Institution: University of Southampton	
Unit of Assessment: 12 Engineering	
Title of case study: 12-17 Improving performance, reliability and cost-effectiveness of rail and critical transport infrastructure	
Period when the underpinning research was undertaken: 2000 – 2020	
Details of staff conducting the underpinning research from the submitting unit:	

Name(s):	**Role(s) (e.g. job title):**	**Period employed by HEI:**
William Powrie	Professor of Geotechnical Engineering	1995 – present
David Richards	Professor of Ground Engineering	1995 – present
Louis Le Pen	Senior Research Fellow	2011 – present
David Milne	Research Fellow	2017 – present
David Thompson	Professor of Railway Noise and Vibration	1996 – present
Anthony Blake	Research Fellow	2016 – present
Xian Ying Zhang	Research Fellow	2013 – 2020
Giacomo Squicciarini	Research Fellow	2011– present
John Preston	Professor of Rail Transport	2006 – present
Simon Blainey	Lecturer in Transportation	2009 – present

Period when the claimed impact occurred: August 2013 – December 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Transport infrastructure research at the University of Southampton has achieved significant performance and reliability improvements for railway and other critical infrastructure systems. It has led to substantial cost and carbon savings, supported government decision-making and enabled industry innovation for economic gain. Over the impact period, University of Southampton research has led to:

- The restart of the UK's rail electrification programme, delivering savings worth an estimated GBP650m to the UK economy.
- An estimated cost reduction of HS2 noise barriers by GBP65m and HS2 geotechnical works by GBP100m, thereby reducing the risk of further costly delays to the project.
- New industry design guidelines and standards that influence engineering practice globally.
- High-level policymaking, including the provision of research-based advice that contributed to the Government's decision to proceed with Phase 1 of HS2 and modelling that contributed to the UK's first National Infrastructure Assessment.
- Industry innovation that led to commercial advantage and growth; including contributing to a GBP18m rise in annual turnover for one UK-based construction company.

2. Underpinning research

Rail is vital to a healthy, decarbonised inland surface transport system. It is far more energy efficient than road, even with mass electrification. Over the last 15 years, rail passenger kilometres have more than doubled; further increasing this and freight rail use remains key to meeting national carbon targets.

Research at the University of Southampton has contributed to improved design and maintenance of railway and other transport infrastructure systems, delivering large cost savings and increasing reliability and capacity. Since 2003, Southampton has led four major, contiguous EPSRC grants in rail and participated in at least seven other large grants related to transport infrastructure. It has held a strategic research partnership with Network Rail (NR) since 2012 and has a key role in the UK Collaboratorium for Research on Infrastructure and Cities (UKCRIC), which has received GBP138m in government investment. It leads the Infrastructure Centre of Excellence in the UK Rail Research and Innovation Network (UKRRIN), which has received GBP64m in industry funding and is described in the Rail Sector Deal (BEIS, 2018) as an opportunity to '*accelerate the take-up of innovation*'.

Groundwater and pore pressure: retaining walls & temporary supports (Powrie, Richards)

Predominantly field-based research during 2000-2010, combining high-quality data sets with detailed numerical and analytical modelling [**3.1**], has led to a progressively better understanding of the factors governing the behaviour of groundwater and pore pressure control systems in real life. Meanwhile, work on embedded retaining walls from 2000 to 2016 focused on understanding the installation effects and long-term stresses on walls in overconsolidated deposits, through laboratory testing, numerical analysis and high-quality field instrumentation [**3.2**]. A second major activity has been understanding the behaviour, quantifying the benefits and developing methods of analysis for temporary supports, especially earth berms.

Performance of railway track systems (Powrie, Le Pen, Milne, Thompson)

Since May 2003 the Southampton group has created and expanded a unique body of railway research, data and expertise encompassing laboratory testing of small elements and systems at scale and at full size, numerical analysis, and field measurements. They have developed a library of performance data for interventions in ballasted railway track; a novel code for discrete element method modelling of the behaviour of railway ballast, validated against laboratory tests; field techniques for monitoring the performance of track in service; and targeted maintenance methods for ballasted track. They have determined the limitations of ballasted track for high speed rail; developed a novel method to determine dynamic track modulus from measurement of track velocity during train passage in the absence of wheel load data [**3.3**]; and developed new understanding of the properties of train load frequencies and their applications.

Railway noise and vibration (Thompson, Zhang, Squicciarini)

Since 2000, Southampton's numerical, laboratory and field based research into railway noise and vibration has developed the understanding of sound radiation from wheels, rails [**3.4**], pantograph and train aerodynamic noise, and ground borne vibration. Fundamental discoveries have enabled applied research into the noise performance of ballasted and slab track; noise behaviour of railway track fasteners; rail dampers; the contribution of vehicle and track to pass-by noise; and the effects of rail roughness.

Railway overhead line equipment (OLE) (Richards, Powrie, Blake)

In 2017 the Southampton group carried out a fundamental review of design methods for railway OLE foundations. This led to full-scale site trials of piled foundations in a railway embankment. Following characterisation of the ground, novel instrumentation was used to measure deformations and displacements at service loads imposed by current equipment designs at various return period wind loads, through to failure. The research extended the historical evidence base, and used the measured data to derive *p-y* (lateral load-displacement response of the ground) curves [**3.5**]. The group also investigated the application of surge arresters and insulated coatings as a means of reducing clearances to overhead high voltage equipment, in order to reduce further the cost of railway electrification by avoiding bridge reconstruction.

Infrastructure systems modelling (Preston, Blainey)

Research from 2011 to 2018 provided insights into passenger demand for rail services and the pressure this is likely to place on infrastructure [**3.6**]. It included the conceptualisation, design and development of a national transport model as part of the NISMOD (National Infrastructure Systems Model) interdependent modelling framework for critical infrastructure systems. The model can quickly produce forecasts of future rail demand and capacity utilisation at the local authority scale.

3. References to the research

3.1 Influence of large-scale inhomogeneities on a construction dewatering system in chalk. M A Bevan, W Powrie and T O L Roberts. *Géotechnique* **60**(8), August 2010. ISSN 0016-8505. https://doi.org/10.1680/geot.9.P.010

3.2 Pore water pressure and horizontal stress changes measured during construction of a contiguous bored pile multi-propped retaining wall in Lower Cretaceous clays. D J Richards, W Powrie, H Roscoe and J Clark. *Géotechnique* **57** (2), 197-205, March 2007. ISSN 0016 8505. https://doi.org/10.1680/geot.2007.57.2.197

3.3 Evaluating railway track support stiffness from trackside measurements in the absence of wheel load data. L Le Pen, D Milne, D Thompson and W Powrie. *Canadian Geotechnical Journal* **53**(7), 1156-1166, 2016. https://doi.org/10.1139/cgj-2015-0268. *Prix R M Quigley Honourable Mention, 2017* *https://www.cgs.ca/pdf/2017-Annual_Report.pdf*

3.4 X Zhang, G Squicciarini, D Thompson, Sound radiation of a railway rail in close proximity to the ground. *Journal of Sound and Vibration*, **362**, 111-124, 2016. https://doi.org/10.1016/j.jsv.2015.10.006

3.5 W Powrie, D J Richards and V K S Mootoosamy (2019) The design of railway overhead line equipment mast foundations. *Proceedings of the Institution of Civil Engineers - Geotechnical Engineering*, **173**(5): 428–447, https://doi.org/10.1680/jgeen.18.00242

3.6 Blainey SP & Preston JM (2019) 'Predict or Prophesy? Issues and trade-offs in modelling long-term transport infrastructure demand and capacity', *Transport Policy* **74**(2):165-173. https://doi.org/10.1016/j.tranpol.2018.12.001

Key underpinning grants

G1 [ref 3.2 above]: EPSRC GR/M95011/01 Lateral stresses on in situ retaining walls in over consolidated deposits: long term behaviour. **Value GBP228,727**

G2 [refs 3.3, 3.4 above]: 5 major contiguous or parallel grants EPSRC GR/S12784/01 Centre for Rail Systems Research; EP/D080207/1 Universities' Centre for Rail Systems Research (RRUK2); EP/H044949/1 Railway Track for the 21st Century (TRACK21); EP/K03765X/1 Track systems for high speed railways (T400); EP/M025276/1 (Track to the Future). **Combined value GBP17,346,007**

G3 [ref 3.6 above]: Two major contiguous grants EPSRC EP/I01344X/1 UK Infrastructure Transitions Research Consortium (ITRC) and EP/N017064/1 MISTRAL: Multi-scale Infrastructure Systems Analytics. **Combined value GBP10,105,480**

4. Details of the impact

University of Southampton research into the engineering of transport infrastructure has underpinned changes to policy and practice that have facilitated the construction of key civil engineering projects in the UK and overseas, and delivered significant economic benefit.

Groundwater and pore pressure, retaining walls and temporary supports: *Enabling construction and reducing the cost of major UK and overseas civil engineering projects*

Effective control of groundwater for deeper excavations and tunnels is crucial for reducing costs and protecting the environment and adjacent infrastructure. Vacuum dewatering techniques developed through Southampton's research [e.g. **3.1**] for the control of pore pressures in low permeability deposits and more permeable strata shaped new design guidance on groundwater control published by the Construction Industry Research and Information Association (CIRIA) in 2016 [**5.1, 5.3**]. Powrie co-authored *CIRIA C750 Groundwater Control: Design and Practice*, which the construction industry '*relies on … as a best practice guide to underpin the design, specification and implementation of dewatering schemes*' [**5.1**]; Powrie co-led a series of workshops in Australia and New Zealand (2017) and Canada (2019) to present the C750 guide to industry overseas [**5.1**]. UK-based WJ Groundwater Ltd, a specialist in dewatering for deep excavations and tunnels, applied the techniques developed with Southampton to its work on Crossrail, HS2, the new River Humber gas pipeline and the Thames Tideway Super Sewer. The research contributed to an increase in WJ's annual turnover from GBP10,000,000 to GBP28,000,000 over the impact period, much of this achieved by expansion in the UAE, Qatar, Israel, Poland and Canada [**5.1**].

Southampton's research data on installation effects of and long-term lateral stresses on embedded retaining walls [e.g. **3.2**] underpins and informs *CIRIA C760 Guidance on embedded retaining wall design* (co-authored by Powrie), published 2017. Southampton methods for quantifying the effects of earth berms in limit equilibrium calculations also underpin the associated C760 guidance and have become the de facto industry standard approach [**5.2**, **5.3**]. The recommendations allow lighter retaining walls with shorter embedded lengths, saving money, carbon and time [**5.2**]. An Arup director, who is HS2 southern section civil works design leader, describes the research as '*critically important*' to the adoption of C760, which is followed globally and '*used on many projects involving underground engineering*' [**5.2**]; C760 is frequently CIRIA's most downloaded guide [**5.3**].

Performance of railway track systems: *Supporting design for increased traffic, improved reliability and predictable, reduced costs, and influencing major policy decisions*

Southampton research [e.g. **3.3**] has solved persistent, localised maintenance problems on HS1 where, for example, a single, targeted intervention to install under-sleeper pads along 5m of track saved GBP100,000 in maintenance costs between 2015 and 2020 for an investment of GBP15,000 [**5.4**]: other sites have been similarly treated. Findings were translated into the University's 2016 publication *A Guide to Track Stiffness* (ISBN: 9780854329946), distributed to 900 users including 500 NR [**5.5**] and 80 Transport for London (TfL) technical staff, supported by Southampton-led workshops. The guide was published online by the Permanent Way Institution and the Rail Safety and Standards Board (RSSB) and is '*used extensively by track engineers in Network Rail and its suppliers in the maintenance, refurbishment and renewal of track*' [**5.5**].

As a result of his "extensive research record in the areas of railway earthworks and retaining walls", Powrie was invited to chair 12 design workshops for HS2 with a view to ensuring HS2 and its supply chain benefited from the latest research findings, resulting in savings of GBP100,000,000 [**5.6**]. With McNaughton, Powrie is an adviser to the Chairman of HS2, who wrote in 2019: *'I will continue to use Professor Andrew McNaughton [Southampton], Lord Mair and Professor William Powrie [Southampton] to work with the HS2 Ltd Chief Engineer to examine the engineering assumptions behind existing designs.'* [**5.7**]

Railway noise and vibration: *Ensuring economic design of noise mitigation measures, supporting UK industry and contributing to international design standards*

The noise from slab tracks was widely believed to be greater than from conventional ballasted tracks. Southampton research [e.g. **3.4**] demonstrated that the difference was smaller than previously understood. As a result, the requirement for additional noise mitigation measures on HS2 was rescinded, reducing Phase 1 costs by GBP65,000,000, delivering a '*significant*' reduction in noise barrier costs for Phase 2a and reducing the risk of delay to the HS2 programme [**5.6**].

As a result of this research strand, Pandrol, a global manufacturer of rail fastenings, gained increased understanding of the noise behaviour of their slab track rail fasteners. This led them to change their emphasis from single to double layer fastening systems, which is beneficial for noise. The company attributed '*significant advantages to Pandrol in this competitive market sector*' to Southampton's research contribution [**5.8**]. In collaboration with Deutsche Bahn, the Southampton group applied their research to develop a cost-efficient alternative to field tests for testing rail dampers. This *'reduced costs by about 90%'* (from up to 100k euros to 10k euros) and the time required for the procedure from six months to one week [**5.9**]. This opened the market to SMEs and removed the need for lengthy traffic restrictions resulting from installing dampers for testing [**5.9**]. Southampton's collaborative research with SNCF on wheel roughness led directly to the revision (in 2019) of the European Standard for Rail Roughness Measurement (EN 15610) to extend its scope to wheel roughness measurements [**5.10**].

Railway overhead line equipment (OLE): *Developing efficient design standards and new techniques to support the affordable decarbonisation of transport*

Southampton research [e.g. **3.5**] allowed the rail industry to adopt a method for specifying OLE foundations that was significantly more cost-efficient than standard practice (which the research showed to be overly conservative), enabling large savings in material cost, programme time and carbon. The method was translated into a new NR specification, *Design and Installation of Overhead Line Foundations*, published in December 2017 and made mandatory for use on all NR projects from March 2018 [**5.11**]. Southampton researchers explained its use in two NR staff workshops.

The beneficiaries are the Department for Transport and NR. UK railway electrification became a sensitive political issue when the Great Western Electrification Project (GWEP) suffered projected cost over-runs of the order of GBP1.9bn [**3.5**]. The scheme was cut back, other schemes were delayed or axed, and the government sought alternatives such as bi-mode trains that were less effective in terms of reliability, cost and carbon. The new design standard has significantly cut costs and reduced embedded and emitted carbon [**5.13**]. It informed a report commissioned from McNaughton (then an independent consultant prior to joining Southampton) by the Secretary of State for Transport into the future costs of electrification [**5.12**] and was reported in the Railway Industry Association's (RIA) Electrification Cost Challenge. The two reports contributed materially to the decision to restart the suspended electrification programme [**5.13**]. The Technical Director of RIA, who was the author of the Cost Challenge report, estimates savings to the UK economy of GBP600,000,000 in the three years to Dec 2020 from this Southampton research and GBP50,000,000 from its associated research on reducing clearances to high voltage equipment [**5.13**]. He also wrote: '*In terms of opportunity cost, without the research it is unlikely that the GWEP and MML [Midland Main Line] projects would have been completed, at a cost to the economy which I estimate with reference to the MML business case of being in excess of £5.5bn*.'

Infrastructure systems modelling: *Underpinning the UK National Infrastructure Assessment*

The seven-university Infrastructure Transitions Research Consortium (ITRC) has developed an integrated interdependent national infrastructure systems model (NISMOD). ITRC is a consortium led by the University of Oxford, with Southampton responsible for transport [e.g. **3.6**] and waste. NISMOD was used extensively by the National Infrastructure Commission in modelling work which underpinned the first ever National Infrastructure Assessment for the UK, published in 2018 [**5.14**]. This document made recommendations for how the identified infrastructure needs and priorities of the country should be addressed, and the Government was required to respond formally to the recommendations. Southampton's research provided long term demand forecasts over a range of scenarios, which influenced the strategic planning of future infrastructure provision. NISMOD was used by the Institution of Civil Engineers to support its National Needs Assessment for UK Infrastructure (published in 2016 [**5.15**]) which David Gauke, Chief Secretary of the Treasury, said was '*a prime example of the exceptional quality of research in this country*'. It was used to produce evidence for the Government Office for Science's 2017 study into the Future of Mobility [**5.16**].

5. Sources to corroborate the impact

5.1 Letter from Dr Toby Roberts. chairman of WJ Groundwater Ltd

5.2 Letter from Asim Gaba, Arup Director and DHJV Leader, HS2 Phase 1 Lots S1 & S2

5.3 Letter from Dr Owen Jenkins, Director of CIRIA

5.4 Email and report from Dr Sin Sin Hsu, Head of Track Engineering, NR High Speed Ltd

5.5 Email from Andrew Buck, NR, Chair of Cross Industry Track Stiffness Working Group

5.6 Letter from Giles Thomas, HS2 Phase One Engineering Director

5.7 HS2 Chairman's Stocktake, August 2019 https://www.gov.uk/government/publications/hs2-ltd-chairmans-stocktake-august-2019 recommendation 3 page 41

5.8 Email from the then Fastening Systems Technical Director, Pandrol

5.9 Email from Deutsche Bahn – benefits of the STARDAMP tool "developed by ISVR"

5.10 Email from Fabien Letourneaux of SNCF, Convenor of CEN/TC256/WG03 sub-committee

5.11 NR spec. NR/L2/CIV/074 2017 *Design and Installation of Overhead Line Foundations*

5.12 *A report on what the target cost for electrification of GB railways should be and the actions necessary to achieve it.* Andrew McNaughton to the Secretary of State for Transport, Sept 2018.

5.13 Letter from Technical Director of Railway Industry Association

5.14 NIC (2018) *National Infrastructure Assessment*, https://www.nic.org.uk/wp-content/uploads/CCS001_CCS0618917350-001_NIC-NIA_Accessible.pdf

5.15 Hall JW et al (2017) 'Strategic analysis of the future of national infrastructure', *ICE Proceedings: Civil Engineering* 170(1):39-47; https://doi.org/10.1680/jcien.16.00018

5.16 Preston JM (2018) *The UK Passenger Rail System: How And Why Is It Changing?*, Foresight, Government Office for Science, esp. pp 4,5 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/761942/Passengerrailtransport.pdf