the new scheme have helped to regenerate Sheffield City Centre and reduced congestion on the existing road and rail networks, through increased capacity by utilizing existing infrastructure [5.2, 5.3]. The route was opened in October 2018, running three services an hour between Sheffield and Rotherham Parkgate. Seven new vehicles were built

and fitted with the new wheel profiles. In 2019 Stagecoach announced: “the route has been in operation for over 12-months and has delivered more than 1,000,000 passenger journeys” [5.2]. The Sheffield tram-train scheme also achieved a 100% customer satisfaction record in its first year of operation as recorded by Transport Focus (the independent watchdog for transport users) [5.2]. In addition, the Senior Engineer- Light Rail, Network Rail, stated that: “no unusual behaviour of track or vehicle has been experienced” on the network between Tinsley and Rotherham Parkgate, despite the increased usage due to the new tram-train service [5.4].

The research has also informed the wider strategic testing and development of tram-train technology for subsequent roll-out across the UK. Following the success of the Sheffield tram-train scheme, Network Rail have confirmed that further ”tram-train schemes are now being actively pursued by a number of UK Authorities” [5.4], with “over ten transport authorities, including Manchester, Birmingham, Glasgow and Cardiff, seeking to create their own tram-train service” [5.3]. These will improve transport links and reduce congestion on the existing UK road and rail networks.

Enabling the Use of a Cost-Effective Wheel Maintenance Procedure

As a result of this research [3.4, 3.6] Economic Tread Turning (ETT) was incorporated into the Railway Group Standard GMRT2466 issue 4.1 (2019). The Chairman of the Industry Wheelset Management Group and Engineering Manager at Avanti West Coast, confirmed that “of particular significance, is the [UoH] work [..] which has demonstrated quite significant cost savings for the industry”. He also comments that “these changes have been adopted through revision of the Standard GMRT2466 issue 4.1. The research can therefore enable significant potential savings in both track and train maintenance costs” [5.6]. The Principal Vehicle Systems Engineer, Rail Safety and Standards Board (RSSB), added “ETT formed a significant part of the revised content and covers its application, geometry and service limits.” [5.7] The standard (GMRT2466), and accompanying Rail Industry Standard for Wheelsets (RIS-2766-RST, 2017), refers directly to a report [5.7] published by UoH (2017), which, along with the research described in [3.6], established the confidence that a range of flange widths could be selected by operators and maintainers while remaining safe and compatible with the infrastructure. In 2016, the researcher (Muhamedsalih) was awarded the ‘Rail Research UK Association / Institute of Mechanical Engineers’ Young Researcher of the Year Award (Ground breaking research dispels UK myths around ETT) for the research work into ETT on GB Railways [3.6]. The award panel concluded that “this research provides valuable and strong evidence to support the case that train operators should be allowed to implement ETT policies and will provide the opportunity to exploit the cost savings associated with ETT without a significant detrimental effect on the infrastructure over which they operate”. These cost savings are estimated by RSSB to be between £880k and £5.1m per year across the GB passenger train fleet [5.8].

The research outputs on wheel profiles and ETT [3.1, 3.6] were trialled in 2017 by Alstom on the Class 390 train fleet operating on the West Coast Mainline, in an attempt to extend wheelset re-profiling intervals and reduce the cost of maintenance. As detailed by the Wheelsets and Components Engineer, Alstom have seen a “13% increase in re-profiling intervals, from 310,000 miles to over 350,000 miles, allowing one additional trainset to be released for service per week.” The benefits of releasing an additional trainset into service “should not be underestimated”, it allows the operator “to provide more train services” and allows the maintainer to have “a better understanding of the performance of its wheelsets” and therefore make smarter decisions regarding day-to-day operations [5.9].

Commercial Exploitation by Railway Operators

Automated non-destructive testing techniques developed from the research [3.4, 3.6] have been commercially exploited by two major rail infrastructure manufacturers, Alstom and MRX technologies.

Since 2017, the tools arising from the research for calculating wheel condition parameters [3.1] have been integrated within the Alstom ‘Trainscanner’ and ‘HealthHub’ predictive maintenance systems to automatically calculate and interpret wheelset condition and support maintenance

scheduling. The Wheelsets and Components Engineer at Alstom, stated that "using these tools, we have recently been able to operate a wheelset up to 500,000 miles (43% increase) without incident as part of trial, and we are currently working with the [UoH] Institute to realize the benefits of this trial across the entire fleet" [5.9].

The wheel surface crack measurement (SCM) technology (2016), developed in collaboration with MRX Technologies [3.3], enabled rail operators and maintainers to reliably detect and characterize the severity of wheel damage which is difficult to quantify through visual inspection [5.10]. Porterbrook, a railway rolling-stock leasing company, have taken the research on SCM and ETT [3.3, 3.6] and applied it to a fleet of diesel locomotives. The Head of Digital Services at Porterbrook, commented: "the operator has trialled this on one fleet, which moved them from a 600,000 miles wheel life to 780,000 miles wheel life (25% extension)" [5.10].

The models developed during the research [3.1, 3.2] are a key element of the wheelset management model, which was incorporated into the Vehicle Track Interaction Strategic Model (VTISM) in 2014. VTISM is a rail industry tool (developed by UoH in association with Serco) for modelling the cost of track and wheelset deterioration. It supports the optimization of maintenance and renewal regimes, thereby increasing wheelset life and reducing costs. This industry-recognized model is run and managed for the UK rail network by the RSSB and is available to all its members for use [5.7]. There are 28 organizations (and 42 users) registered to use the model, of which five are rail industry suppliers, nine are train operating companies, one is an infrastructure manager and the remainder are research organizations. This represents a significant proportion of the UK rail sector.

5. Sources to corroborate the impact

1. Testimonial Letter from Stagecoach SuperTram, Head of Engineering, Rolling Stock and Infrastructure, April 2020.
2. Sheffield City Region, Tram-Train Marks One Million Passenger Journeys, October 2019.
3. Rail Business Daily, South Yorkshire Blueprint to Benefit Future Tram-Train Schemes, October 2020.
4. Testimonial Letter from Network Rail, Senior Engineer, Light Rail, May 2020.
5. Testimonial Letter from Avanti West Coast, Chairman, April 2020.
6. Testimonial Letter from RSSB, Principal Vehicle Systems Engineer, March 2020.
7. Economic Tyre Turning – Practical Considerations for Creating Thin Flange Variants of Wheel Profiles, 2017, sparkrail.org/Lists/Records/DispForm.aspx?ID=24866.
8. Rail Safety and Standards Board, Economic Tyre Turning - Can We Cut Wheelset Costs in an Easy and Safe Way? January 2018.
9. Testimonial Letter from Alstom, Wheelsets and Components Engineer, December 2020.
10. Testimonial Letter from Porterbrook, Head of Digital Services, January 2021.