ANNUAL REPORT 2022
TRANSPORTATION RESEARCH GROUP

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1. OVERVIEW

The Transportation Research Group (TRG) was established at the University of Southampton in 1967 and is part of the Faculty of Engineering and Physical Sciences.

TRG is located at the University's Boldrewood Innovation Campus where the £46 million National Infrastructure Laboratory (NIL) was completed in May 2019 (see below).

Professor Tom Cherrett became Head of the Group in August 2020.

Virtual Reality Cave at Boldrewood

This report covers the research activities within TRG during the calendar year 2022.

TRG academic staff members during 2022 were:

- John Preston, Professor of Rail Transport
- Tom Cherrett, Professor of Logistics and Transport Management
- Ben Waterson, Associate Professor, specialising in modelling and simulation
- Simon Blainey, Associate Professor, specialising in rail transport and modelling
- Katie Plant, Associate Professor in human factors engineering
- Ioannis Kaparias, Lecturer in transportation engineering
- Shahram Heydari, Lecturer in transportation.
- Laila Ait Bihi Ouali, Lecturer in engineering economics and management

Research Staff in TRG during 2022 included Dr John Armstrong, Adrian Hickford, Fraser McLeod, Dr Alan Wong, Dr Rich McIlroy, Dr Matt Grote, Dr Marcus Young, Dr Katie Parnell (awarded an Anniversary Fellowship), Dr Henrietta Howarth and Dr Jisun Kim. During the year we welcomed Jade Melendez, Ismail Aydemir and Siobhan Merriman. We said goodbye to Matthew Webster.

Their research activities are summarised in later paragraphs. **Technical Staff** supporting TRG included Joy McKay, Alex Smith, Jason Drummond, Sophie Hallam and Roman Bolton. During the year, we welcomed Annabelle Hutchins-Lander.

Melanie Hallford continued supporting the Group in her role as **Senior Administrator** for the Department.

Mike McDonald and Neville Stanton continue as Emeritus Professors and Nick Hounsell as Visiting Professor. We have a number of other Visiting Professors and Research Fellows who contribute significantly to the Group. These include Professor Jianping Wu, Tsinghua University; Professor Pengjun Zheng (Dean of the Faculty of Maritime and Transportation Engineering) at Ningbo University in China; Professor Alan Stevens (formerly of TRL); Dr John

Schoon, Dr Shahjahan Miah, Dr Craig Allison, Dr Bani Anvari, Dr Victoria Banks, Oliver Davey, Sophie Hart, Kiome Pope, Dr James Pritchard, Professor Paul Salmon, Iain MacGregor, Dr Birendra Shrestha, Dr Alejandro Ortega-Hortelano, Cdr Justin Saward, Rachel Wynne and Dr Aaron Roberts.

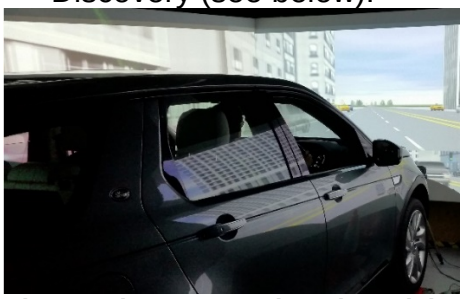
We also had over 30 students attached to the Group undertaking PhD or EngD (Engineering Doctorate) research in transport. In 2022, PhD degrees were awarded to Sungbae Yoon, Luke Hutchinson, Hamad Almujibah, Aditya Tafta Nugraha, Sylwia Kaduk, Minh Tam Vu and Jediah Clark.

Postgraduate teaching continues to be an integral part of TRG activities, particularly the MSc in Transportation Planning and Engineering. We continue to offer three pathways through the course, offering students a choice of specialising in Infrastructure, Behaviour or Operations on either a full time or part time basis, with 40 new students enrolled in September 2022, the largest cohort for many years. We also formally launched a new remote learning option for the course in September 2022, whereby students attend teaching activities online via live streams from the lecture rooms, and attend on-campus for one week each semester to undertake practical activities.

Overall, we have maintained a healthy portfolio of research in 2022. By the end of the year, our research grants and contracts had a total value of over £10 million, with over £4 million of this from EPSRC.

TRG facilities include:

- **SUDS (Southampton University Driving Simulator)**, located in Building 176 at Boldrewood and equipped with a Land Rover Discovery (see below).

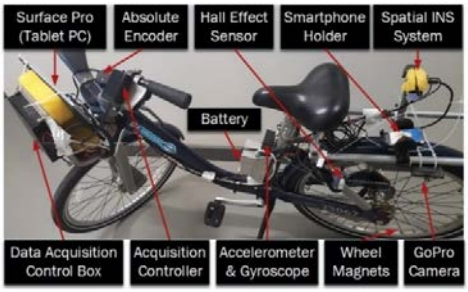


The Southampton University Driving Simulator (Mark 2)

- **The TRG Instrumented Vehicle (IV3)**. Following a successful bid to the University's 'Delivering Innovation to the Next Generation (RESOUNDING) Fund' in 2019, a plug-in hybrid Toyota Prius was procured and delivered in March 2020. It is fitted with a variety of sensors and supports a range of applied in-lab and on-road research.

TRG Instrumented Vehicle (IV3)

The IV3 and an instrumented bicycle (iBike) for on-road trials, are hosted in the garage facility in Building 185 at Boldrewood.



The TRG Instrumented Bike

- Our transport data analysis facility is located in Building 176, Boldrewood.

- **ComTET** – A command teamwork experimental test bed for submarine control rooms, located for most of the year in Building 21, Highfield but relocated to Building 19 towards the end of the year.

The ComTET Submarine Control Room Simulator

- **Virtual reality environments**. Through an equipment grant from DAFNI, TRG has now developed a set of immersive environments to assist in data visualisation and public engagement including a 360^0 virtual reality (VR) cave and series of VR headsets.

TRG Virtual Reality Cave

TRG Virtual Reality Headset

Outreach

Public engagement and outreach activities continued to be delivered largely online during 2022. Dr Shahram Heydari organised the Future Cities summer course for Y12 students from 25th to 27th July. The course included activities relating to different areas of civil engineering. Members of TRG offered an activity on Low Emission Mobility and Autonomous Vehicles. The staff involved were John Preston, Ioannis Kaparias and Alan Wong, along with PhD students Hameed Jehanfo, Paraskevi Sarri, Georgios Rempelos and Siobhan Merriman.

TRG also managed or contributed to a number of activities for the University's annual Science and Engineering Festival, which was held online during Science Week between 11-20 March, and in person for Science and Engineering Day

on 7 May, including hands-on activities related to the Future Cities Community Hub and virtual reality logistics drone corridors. The latter was also demonstrated at the New Forest Show in July and ‘Hands on Humanities Day’ in November as part of the EPSRC E-Drone project, with over 600 members of the public experiencing what future drone logistics corridors might be like in the future. TRG also provided multiple inputs on behalf of the UK research community to conceptualise ‘Tomorrow's Engineering Research Challenges’ for the Engineering and Physical Sciences Research Council. Hameed Jehanfo presented his research to students at Bradford College as an industry speaker on highway infrastructure in November 2022

The E-Drone virtual reality exhibit at the New Forest Show (July 2022)

2. EXTERNAL ACTIVITIES

The following sections summarise the range of external activities undertaken by TRG Academic Staff members in 2022:

Tom Cherrett:

- Member of the Editorial Board, Proceedings of the ICE: Transport Journal.
- Member of the Logistics Research Network (LRN) committee.
- Member of the Chartered Institute of Logistics and Transport's Freight and Logistics Policy Group.

John Preston:

- Member of the EPSRC Peer Review College.
- Committee Member of the International Association of Rail Operations Research (IAROR) and the International Conference on Competition and Ownership in Land Passenger Transport.
- Member of the Future Traffic Regulation Optimisation (FuTRO) Project Control Board and the Vehicle/Train Control and Communications Systems Interface Committee.
- Editorial Board Member: Journal of Transport Policy and member of the Scientific Committee of the World Conference of Transport Research Society.
- Chaired Workshop 1 Regulatory regimes: national and comparative regulation of public transport at the 17th International Conference on Competition and Ownership in Land Passenger Transport, Sydney, Australia, 4th-8th September 2022.
- Chaired World Conference on Transport Research Society Webinar on The Railroad to Recovery: Rail Research in a Post-Covid World. 28th July 2022.

Simon Blainey:

- Specialist Advisor, House of Lords Built Environment Committee
- Member of the Governance Board for the Data Analytics Facility for National Infrastructure (DAFNI.)
- Member of the EPSRC Peer Review College.
- Senior External Examiner for MSc, BSc, DipHE and CertHE courses in Railway Operations Management, Glasgow Caledonian University.
- Editor-in-Chief, Transportation Planning and Technology
- Member of the Editorial Board for the Journal of Transport Geography
- Guest Lecturer at Department of Geography, Ghent University

Ioannis Kaparias:

- Honorary Lecturer at the Department of Civil and Environmental Engineering of Imperial College London
- Independent expert for the European Commission on research and innovation activities, acting as an evaluator of proposals submitted to the Horizon Europe programme
- External PhD examiner, University of Bristol
- Member of the US Transportation Research Board's Committee on "Human Factors of Infrastructure Design and Operations" (ACH40) (formerly "User Information Systems" (AND20))
- Member of the US Transportation Research Board's Committee on "Pedestrians" (ACH10)
- Deputy Editor-in-Chief of the IET Intelligent Transport Systems journal (Institution of Engineering and Technology)

- Member of the Scientific Committee of the 12th International Scientific Conference on Mobility and Transport (mobil.TUM 2022), 5 – 7 April 2022, Singapore
- Member of the Scientific Committee of the 10th Symposium of the European Association for Research in Transportation, 1-3 June 2022, Leuven, Belgium
- Member of the Steering Board Committee of the 6th Conference on Sustainable Urban Mobility (CSUM 2022), 31 August – 2 September 2022, Skiathos Island, Greece
- Member of the Smeed Prize committee at the 54th Annual Conference of the Universities' Transport Study Group (UTSG), 4-6 July 2022, Edinburgh, UK
- Member of the Scientific Committee of the 8th International Conference on Models and Technologies for Intelligent Transportation Systems, 14-16 July 2023, Nice, France

Katie Plant:

- Chartered Member of the Chartered Institute of Ergonomics and Human Factors
- External Examiner for University of Derby's MSc in Ergonomics and Human Factors
- Associate Editor for Ergonomics and Human Factors in Manufacturing and Service Industries journal
- Associate Editor for Transportation Planning and Technology journal
- Editor of Special Issue in 'Human Factors and Ergonomics response to Covid-19'
- (in Human Factors and Ergonomics in Manufacturing and Service Industries)

Shahram Heydari:

- Member of the editorial board of Analytical Methods in Accident Research.
- Collaborative member of the Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT)
- Member of the Network of Excellence in Air Quality at Imperial College London

Laila Ait Bihi Ouali:

- Affiliate member of Transport Strategy Centre, Centre for Transport Studies (Imperial College London)
- Reviewer for PlosOne and the International Economics and Travel Behaviour and Society journals

3. RESEARCH

TRG research fits within a view of transport as a socio-technical system capable of delivering sustainable outcomes, but also with the potential for unsustainable outcomes if the interactions between transport technology and society are not adequately addressed. We are particularly interested in how society shapes, and is shaped by, technological developments in transport. This requires an interdisciplinary approach involving the engineering and physical sciences, along with the social sciences and humanities. In particular, we bring together traffic engineering, transport economics and human factors with TRG's work being multi-modal, covering both passenger and freight transport.

A focus of our research remains on Intelligent Transport Systems, with a strong portfolio of studies on Human Factors in Transport. We also undertake research on a number of other interrelated themes, including energy and environment, freight and logistics, future technologies, rail and transport economics and policy.

The remainder of this report summarises TRG research activities ongoing in 2022 within different topic areas. Research titles listed in **blue** represent contract (funded) research, whilst those in **green** are studies by Postgraduate Research students (PhD, iPhD or EngD).

3.1 Freight and Logistics

Open Skies Cornwall (Innovate UK, from December 2022 to 2024, specialist partner). Prof J. Scanlan, A. Oakey, External Consortium with DronePrep, NHS Cornwall, Mott MacDonald, Royal Mail, JHUBMED, Cornwall Council, Skyports Drones, Neuron Innovations. *Contract Holder*: Prof T.J. Cherrett.

The Open Skies Cornwall project is investigating the best use of drones for multiple use cases in Cornwall, including medical and ship-to-shore deliveries, and aerial surveillance work. Providing specialist inputs, the University of Southampton supports the Open Skies Cornwall project with regards to medical stability testing and the development of new airspace management solutions.

e-Drone (EPSRC, from December 2020 to June 2024). Prof J. Scanlan, Dr M. Grote, Dr J. Drummond, Dr B. Waterson, A. Pilko, A. Oakey, K. Theobald. External Consortium with UCL, Bournemouth University, University of Leeds. *Contract Holder*: Prof T.J. Cherrett.

The E-Drone project examines the energy reduction potential of integrated logistics solutions involving Uncrewed Aerial Vehicles (UAVs, commonly known as drones) operating alongside traditional and sustainable last-mile delivery solutions (e.g. vans, cargo cycles, walking porters).

This involves generating fundamental new understanding of how drone operations will function in shared airspace in harmony with traditional, crewed aircraft under various regulations. The project uses a case study approach based around NHS patient diagnostic sample transportation involving simulated and live trials across the Solent region. Key research during the period has been:

1) **Approaches to best manage crewed and uncrewed aircraft in shared airspace**: Through a series of national workshops involving the general aviation

community and drone operators, the E-Drone project has been investigating how best to equitably share airspace where crewed and uncrewed aircraft can operate simultaneously without the need for the current restricted access corridors in the form of 'temporary danger areas'. The dialogue and discussion emanating from the workshops has led to the development of a shared airspace concept called Project Lima where drones carry transponders to enable their trajectories to be visible to other airspace users. This along with a 4D airspace booking system strategically deconflicts planned trajectories in a discretised model of the airspace where conflicts are dealt with via a simple first-come-first-serve principle, with all traffic assumed to be of equal importance. This concept has been trialled at the Llanbedr testing ground in North Wales.

2) Quantifying the air and ground risk associated with operating commercial drone services in order to design safe drone corridors: Ground and air risk models have been developed using population density and air traffic data to allow drone operators and airspace managers to understand the relative risk of drone failures injuring people on the ground. The project has developed a tablet game which uses the models as part of a visual drone route planning tool where players can understand the implications on drone energy use of taking longer, less risky route paths.

3) Quantifying the potential implications of drone flight on the quality of flown medicines: Flight trials have been undertaken where redundant chemotherapy treatments (mAbs) have been subjected to flights in different types of fixed-wing and rotary-rotary wing drones. The results have shown that there are differences in the vibration profiles of different drones and that in some cases, the outer packaging system can either amplify or mitigate the vibration. From the flight trials, no monoclonal antibody medicines were adversely affected in terms of their quality as a result of exposure to drone flight.

4) Applying current dangerous goods carriage legislation to uncrewed aerial vehicles: A comprehensive review has been published into how the current dangerous goods carriage legislation can be interpreted and adhered to by the operators of uncrewed aerial vehicles. Members of the E-Drone project team sat on the Dangerous Goods RPAS Challenge Group and contributed to the consultation on developing a regime for approving crash-protected containers for RPAS operators carrying dangerous goods.

5) Using virtual reality to convey how new novel transport modes might operate: The E-Drone project has developed novel virtual reality (VR) worlds where logistics drones can be accurately replicated and situated in places that are familiar to people. The project has taken the VR to high streets, inviting passing members of the public to experience the drones flying over the location where they are sitting to give an idea of how cargo drones might look and sound in the absence of direct experience. The approach was piloted on the Bournemouth University campus before being used in Bournemouth and Boscombe town centres and Southampton City Centre where a total of 241 people took part.

6) Using serious games to further debate and understanding about future new transport systems: The E-Drone project has developed a novel board game that enables players to

reflect on the use of delivery drones in a local context providing an effective format for undertaking focus group activities. The board shows well known locations around Bournemouth and the gameplay involves realistic drone scenarios including choices related to risk, time and energy along with other operational parameters with prompts throughout the game requiring participants to reflect on different aspects of drone delivery. (https://www.e-drone.org/).

Solent Future Transport Zone. Theme 2: Freight Transport (DfT, October 2021 to September 2024). F.N. McLeod, A. Oakey, Dr M. Erbil, (2 RF posts to be funded), Prof J. Scanlan (Co-I), Dr T. Waters (Co-I). Dr A. Martinez-Sykora (Co-I) *Contract Holder:* Prof T.J. Cherrett.

In March 2020, Solent Transport was awarded £29 million by the Department for Transport (DfT) to implement innovative transport solutions in a Future Transport Zone (FTZ). TRG is leading the freight related programmes (£3.4m) which cover i) Macro Logistics, ii) Micro Logistics, iii) Drone Logistics. The drones project started in advance of the formal FTZ kick-off in response to the Covid pandemic and the NHS Isle of Wight Trusts need to investigate alternative logistics opportunities. Windracers 'Ultra' fixed-wing drone was brought into service ahead of schedule and an experimental air bridge was established between Lee-on-Solent and Binstead airfields to allow supply of medical goods should it be needed during the first lockdown. The trial delivered the first Beyond-Visual-Line of Sight (BVLOS) flight to the island (https://www.bbc.co.uk/news/technology-52419705?msclkid=72430343b11011eca688066b0b067f6d) and has paved the way for subsequent operations to the Isles of Scilly. As part of this research, TRG has worked with colleagues in the university's Institute of Sound and Vibration research along with colleagues from Kings College London to investigate to what extent drone flight might adversely impact in medical cargoes (particularly aseptic medicines) in terms of vibration. This has also included the design and testing of vibration mitigating packaging. Other core research has involved investigating how dangerous goods carriage legislation can be applied to drones and the implications of introducing specific crash-proof containers. As part of the macro and micro logistics projects, a review has been undertaken of land use planning issues related to freight facilities across the Solent region, highlighting current infrastructure by freight activity. Three feasibility studies have also been undertaken looking at the scope for shared-fleet logistics: 1) where the rounds of an existing patient transport service fleet are adapted to collect patient diagnostic samples from local GP surgeries; 2) electric vans operated by a local authority courier service also collect from local suppliers servicing a cruise operator via a freight consolidation facility; 3) electric vans operated by a local authority courier service also collect patient diagnostic samples from local GP surgeries. These have all demonstrated the carbon savings that can be realised with potential live trials being negotiated. A fourth study is looking into the potential for consolidating university halls of residence post through the Southampton Sustainable Distribution Centre in Southampton.

FLIPGIG (Digitally transforming deliveries and collections in the gig-economy: fairer and more sustainable last mile parcel logistics) (EPSRC, from 2019 to 2022). F.N. McLeod. *Contract Holder:* Prof T.J. Cherrett

Gig-economy couriers form an integral part of many last-mile logistics operations, but the industry has come under increasing scrutiny due to concerns about poor working conditions. The project has identified inefficiencies and perceived unfairness relating to unpaid time and low pay, biases to using motorised vehicles, hiring too many people for the work available, which can lead to hazardous working conditions as couriers take risks to earn a living. Working with leading parcel delivery and cycle logistics companies, we have modelled delivery options that optimally balance fair distribution of work according to job and worker availability, choosing the most sustainable transport mode for delivery, while empowering gig-economy couriers to better meet their personal working preferences. Project website: http://www.flipgig.org/

Investigating the Potential for Autonomous and Cycle-Based Freight Systems to Support the National Health Service as Part of a Mixed-Fleet Logistics Operation (PGR student, from October 2019 - part-time from October 2021). Andy Oakey. *Supervisors*: Prof T.J. Cherrett, Dr A. Martinez-Sykora, Prof J.P. Scanlan.

The demand for same day deliveries is ever growing, whilst journey times in urban areas continue to worsen as a result of increasing congestion. Typically, little thought is given to logistics in urban planning, nor the environmental burden faced by everyday deliveries. Transfer to more sustainable practices across multiple, cleaner transit modes can help to relieve some of these pressures.

This research aims to investigate the potential for autonomous and cycle-based multi-modal logistics fleets to operate across many health care applications in several environments, using NHS same day delivery systems in the Solent region as the main case studies.

This includes: the transfer of diagnostic specimens for analysis from GP surgeries to hospitals, as well as between hospitals, ad-hoc and emergency blood stocks from Southampton Blood Centre to recipient hospitals, cytotoxic and radiopharmaceutical medicines for cancer treatments to hospitals. Multiple modes will be considered, taking advantage of each mode's beneficial traits, e.g. fast and direct transport by drone, short range urban transport by cycle courier, or longer distance and heavier transport by LGV. The selection of vehicle type, as well as the interaction between the platforms will be key to the development of this system. Consideration of the transportation regulations and standards will also be particularly important in the medical setting of this research.

To optimise the use of these vehicle assets, an allocation system will be developed, considering factors such as time criticality, cost, and routing restrictions. In the NHS setting, improving delivery timescales is a key target. Across all of the case study elements, there is potential to create knock-on savings across the NHS, improve quality of care, and save lives; though, the realistic practicalities may limit success.

To further improve the sustainability of multimodal fleets, this research will consider how such a fleet could be shared by multiple parties in a collaborative partnership.

Investigating the Economic and Environmental Benefits of Horizontal Collaboration in Urban Logistics Involving Private and Public Sector Participants (PGR student, from January

2022 - part-time from October 2022). Ismail Aydemir. Supervisors: Prof T.J. Cherrett, Dr A. Martinez-Sykora; Dr L. Ait Bihi Ouali.

The aim of this research is to understand the ways in which shared-fleet and mixed-fleet operations involving public sector operated vehicles, could be implemented to relieve environmental and operational urban logistics problems using case studies in the Solent region. Business-as-usual urban logistics operations are being investigated for a number of different municipal fleets with a view to using various optimisation approaches to quantify the scope and transport benefits of shared-fleet operations. These would involve the public sector 'donor' fleets undertaking work for other public and private sector bodies. Southampton City Council's fleet operations are being used as the main case study 'donor' operation.

The 2nd New Normal Flow of Container Transshipment Logistics after the Pandemic: A Case Study of the Port of Busan (PGR student, from May 2022) Kimoon Jang. *Supervisors*: Prof J.M. Preston, Dr Laila Ait Bihi Ouali.

Container shipping in maritime plays a key role in global economy and trade. After the beginning of containerization in the 1960s, global container logistics in maritime (GCLM) has developed dramatically and continuously almost all the time, which has made global trade more efficient and effective. As GCLM developed, transshipment activities also have become more necessary to support the GCLM both geographically and functionally. As a result, transshipment logistics in GCLM has developed continuously too.

As the global economy and trade increase, the volume of containers for shipping has also increased and economies of scale have spread to industries of the GCLM, e.g., ship building, liners, and port operators, which could be defined as the 1st new normal flow in GCLM considering the similar singularity emerged over the industries. Since around the 1st new normal flow, there have been fierce competitions for being a transshipment hub port especially in Asia where there is high demand for transshipment due to the large volumes and dense network of container shipping. The port of Busan has been ranked the 2nd largest transshipment port in the world since 2015. Due to the development and active operation of the transshipment hubs at ports like Singapore, Hong Kong, and Busan, GCLM has become dense, and liners could have various options to call at several ports before arriving to their destination ports considering the demands of shippers like delivery time or freight rates. We can describe that GCLM in the 1st new normal flow was flexible in the perspective that there were diverse ways for selecting ports to call at due to dense and efficient shipping network from using transshipment hub ports.

However, after the outbreak of the unexpected Covid pandemic, there have been sudden changes in GCLM. Most procedures related with maritime shipping, such as the operation of ports and ships, have had delays because of the lockdowns and quarantines in ports and cities. This resulted in a series of backlogs over the GCLM supply chain. The widespread delays in GCLM lowered the turnover of ships and caused a shortage of container ships, which made liners focus on specific routes with high transport demand and profit. In the case of the port of Busan, unusual changes in transshipment logistics were observed on

some routes including those between China and the U.S. that had previously had a significant demand for transshipment. . These changes, involving the stagnation or reduction of transshipment logistics, are apparently different from those of the 1st new normal flow of GCLM, therefore we can define this as the 2nd new normal flow. The most different feature in the 2nd new normal is that the transshipment logistics has become less flexible (or stiffer) than that of the 1st new normal. The expression "flexible" or "stiff" can be explained reasonably by using Origin/Destination statistics or relevant indices like LSBCI (Liner Shipping Bilateral Connectivity Index) developed by UNCTAD (United Nations Conference on Trade and Development.

In this study we will monitor the progress of transshipment logistics focused on the port of Busan from 2020. The observation and analysis in this study will also give us an answer whether recent unusual phenomena in GCLM after the pandemic is a 2nd new normal flow or a manifestation of the bull-whip effect or the cobweb model. We will derive models which explain the specific phenomena in GCLM by utilizing multiple regression analysis with relevant variables such as throughput of transshipment, maritime transit time of container and relevant economic indices etc. This model will be useful for not only relevant industries but also Governments globally to understand the trends of GCLM more, better cope with unexpected situations like a pandemic, and as a result, make GCLM more efficient and effective.

Restructuring the Supply Chain to Better Serve Rural Farmers: A Case Study of Thailand's Mango Supply Chain (PGR student, from October 2017) Korawit Fakkhong. *Supervisors*: Prof T.J. Cherrett, Prof J.M. Preston, Dr A. Martinez-Sykora (external). **Awarded 2022**

In this study, the research addresses one of the Thai Government key goals related to its food production policy; namely, to create a more inclusive operating environment for rural farmers to improve their transport efficiency and ensure that they can remain competitive. Original primary data were gathered on the production of mangoes by rural farmers across Thailand and used to develop the business-as-usual logistics case along with alternative operating scenarios using range of collaborative logistics options. The Clarke and Wright saving algorithm was used to quantify the benefits of different operating scenarios involving (i) farmer sharing vehicles through a farmer's co-operative, and (ii) a 3rd party vehicle to make milk-round collection. In addition, an important aspect of the collaboration is to decide on how to share the benefits, and how the transportation cost should be distributed fairly among the group of farmers. To investigate these issues, two different cost allocation methods were used – proportional based on volumes and stand-alone cost and the Shapley value methods based on co-operative game theory.

Demand Forecast and Capacity Appraisal of the United Kingdom Lift-on Lift-off Container Ports System (SMMI PhD studentship from January 2016). Manuel Buitrago. Supervisors: Prof J.M. Preston, Prof T. Bektas (University of Liverpool).

The maritime sector is of the utmost importance for the United Kingdom's economy. Great Britain relies heavily on the use of sea-borne transport for most of the freight commodities.

For bulk and containerised commodities, which usually present a lower value density and higher volume, maritime transport is the only feasible option. As a result, up to 96% of the volume of all UK import/export trade flows use the UK ports. Roll-on roll-off (ro-ro) and lift-on lift-off (lo-lo) container terminals are essential to accommodate container flows. Besides, amongst lo-lo terminals, the UK also needs a certain deep-water capacity to be able to cater for ultra-large container ships (ULCS) that are deployed to the main maritime route that links the Far East with Northern Europe. Ensuring the availability of enough spare deep-water capacity has become even more important on the eve of Brexit.

Apart from enabling the trading capability of the nation, the ports are crucial for the UK's economy in, at least, two other important ways. Efficient ports increase the competitiveness of the UK economy, reducing dwell times and facilitating trade. Secondly, ports generate important spill overs. These include value generation, creation of jobs and the formation of clusters and industrial poles.

The UK container port system has experienced profound change since the 1980s. The system underwent a change in two dimensions. Firstly, all major UK container ports are privately-owned, after a privatisation wave during the 80s and 90s. Secondly, the container traffic is concentrated in just three major ports of the south-eastern coast of the UK, which handle more than 70% of the total yearly throughput.

This research project develops new models to assess capacity and demand for the lift-on lift-off container seaports in the United Kingdom. The evolution of the UK container port system has been analysed. Besides, the system capacity has been analytically appraised using a system of systems approach.
An aggregate forecast of the demand for lo-lo container traffic of the United Kingdom system of container ports has been calculated up to the year 2050, using econometric models that incorporate economic growth and the cost of energy as predictors. Several scenarios have been incorporated to reflect the uncertainty and the potential disruption caused by the future UK-EU relationship. Finally, the forecast traffic is allocated to the individual UK containers ports by means of a ground-breaking Lotka-Volterra dynamic competition model.

This research presents insights to decision-makers to base port policy on evidence and informs crucial strategic investment decisions for government and industry alike. This PhD provides a rationale to substantiate where and when to invest in capacity expansion. Finally, the results can be used to signpost risks to the port system, in terms of congestion, loss of traffic and vulnerability of the port infrastructure network.

Port-Cities of the future: Developing sustainable development guidance for port-cities (EPSRC CDT Sustainable Infrastructure Systems PhD with Ramboll, from September 2017). Toby Roberts. Supervisors: Prof. I. Williams, Prof. J.M. Preston

This study has developed the Southampton Port City classification system based on city size and port traffic. Online questionnaires have been developed for port authorities (up to 58 respondents in 24 countries) and their city counterparts. Finding have focussed on economic issues concerning diversification/specialisation and expansion/relocation, environmental

issues concerning emissions and the circular economy and social issues related to port-city relationships.

3.2 Traffic Operations and Safety Management

Travel Time Reliability for Micro-mobility and Its Impact on Route Choice Behaviour (PhD from January 2022). Zafer Kupeli. Supervisors: Dr I. Kaparias, Dr S.P. Blainey.

Micro-mobility modes such as e-scooters have become increasingly popular in cities worldwide due to the advantages they offer in terms of providing fast and environmentally sustainable point-to-point transport as an alternative to the car or conventional public transport.

However, micro-mobility comes with some disadvantages, mainly relating to users' concerns regarding road safety, riding comfort and the actual magnitude of any travel time gains when using e-bikes and e- scooters on roads with specific characteristics. For instance, a travel time prediction by a journey planner for a point-to-point trip using an e-scooter may appear beneficial compared to other modes; however, the reliability of that prediction is still unknown, as the journey planner would generally not consider aspects like initial vehicle availability, slower speed, and more cautious riding due to use of main roads, unreported obstacle encounters, narrower widths, or uphill gradients. Numerous factors affect the reliability of micro-mobility trips and, consequently, route choice, which are currently unexplored.

This study aims to quantify travel time reliability for micro-mobility modes and to investigate its importance on passenger route choice. This will be achieved by developing a model for measuring reliability, considering aspects such as route geography and geometry, obstacles, and initial vehicle availability at docks, and then implementing this model in a routing algorithm. The algorithm will be used to generate scenarios in a selected case study area for a stated preference survey that will investigate micro-mobility user route choice behaviour. The findings will then be validated through expert surveys, macroscopic traffic simulation, and, potentially, a small field experiment.

Investigating the safety correlates of active travel modes in Great Britain (PGR Student, from May 2021) Michael Forrest. *Supervisors:* Dr S. Heydari, Prof T.J. Cherrett.

There is increasing encouragement from the government for people to adopt walking and cycling as a means of transport for the sake of congestion, air quality and physical health. Statistics from the DfT reveal that in Great Britain in 2019, cyclists and pedestrians, respectively, incurred 4,891 and 1,640 casualties per billion passenger miles travelled, whereas for cars this value is only 195. With this in mind, understanding the safety implications of a modal shift to more active travel is necessary.

This research will identify and investigate the factors that correlate with the frequency and severity of walking and cycling crashes in Great Britain. Extensive data is available on the location and circumstance of these crashes and also on measures of vehicle exposure, socio-demographic composition, and environmental characteristics at varying levels of granulation.

This research will employ advanced statistical modelling techniques, which can account for unobserved

heterogeneity and spatial dependencies. Inferences drawn are thus expected to contribute to a more complete understanding of active travel safety, with the aim of influencing future traffic safety and transportation planning policies in Great Britain.

Developing a Traffic Flow Controlling Method using Autonomous Vehicles to Dissipate Congestion on Motorways (PhD Studentship from September 2019), Hassan Abu Saq. Supervisors: Dr I. Kaparias, Dr B.J. Waterson

Reducing congestion is a key challenge for any road transport system operator. Traffic congestion is estimated to cost the UK around £7.9 billion per year (with drivers spending an average of 178 hours per person per year in traffic congestion). Congestion also leads to more acceleration and deceleration of the vehicles, which results in greater fuel consumption and higher pollutant emissions. As it is now widely recognised that building new roads can only offer short-term relief to the problem of congestion, efforts have more recently shifted to the solutions in the domain of technology. Current techniques for controlling the traffic flow and for reducing and dissipating congestion include predominantly infrastructure-based systems, such as Variable Speed Limits and Lane Advisory Information. However, these techniques have limitations e.g. concerns static control and lack of adequate enforcement, which often reduce their effectiveness. This project attempts to overcome these limitations by investigating whether alternative dynamic control approaches using autonomous vehicles (driverless cars) could be more effective.

3.3 Energy and Environment

Decarbonising Transport through Electrification (DTE) (EPSRC Network+ Grant. September 2019 – December 2023). *Contract Holder:* Prof J.M. Preston

This network is led by Prof L. Cipcigan of Cardiff University and also includes Birmingham, Bristol and Cranfield Universities. The DTE Network+ brings together academia, industry and the public sector to address the challenges limiting the current implementation of an electrified, integrated transport system across the automotive, aerospace, rail and maritime sectors. The DTE Network+ is exploring drivers for change within the transport system including technological innovation, individual mobility needs and economic requirements for change, alongside environmental and social concerns for sustainability and consider the role, social acceptance and impact of policies and regulations that will result in emissions reduction. It has adopted an integrated whole system approach that will address short, medium and long-term time-frame challenges, using a multi-layered approach that considers vehicles and technology, charging infrastructure, the supply of electricity and smart mobility. Further webinars were held in 2022 and further seed-corn funded research projects have been initiated. For more details see: https://dte.network/

Centre for Re-Engineering for Electric Mobility (RE4EM) (Faculty of Engineering and Physical Sciences, January 2020 to December 2023) *Contract Holder:* Prof J.M. Preston with Prof A. Cruden (Energy Technology Group) and Prof L. Wang (nCATS – National Centre for Advanced Tribology at Southampton).

With the climate emergency high on the global agenda, and many nations planning to prohibit the sale of new diesel and petrol cars within the next two decades, there is an urgent need for progress towards cleaner transport systems – in particular, electrified systems. This Centre of Excellence will accelerate the pace of change through advances in energy storage technology, the development of digital tribology to optimise electric vehicle (EV) components, the redesign of human–machine interfaces and a systems approach to infrastructure planning RE4EM's approach involves re-engineering existing infrastructure and vehicles to deliver a more sustainable, interconnected transport system, with a focus on road transport as well as the transition to electric propulsion for rail, air and sea transport systems. Recent work has included a seminar on whole system approaches to decarbonisation, a series of undergraduate and taught postgraduate student projects and PhD research on the wear of electric motors (Daniel Powers). For more details see: https://www.southampton.ac.uk/re4em

Decarbonising Maritime Freight Transport (PGR Student, from September 2022) Eleanor Tunick. Supervisors: Dr L. Ait Bihi Ouali, Prof A. Sobey

With 95% of all UK imports and exports undertaken via shipping, it is clear to see the increased reliance that the global supply chain has on maritime freight. Targets of a 50% reduction in greenhouse gas (GHG) emissions by 2050 have been set by the International Maritime Organisation (IMO), leading to decarbonisation being pushed forward as a key priority in the shipping industry. One major, and often overlooked contributor to GHG emissions are ports; delays and inefficient processes often lead to long queues, resulting in engine idling, and ultimately more GHG being released. This research will investigate ship's behaviours in port using automatic identification system (AIS) data; in addition to this, the economic effects of port delays will be explored. Particular interest will focus on any incentives that may encourage port delays, as well as how to make efficient ports stops and other emission reducing practices more economically viable to shipping companies.

3.4 Future Technologies

Solent Future Transport Zone. Theme 1: Personal Mobility (DfT, January 2021 to June 2025). Dr H. Howarth, Dr J. Kim, Dr R. McIlroy, J. McKay, Dr A. Wong, Dr M. Young. *Contract Holder:* Prof J.M. Preston.

Solent Transport has been awarded £28.8 million by the Department for Transport (DfT) to develop a 'Future Transport Zone' (FTZ) for the region, in partnership with the four local authorities of Hampshire County Council, Isle of Wight Council, Portsmouth City Council, and Southampton City Council. Running now until June 2025, the programme involves developing and trialling innovative transport solutions, including: (1) 'Breeze', an integrated multi-modal platform and Mobility-as-a-service (MaaS) app; (2) a new range of 'Solent Go' travel products; (3) wide-scale use of hire e-scooters, bikes and e-bikes in Portsmouth, Southampton and the Isle of Wight; (4) pilot trials of dynamic demand-responsive transport; (5) new mobility credits incentives; (6) wider business-to-business engagement for sustainable travel; (7) freight macro- and micro-consolidation of deliveries; and (8) drone

logistics. (The macro/micro/drone logistics projects are described further in section 3.3 above.)

TRG is leading the monitoring and evaluation (M&E) of the overall FTZ programme, working in conjunction with TRL, who act as the lead advisor for Solent Transport, and the University of Portsmouth, who lead on the M&E of the MaaS and logistics projects. The team also engage, report and share insights with NatCen, who lead on the national evaluation of all the UK FTZs on behalf of the DfT, as well as refining the Logic Maps for mapping the programme and project objectives/inputs to expected outputs and outcomes, the dedicated M&E traffic and transport 'Data Explorer' visualisation and analysis tool has been expanded to encompass:
(1) daily and hourly traffic network information from the available on-road sensors in Portsmouth and Southampton;
(2) data from the Sub Regional Transport Model (SRTM) as provided by SYSTRA;
(3) the Propensity to Cycle Tool as developed by Lovelace and Goodman;
(4) Data on the use of ITSO Smartcards, provided by Unicard.

Fundamental research is being undertaken to assist in the development of a Mobility-as-a-Service (MaaS) app that has been commissioned from the platform provider Trafi and their partners (Behavioural Insights Team and Unicard). TRG research and development work focuses on two areas. The first is user requirements in terms of the information (and incentives) required to overcome barriers to change, including information concerning the environmental impact of travel decisions. This has involved in-depth literature reviews, detailed study of the University's 2019 and 2022 travel surveys and the development of asynchronous online focus groups. The second is the use of Human Factors methods to design the digital interfaces. This has included the use of user centered ecological interface design and the principles of iterative inclusive design. Benchmarking work has continued through the use of heuristic analyses, whilst workshops have been held on Iconography and Design with Intent. In addition, extensive Cognitive Work Analysis has been undertaken. Detailed recommendations have been made to the app provider.

Increasing User trust in Mobility-as-a-Service IoT ecoSystem (UMIS) (EPSRC PETRAS National Centre of Excellence for IoT Systems Cybersecurity, April 2021 to June 2022) Working in conjunction with colleagues in Electronics and Computer Science (G. Wills, N. Tsakalakis, S. Stalla-Bourdillon, T. Omitola and R.Gomer), Dr B.J. Waterson, Prof T.J. Cherrett

The UMIS project investigates mechanisms for increasing user trust in Mobility-as-a-Service (MaaS) in an IoT ecosystem for the next-generation transportation-systems.

IoT-enabled MaaS systems bring together multiple transport networks and services into a single cohesive user experience enabling citizens to use multiple modes of transport to find and complete their journeys. For a user to plan a journey, they will need to provide their travel plans (to the MaaS), and to make a journey, they will need to supply payment credentials. At the same time, end-users also need to consume data from the system. Collaborative sharing and linking of safe, useful data between different stakeholders under secure and rights-respecting conditions will be vital for building a trustworthy process and making the service highly trusted.

Effective, appropriate, secure and privacy-preserving data usage, sharing, and re-usage requires well-defined data governance roles and processes.

This project will create a data governance framework that is by-design trustworthy and compliant with UK data protection law facilitating legal and ethical data re-usage between the MaaS stakeholders. The project will develop models used to protect privacy of user data especially during data analytics, inferencing and exchange, resulting in a Privacy-preserving and Privacy-enhancing model for data governance for next-generation transportation systems.

Examination of the Effects of New Transportation Technologies and Business Models on Urban Structure

(PhD from January 2019). Paraskevi Sarri. Supervisors: Dr I. Kaparias, Prof J.M. Preston

The past years there has been a start of a new era in transportation, which will change the way people travel daily and impact their lives. More specifically new technologies, such as driving autonomy and business models that help for personalised travel plans and network efficiency have been researched in depth. Interestingly, combinations of technologies and business models result into even more sophisticated and sustainable travel options. The main goal of these interventions is to develop mobility solutions with integrated pricing. The last time that such innovative interventions in transport were implemented was when the first car that was created and was powered by an internal combustion engine. The car opened financial opportunities and contributed for the distribution of land uses for the cities of today.

As mentioned, the literature for the new technologies and business models is extensive. However, the impacts of these on the urban structure is still a subject that has not been researched as much as it should have. In order examine in depth this subject mathematical modelling and simulations are essential, but most importantly the change of their internal structure is the most significant element of analysis. A question that concerns researchers is how classic urban planning should be linked with other kinds of planning. Using integrated land use and transport modelling, would be the most appropriate way of achieving the aim of this project, and Land Use and Transport Interaction (LUTI) models are the most appropriate tool for simulating autonomous vehicles and receiving land use results. Consequently, they could also be used for modelling various types of transport technologies and business models.

Predicting the impacts of these technologies in everyday life is necessary at this point. Providing predictions is a practice that is deeply linked to science and is an integral part of the design of urban systems around the globe. In order to integrate new technologies and business models in LUTI models, it is inevitable that the internal mathematical structure of LUTI models has to change and become more adaptable. To achieve this using multidisciplinary models and various mathematical relationships that relate transportation, location and land use characteristics is essential describe and analyse urban systems. The DELTA LUTI model has been chosen in this project, as it has been deemed appropriate due to its strong theoretical foundations.

More specifically, the methodology that has been developed includes analysis of

discrete choice models, which are currently being developed. Moreover, the estimation and incorporation of different kinds of costs, relating to car ownership, vehicle operating costs and values of time. Finally, sensitivity analysis as well as the use of the Delphi method are also integral parts of the procedure as it can relieve a number of essential results that are important for conducting the conclusions from this analysis.

The results of such a study come from both the urban models but also other aspects, such as transportation models and data from new technologies, thus they can be beneficial for both the individual and the society in general. Here it is important to mention that some of the results that have occurred from analysis in this project were accepted for presentation from the 9th and 10th Symposium of the European Association for Research in Transportation and to the 10th International Congress on Transportation Research and submitted to peer reviewed journals and conferences for assessment. New technologies such as autonomous vehicles, can bring sustainability to mobility solutions in the future and thus being able to predict the impacts of them can prevent possible policy and planning mistakes. The new and more versatile to new technologies framework can be used as a tool for both urban design and transportation planning and engineering.

Exploring person-based signal control paradigms in urban road networks

(PhD from January 2018). Zongyuan Wu. Supervisors: Dr B. Waterson, Dr B. Anvari (external)

This project aims to better understand the impacts of occupancy information from connected vehicles on urban signal controls and potential benefits of adopting them, in terms of person related performances. The report reviews existing urban signal control strategies involving vehicle-based controls and person-based controls, points out their drawbacks and highlights the research gaps. This research proposes a Proposing an Adaptive Person-based Signal Control Algorithm (PerSiCon-Junction) to minimize person delay by exploring all phase combinations and feasible signal plan strategies in isolated urban junction under 100% CV penetration rate. A Coordinated Person-based Control (PerSiCon-Network) then developed to extend PerSiCon-Junction to be coordinated in large road network scales. PerSiCon-Junction is also improved to an Adaptive Person-based Signal Control Algorithm with Buses (PerSiCon-Bus) to incorporate bus mode and achieve person-based objectives in more complicated vehicle mixtures. The research builds evaluation frameworks for coordinated PerSiCon-Bus in a real-world large scale case study with variety traffic demand levels and penetration rates, and other different parameters. An Estimation status of Unequipped Vehicle with Occupancy (EUVO) was then proposed to improve the performances of PerSiCon-Bus in low CV penetration rates.

Effects of Connected Autonomous Vehicles on highway infrastructure performance: A whole-life costing approach to design optimisation

(sponsored by the EPSRC Sustainable Infrastructure Systems CDT, iPhD studentship from September 2017). Hameed Jehanfo. Supervisors: Dr I. Kaparias, Prof J.M. Preston

It is estimated that by 2025, the global intelligent mobility market will be worth £900bn per year, with fully autonomous vehicles predicted to hold a 25% market

share in the automobile industry by 2030. The UK has signalled its resolve to be prepared for this transport shift by launching the Centre for Connected and Autonomous Vehicles (CCAV) in 2015 with the sole objective to “keep the UK at the forefront of the development and deployment of [CAV] technology”, investing more than £250m into 70 research and development projects from 2014 to 2018, and enacting the Automated and Electric Vehicles Act 2018, which provides bespoke insurance for CAVs accidents. Yet, the government acknowledges that the existing roads – which have been design and constructed using standards developed for conventional vehicles - are unfit for CAVs. But developing a new approach to road design for CAVs must be supported by adequate research to avoid uneconomical over-designs or under-designed highway infrastructure which fail prematurely. An optimised whole-life cost (WLC) design solution is required to achieve a balanced approach.

A key component in whole-life cost analysis is the physical road infrastructure, of which the structural pavement forms a major constituent. Current pavement designs are deliberately conservative due to two main factors. Firstly, the lane distribution models of manual trucks on multi-lane highways are indeterminate. However, the lane choice of CAVs can be more precisely controlled, reducing uncertainty in pavement fatigue loading. Secondly, wheel channel positions of manual trucks within the lanes follow a normal distribution function, which moderately concentrates the wheel loads, very much unlike the zero (high wheel load concentration) or uniform wander (no wheel load concentration) models of connected autonomous trucks (CATs).

Investigations into relationships between CAVs and engineering aspects of road design are scarce. Although there is some activity in the area of pavement analysis for CATs, none provides a whole-life optimised solution for highway re-design. Also, the existing studies do not account fully for the effect of lane widths on pavement deterioration in their analysis.

The core aim of this research is to find highway design solutions for CATs that optimises the WLC of the highway infrastructure. This will be achieved by analysing the pavement failure effects of CATs as the main focus, and then extending the work to incorporate the highway engineering variables (such as lane configuration and widths), that significantly impact on pavement deterioration. A complex amalgamation of inter-linked transportation mathematical models involving CAT proportions, actual speeds, posted speed limits, lane widths, free-flow speeds, traffic volumes, lane capacities, lane utilisation distributions, construction cost-time models and pavement failure rates, will be used to determined travel cost. In additional WebTAG and other CAT performance secondary models for accidents and emissions would be applied to measure costs.

Based on a conceptual motorway link, multiple scenarios will be generated and analysed, and then costings integrated to produce an optimal highway infrastructure design model for CATs. The research will formulate a new WLC optimisation technique which can be used to produce a model for designing highways for CATs.

3.5 Rail

An Open Source Rail Dataset for Africa Phases 1 and 2 (FCDO, March 2022 to December 2022). Dr M.A. Young. *Contract holder*: Dr S.P. Blainey, subcontract from University of Oxford

The aim of this project was to extend previous work to create a routable rail network for East Africa (Kenya, Uganda, Tanzania, and Zambia) to cover the whole of the African continent. Due to the extensive nature of the existing networks (including light rail, subway and tram), and large number of construction schemes and scheme proposals, work primarily focused on creating an accurate routable network of the existing heavy rail lines currently in use in each country. The countries processed have been thoroughly researched based on information available via web-based sources. As with the previous work in East Africa, a single line is used to represent the network irrespective of the number of physical tracks (unless alternate gauges exist) and where possible an existing line mapped in OpenStreetMap has been used. The rail network created identifies the track gauge (including dual gauge where applicable) and whether lines are used for passenger and/or freight services.

Understanding the impact of Heavy Axle Weight (HAW) (RA9 and RA10) on infrastructure (RSSB, October 2022 – July 2025) Dr S.P. Blainey, Dr J Armstrong, Dr M.A. Young. *Contract Holder:* Prof W. Powrie

There is a lack of coordinated scientific evidence, data and analytical tools to enable understanding of the true effect of heavy axle loads on railway infrastructure. Discussions within the railway industry have identified the need to develop a HAW Infrastructure Interaction Model, the aim of which would be to equip the industry with a scientific approach to assessing and quantifying the impact of heavier axle weight vehicles on a route level basis. This would in turn give an understanding of additional maintenance needs and costs, and hence confidence in investment decisions on infrastructure enhancements. This project will meet this need by developing a proof of concept / demonstration interactive “MVP-light” tool for analysing and visualising the rail network, taking into account existing HAW restrictions and assets that should be considered when it is desired to exceed existing restrictions. This will interface with work carried out elsewhere in the University as part of this project to develop enhanced degradation models for rail infrastructure in response to repeated loading.

Assisted VSTP (Very Short Term Planning) (Bellvedi/Tracsis for RSSB from July 2020 to May 2022). Dr J Armstrong. *Contract Holder*: Prof J.M. Preston.

Timetable planning for Britain’s railways is a long-term process, starting over a year prior to the twice-yearly introduction of new national timetable. Alongside the longer-term term timetable planning (LTP) process, there is also a requirement for the short- (STP) and very short-term planning (VSTP) of passenger and freight trains in the days and hours prior to their operation, in response to changes in demand and operating circumstances, including operational disruptions. The short timescales available for STP and, especially, VSTP services currently precludes their full validation, introducing performance risks and the likelihood of sub-optimal infrastructure, rolling stock and traincrew resource allocation.

TRG assisted Bellvedi/Tracsis in the development of an improved VSTP system, focussing on the identification of robust VSTP train paths and the development of improved contingency plans in response to operational disruptions.

Carbon Accounting for Bridges (Funded by Network Rail, PhD from February 2021). Hamish Moodley. *Supervisors*: Dr S. Afshan, Dr S.P. Blainey, Prof J.M. Preston.

Reinforced concrete is a commonly used material for bridges as it is perceived as versatile, durable and economical. However, corrosion of reinforcement bar is considered as the primary cause of deterioration of reinforced concrete structures, which leads to reduced safety, serviceability and shortens design life. This of particular concern in reinforced concrete bridges in environments, such as marine environments, where exposure to chlorides leads to the initiation and propagation of chloride-induced reinforcement bar corrosion.

Stainless steel reinforcement bar provides a solution to the corrosion problem in reinforced concrete structures having superior corrosion resistance to traditionally used carbon steel reinforcement bar. The inherent corrosion resistance of stainless steel reinforcement bar is due to a transparent and tightly adherent self-healing thin layer ($5x10^{-6}$ mm) of chromium rich oxide that forms on the surface of the stainless steel reinforcement bar. However, stainless steel reinforcement costs approximately four to nine times more than carbon steel reinforcement bar. Therefore, it is fundamental to investigate the economic, environmental and social life cycle cost of stainless steel reinforced bridges and compare this with carbon steel reinforced concrete bridges.
This research will conduct life cycle cost analysis on reinforced concrete bridges comparing stainless steel and carbon steel reinforcement bar, alongside other corrosion prevention methods such as increased concrete cover, reduced water/cement ratio and hydrophobic coatings. Furthermore, due to the limited research on stainless steel reinforced concrete structures, this research project will investigate the mechanical properties of stainless steel reinforcement bar and stainless steel reinforced concrete members. This investigation into mechanical properties will be used for the optimisation of the stainless steel reinforced concrete bridge design, allowing for a more comparable life cycle cost analysis.

Carbon Footprinting of Railway Embankments and Cuttings: Assessing Potential for Carbon Reduction and Carbon Offsetting to Reach Net Zero (Sponsored by Network Rail, PhD from February 2021). Tracey Navaei. *Supervisors:* Dr S.P. Blainey, Prof J.M. Preston, Prof W. Powrie.

It is now an established fact that there is human influence on the climate system, and that the global average surface temperature increase in the period 2010-2019, relative to the pre industrial comparator 1850-1900, lies between 0.8 and 1.3°C. Reaching net zero GHG emissions is therefore essential for temperature stabilisation, and there may even be a requirement for net negative CO2 emissions to return global temperatures to lower levels in the long term.

With the government's enactment into law of the requirements to reach net zero carbon emissions by 2050, Network Rail

has taken up the challenge to reach these ambitious targets via Science Based Targets and the embedding of these into its Environmental Sustainability Strategy.

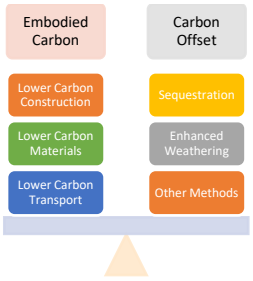
Currently there is little data in the literature on specific railway geotechnical assets, with these often being grouped together as “earthworks.” This research project aims to extend current knowledge via identification and categorisation of different railway geotechnical assets, specifically embankments and cuttings (both soil and rock), across the UK mainline railway, and quantifying the Business As Usual (BAU) Carbon Footprint (embodied CO2e) in the materials and processes within each asset type.

BAU footprints of case studies can be analysed and carbon “hotspots” can be identified. The potential for emissions reductions can then be explored and recommendations made to reduce the carbon footprint for these types of intervention.

During 2022 six case studies have been footprinted for the BAU scenario using the Rail Safety and Standards Board Rail Carbon Tool (RSSB RCT). It is anticipated that tens of further case studies will be received from NR over the course of the first quarter of 2023, allowing for a large data set to be amassed and analysed to provide granular details of where the carbon lies in these types of interventions. This will then indicate the potential pathways which could be followed in order to reduce emissions.

The project will then further expand these BAU scenarios into whole life footprints covering PAS2080 (Publicly Available Specification for Carbon Management in Infrastructure) life cycle stages A1-C4, which encompass before use, use and end of life stages. These expansions will be created in the RSSB RCT using the PAS2080 template to provide consistency with, and adherence to, this PAS.

Following analysis of the BAU and expansion scenarios, the potential for emissions offsetting will be investigated via a variety of Negative Emissions Technologies, such as tree planting, across a variety of intervention lifespans (maintenance 2 years, refurbishment 20 years, and renewal 120 years). This will enable assessment of how such technologies could allow the balancing of emissions associated with geotechnical infrastructure to reach net zero, as per the figure below.



Net Zero Carbon Balanced Scales

Research on High-speed Railway Network Capacity Utilisation & Optimisations (Funded by China Scholarship Council, PhD from September 2020). Jiaxi Li. *Supervisors*: Prof J.M. Preston, Dr J. Armstrong.

Rail transport, with its eco-friendly effects and high carrying volumes, creates strong economic linkage among cities and is a valuable solution to commuting crowds and other travel for most countries. However, what troubles railway operations throughout the world, no matter whether the railway is a high-speed system or not, is the increasingly intensive capacity utilisation of railway

infrastructures in some busy areas, in peak periods, or both. This causes a gap between train service supplies and travel demands.

Capacity utilisation indices, based on timetable compression, were first developed for plain track and more recently have been developed for nodes (junctions and stations), including work at the University of Southampton. However, they are rarely developed for networks. Building on previous works by the student in undergraduate and postgraduate research, the initial focus will be on optimising capacity utilisation for the China High Speed Rail Network, the largest high-speed railway network in the world, serving a complex Origin-Destination Passenger Flow structure.

This research will develop an optimisation framework of railway network capacity utilisation to achieve a balance between a train operation structure (TOS) (the time distribution of a certain number of train lines) and a highly efficient capacity utilisation of a high-speed railway network. Particular attention will be paid to cross-line trains that are particularly common on the Chinese High Speed Rail network.

The transferability of the analytical framework and assessment method to classic rail services and the interaction between high speed and classic rail service will be examined, possibly adopting a case study of High-Speed 2 in the UK and its interaction with classic rail services provided by the West Coast Partnerships.

Streamlined Train Travel: Assessing and Reducing Door-To-Door Journey Times Associated with New Rail Infrastructure (funded by the Turkish Government, PhD Studentship from September 2018) Emine Tugba Yazici. *Supervisors:* Dr S.P. Blainey, Dr M.A. Young

There are many reasons for investment in high-speed rail (HSR), such as increasing transport capacity, enhancing network, supporting mode shift from air travel to HSR, but often one of the primary reasons for promoting HSR investment is a reduction in journey time. While HSR services are usually able to achieve a reduction in on-board time between major centres, not all HSR services are necessarily successful in achieving reductions in door-to-door journey time. Therefore, this research reviews high-speed rail routes and their stations around the world to investigate factors affecting the door-to-door journey time such as station connectivity, accessibility, location, HSR route alignment and service operation. As assessment will be made with respect to the options for HSR to serve the East Midlands. Then, with the assessment of the existing applications, for the future HSR construction, a guideline will be provided to help transport planners on the provision of HSR services in a way which maximises the potential journey time benefits.

An Assessment of Reforms to Optimise the Railway Organisation in Saudi Arabia (PhD from April 2018). Sultan AlSaedi. Supervisors: Prof J.M. Preston, Dr S.P. Blainey.

The Saudi government has started to reform its railway industry by following the international trends in railway reform. The initial stage of railway reform that has occurred was the ownership reform when the government created a new railway company, Saudi Railway Company (SAR), for the North-South Railway project rather than constructing and

operating this project under Saudi Railway Organisation (SRO) responsibility. The reforms also involved privatising Haramain High-Speed Rail (HHSR) under a build-operate-transfer (BOT) contract with a Saudi-Spanish alliance. Most recently, there has been a merger in which SRO assets have been transferred to SAR. Despite these reforms, the railway's industrial organisation can be seen as not fully developed compared to the other industries. In addition, the rail infrastructure is not yet fully developed. The current rail network has a total network-line length of 4,580 km, and the planned rail projects will expand the network up to 9,900 km by 2040. Therefore, the aim of the research project is to determine the optimal organisation of rail services in Saudi Arabia that has not fully developed its rail network. Moreover, the project assumes different forms of railway reform to achieve the optimisation.

The railway reform can be described as any changes in the rail policies, investment plans and the structure of the rail industry. Practically, the railway reform can be clustered in three blocks based on country experiences. The first block is the regulation reform, which aims to introduce different forms of competition, to impose different levels of economic regulation, to create regulatory bodies, etc. The second block is the structural reform, where the railway organisation is restructured horizontally and/or vertically in two models. A vertical separation model is a form of separating the rail infrastructure from train operation. A horizontal separation model is a form of segregating passenger from freight rail services and/or regional division. The last block is the ownership reform, which takes a form of explicit privatisation or deregulation of the rail market.

To deliver the assessment, the project sets three measures to select the optimal railway organisation. The first measure is the technical efficiency, which aims to identify the most railway reform option that can maximise production technology. The second measure is the cost efficiency, which aims to select the optimum railway reform that can achieve cost minimisation. For these two measures, the project will develop a benchmark by using the Data Envelopment Analysis (DEA), Corrected Ordinary Least Squares (COLS) and Stochastic Frontier Analysis (SFA). The last measure is the socioeconomic efficiency, which means that different forms of railway organisation will be assessed with respect to welfare economics. This will involve an assessment of whether regulatory changes impact on demand level. The project has selected 32 countries from Europe, the Middle East, the Central and East Asia between 2000 and 2017 with a maximum of 439 observations. At the end, the project will draw some conclusion and recommendations regarding the rail policies, and these recommendations will be validated by interviewing the railway industry experts.

A Whole Life Carbon Model for Railway Track System Interventions

(EPSRC and Network Rail Sustainable Infrastructure Systems iPhD from January 2018). Georgios Rempelos. *Supervisors:* Prof J.M. Preston, Dr S.P. Blainey.

The UK's rail network consists of approximately 20,800 miles of track and estimates suggest that the volume of maintenance and renewal required results in approximately 430,000 to 934,000 t CO_2 per annum. This project aims to develop a cost and carbon

emissions model framework for railway track systems, covering the whole life of the infrastructure. The model will be capable of modelling the impacts of a wide range of track system interventions, including the full range of engineering solutions developed during the Track21/Track to the Future (T2F) research programmes. In essence, this project aims to produce a framework which will work as an analytical tool to better understand the carbon footprint of today's rail industry and, subsequently, assist the decision-making process for both minimising CO_2 and realising sizeable financial/social benefits. The results from this work are purposed to be fed into a wider Cost Benefit Analysis (CBA) framework, in order to objectively assess different track interventions qualitatively and quantitatively at a macro level and subsequently assist stakeholder decision-making.

Presently, the project is focussed on analysing a range of future track systems, both for plain track and for switches and crossings. In order to establish the extent to which these are an improvement over existing ones, it is necessary to undertake a whole-life environmental appraisal of their relative performance. Aside of the environmental externalities of the infrastructure, the project attempts to provide a link between both cost and carbon, examining prospective trade-offs between the upfront and the on-going financial and environmental externalities throughout the useful life of these structures. Of particular interest are potential performance comparisons between different optimised ballasted track forms with interventions developed during Track21/T2F.

Work so far focussed on individual life cycle cost (LCC) and carbon foot-printing studies based largely on existing embodied carbon factor databases such as the 'Bath Inventory of Carbon and Energy', the 'Rail Carbon Tool' by Rail Safety and Standards Board (RSSB), and a rail industry-specific software, VTISM. In detail, this includes a streamlined LCA study to evaluate and compare the lifecycle Greenhouse Gas (GHG) emissions associated with the four most common sleeper types present in the UK rail network. This work is now extended with a focus on LCC and GHG emissions modelling of optimised ballasted track forms (e.g. fibre-reinforced ballast, under sleeper pads, twin-block sleepers, composite sleepers, re-profiled shoulder track, and finer ballast gradings, etc.) through route-based case studies. To do that, a methodology, based on relative settlement was proposed to adapt the results of laboratory tests into a suitable parameter for input into VTISM.

Future work will extend the proposed framework to include other costs/revenues and externalities, with the overall aim of developing an integrated methodology for investigating the potential of different interventions to reduce both LCC and externalities of ballasted track. This is important as it could provide new perspectives for targeting lifecycle enhancements, as well as better aid project and policy decisions.

Feasibility of Public Private Partnership for the Railways in the GCC countries (PhD (Part-time) from October 2018). Fawad M Rajput. *Supervisors:* Prof J.M. Preston, Dr S.P. Blainey.

The purpose of this research is the "Investment choice" of establishing a modern rail, and other transport, networks

in the Gulf region. From recent literature and media review it emerges that almost all Gulf Cooperation Council (GCC) authorities are seeking alternatives to state investment in major transport projects. An example of this could be the ambitious yet hugely delayed GCC rail project. It is unclear if, or how, an investment model has been considered in the strategic decision of the GCC rail network, but it seems that any such studies have only been done at a rudimentary level. It is argued by Harry Markowitz that stock investors with sufficient computational resources can be compared with government bodies and client organisations and therefore it is feasible to assume that portfolio theory can either be utilised prior to the investment decision or soon after the feasibility study and decision to go ahead with one or the other project. Therefore, in the context of GCC rail projects, this research will draw parallels with the investment portfolio theory and look at alternative models such as Public Private Partnerships (PPPs).

In doing so, this research will explore the state of the PPP investment in the GCC transport infrastructure, in particular rail network. By conducting empirical studies such as surveys and interviews from key decision makers in the GCC establishments, the research will compare GCC model with the popular and practised model of PPP in the western world. As a result, a PPP template for the GCC region with due regards to its own unique features of mode of governance would be proposed.

As noted above, the GCC rail project is a long-term commitment and a programme of a series of projects which are to be built over many years and perhaps decades. From an organisational point of view the GCC rail programme is akin to a portfolio of projects requiring certain budgetary commitments on their own merit and on competing terms with each other. The knowledge of the current PPP practices in the GCC states acquired through this research can be used to further explore if a portfolio theory can be used for decision making among a portfolio of projects such as GCC rail and how this can be beneficial for the project proposers as well as investors.

The study will provide recommendations, a framework and a model for transport infrastructure investment in the GCC region. This study will be useful for government organisations and other stakeholders for investment choice for a new railway network. Additionally, this research work can also recommend on existing networks to establish network wide polices of freight and passenger movement, for a viable business case.

3.6 Transport and Infrastructure Policy

Routable Active Travel Infrastructure Networks (RATIN) Phases 1 and 2 (Ordnance Survey, January 2022 to March 2023). Dr M.A. Young. *Contract holder*: Dr S.P. Blainey, jointly with GeoData Institute.

Active travel has received increased investment and interest in many countries both due to COVID-19 and to policies which promote a shift to active travel (AT) to support a wide range of public and individual goods. However, the majority of investment so far has been focused on physical infrastructure to facilitate active travel, rather than on the data infrastructure which can help enable people to shift trips to active modes. There is no comprehensive geospatial representation of the active travel

infrastructure network in the UK, and current fragmented data and data models and a lack of data standards pose a barrier to the development of the applications which are needed to support planners, users and journey planning. There is therefore a need for a more integrated, better-connected and more richly attributed active travel geospatial network model, linked to comprehensive datasets on the location and characteristics of active travel infrastructure. Phases 1 and 2 of the RATIN project aim to make a significant contribution towards meeting this need. Phase 1 undertook a comprehensive review of datasets and data models for active travel infrastructure, and developed a high level data framework for geospatial active travel infrastructure networks. Work in Phase 2 has then started to develop methods to populate this framework for a case study area in England, building on the existing Ordnance Survey Mastermap transport networks and the NGD Street Scene dataset. There has been a particular focus on three strands of work. The first involves using crowd-sourced data from OS Maps providing GPS traces of actual active travel trips to fill gaps in the base OS path network. The second involves extending the Mastermap data model to allow the representation of differential pavement presence characteristics and crossing points on individual road links. The third strand of work further enhances this pavement presence information by calculating detailed information on pavement widths derived from OS Mastermap topography data. The outputs from the data processing are integrated and presented in a demonstrator routing tool, allowing the benefits of the enhanced datasets to be easily demonstrated to key stakeholders.

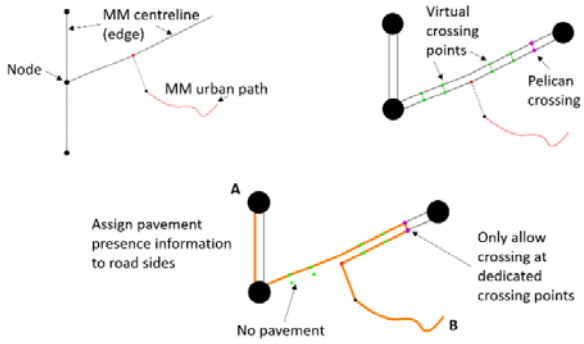


Figure: Enhanced representation of path data via two-sided road links

DAFNI ROSE (EPSRC from April 2021 to March 2023). *Contract Holder:* Dr S.P. Blainey, jointly with STFC and twelve other universities.

This EPSRC Research Only Strategic Equipment grant aims to increase usage and capability of the Data and Analytics Facility for National Infrastructure (DAFNI), to support research in EPSRC's Engineering programme and related fields. DAFNI has been developed over a 4 year development phase, thanks to a capital grant from EPSRC. The system is now ready to deliver game-changing computational and data services to the community researching into infrastructure systems. The ROSE grant is allowing the DAFNI team to build on and expand the user group that has been established within the development phase of DAFNI, thus allowing a larger group of researchers to take advantage of the benefits of the investment in DAFNI. The funding provide by ROSE has facilitated the provision of two years of high-quality service, with continuous improvement to the DAFNI system.

Decision Support Systems for Resilient Strategic Transport Networks in Low Income Countries (FCDO, July 2020 to January 2023). A. Hickford, Dr M.A. Young. *Contract Holders:* Dr S.P.

Blainey, Prof J.M. Preston, jointly with University of Oxford.

This project forms part of the FCDO High Volume Transport applied research programme, and has involved developing and delivering what is (to the best of our knowledge) the first multi-state transport infrastructure decision support system in a developing context. The system aims to support investment decisions and option selection for long distance strategic land transport projects by providing a fast and consistent methodology for comparing the advantages and disadvantages of different project options. As well as covering infrastructure investments, the system is sufficiently flexible to also allow assessment of changes to the management and operation of long-distance road and rail systems. The project is working at national and international scales, modelling the road, rail and port networks in Kenya, Tanzania, Uganda and Zambia, with a particular focus on strategic freight network development. Initial work focused in two areas. Future scenarios for strategic transport networks have been developed covering both exogenous factors such as population and economic development and endogenous factors including infrastructure changes and advances in transport technology. The project has also assembled datasets to represent the transport infrastructure networks across the case study region and the usage of these networks. These datasets and scenarios have been used as the basis for the development of a methodology for calculating sustainability metrics associated with potential transport schemes, including (for example) carbon emissions, local air pollution, network resilience and safety. A comprehensive network resilience assessment has also being carried out, including the identification of locations which are exposed to climate hazards and quantification of the risk to transport networks at these points. The final stage of the project involved building a web-based tool to allow transport stakeholders to explore future scenarios, navigate trade-offs between different sustainability goals and compare transport investments and policies. This was demonstrated to over 50 local stakeholders in a series of four in-country workshops in September 2022, and is available via https://east-africa.infrastructureresilience.org/.

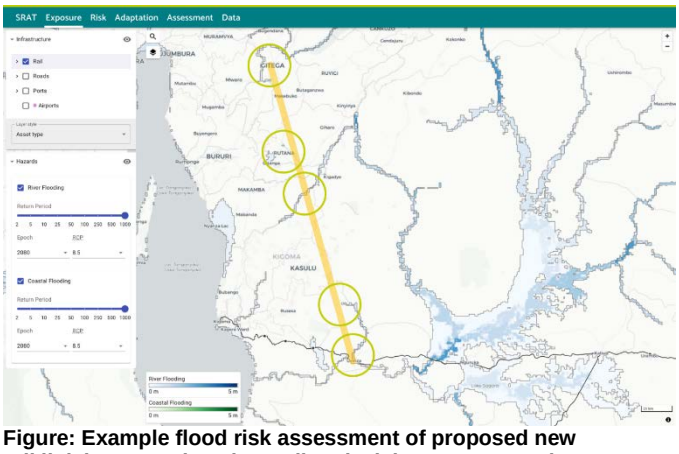


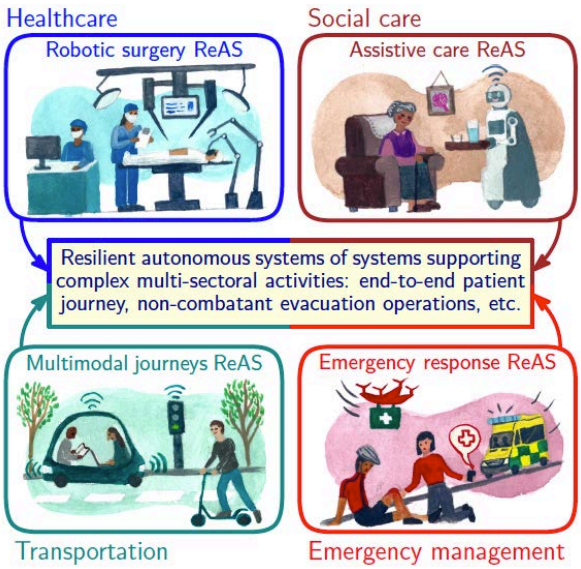
Figure: Example flood risk assessment of proposed new rail link in Tanzania using online decision support tool

REsilient Autonomous SOcio-cyber-physical AgeNts (REASON - Trustworthy Autonomous Systems Node in Resilience) (EPSRC from Nov 2020 – May 2024) Dr K.J. Parnell, S.E. Merriman. Contract Holder: Dr K.L. Plant.

Recent and forthcoming technological advances will provide autonomous systems with many of the sensors, actuators and other functional building blocks required to achieve the desired resilience levels, but this is not enough. To be resilient and trustworthy in these important applications, future autonomous systems will also need to use these building blocks effectively, so that they achieve complex technical requirements without violating our social,

legal, ethical, empathy and cultural (SLEEC) rules and norms. Additionally, they will need to provide us with compelling evidence that the decisions and actions supporting their resilience satisfy both technical and SLEEC-compliance goals.

To address these challenging needs, our project will develop a comprehensive toolbox of SLEEC-compliant resilience-enhancing methods, and systematic approaches for developing, deploying, optimising, and assuring highly resilient autonomous systems and systems of systems. The project involves close collaboration with project partners at the University of York, Sheffield University, Lancaster University and the Open University.



The REASON toolbox aims to allow resilient autonomous systems across various sectors

Trustworthy Human-Swarm Partnerships in Extreme Environments (EPSRC as part of the Trustworthy Autonomy Systems Hub, from March 2021 to March 2022). Dr K.J. Parnell, *Contract Holder:* Dr K.L. Plant

The aim of this project is to understand the contextual factors and technical approaches underlying trustworthy human-swarm teams. The project will draw on co-creation with partners and potential users to generate potential use cases and operator-centred requirements. AI-based algorithms will be used to estimate the swarm state and recommend control actions to the human operators in extreme environments. We will evaluate the trustworthiness of our system in a user study with a proof-of-concept HAC simulation and testing platform. The vision is to make our approach broadly applicable in human-swarm use cases, within and beyond the TAS Programme.

Open Flight Deck simulator. Photo credit: GE Aviation as part of the Open Flight Deck Project

ACHILLES (Assessment, Costing and Enhancement of Long-Life, Long-Linear Assets) (EPSRC Programme Grant, July 2018 to December 2023). Dr J. Armstrong. *Contract Holder:* Prof J.M. Preston.

ACHILLES is led by Newcastle University and also includes universities at Bath, Durham, Leeds and Loughborough, as well as the British Geological Survey. TRG is working closely with the Infrastructure Group at the University of Southampton. ACHILLES is focussed on

long-linear assets that are critical to the delivery of services over long distances such as road and rail embankments and cuttings, pipeline bedding and flood protection structures. TRG's work provides economic forecasting and decision support at the network level. More specifically, a model of Whole Life Costs of interventions is being developed and the social costs of service disruptions examined. Risks and uncertainty will be considered using Monte Carlo Simulation within a Bayesian hierarchical structure. Decision making using a variant of minimax regret is being assess. An analysis of infrastructure on the London – Bristol corridor is being undertaken as part of a Simulation and Modelling theme (SaM). This will then contribute to the Design and Decision (DaD) theme which will also consider the cost and benefits of improved information, for example from remote monitoring of slope condition.

The impact of transport project appraisal on balanced regional development in South Korea (PhD studentship, from September 2022) Changhoon Lee. *Supervisors:* Prof J.M. Preston, Dr L. Ait Bihi Ouali

South Korea has introduced and operated an appraisal framework called a Preliminary Feasibility Study (PFS) to determine whether to implement large-scale transportation projects since 1999. PFSs have contributed to effectively utilizing a limited budget by prioritising the establishment of transportation networks from a national perspective and limiting the promotion of non-urgent projects. However, on the other hand, due to the appraisal that emphasised economic efficiency, intensive investment has been made in metropolitan areas, which already have high transport demand and a relatively well-equipped network. In addition, this could be seen as one of the factors that has widened the gap between the metropolitan areas and the rural areas, and might preclude sustainable, inclusive, and balanced development.

Therefore, this research analyses how the PFS appraisal framework has affected transport facility investment by region, identifies the relationship between transportation facility and balanced development, and studies ways to improve it. The study's objectives are as follows.
1. To assess the impact of PFSs on transport investment decisions in Korea.
2. To determine whether PFSs result in regional imbalances in transport investment decisions in Korea.
3. To develop alternative transport appraisal and evaluation processes that ensure more regionally balanced and sustainable investment.
4. To apply this revised appraisal process to a set of transport investments in Korea

Evaluating the Long-Term Impacts of Local Transport Policies
(PhD from September 2022). Ahmed AL-Shuaili. Supervisors: Prof J.M. Preston, Prof T.J. Cherrett.

This project will examine the long-term impacts of a raft of policy initiatives on the city of Southampton, and its immediate surrounds, that originated with the Local Sustainable Transport Fund in 2011, and continued with the Access Fund (2017), the Transforming Cities Fund and the Future Transport Zone (both 2020). For passenger travel, these initiatives have included infrastructure investment (particularly in cycling), public transport improvements, the development of shared micro-mobility, marketing initiatives and the development of smart cards and a Mobility-as-a-Service app. For freight, they have involved the

development of micro- and macro-consolidation centres and smart logistics.

The project will develop and apply an evaluation framework that would deal with the counterfactual by determining what might have happened to the local transport system in the absence of these interventions and would be able to attribute effects to different interventions. It would investigate the use of new forms of data, models and aggregations to assess the most recent interventions in terms of economic, social and environmental impacts. Initial work has focussed on collating and reviewing the bid proposals and evaluation documents and tracking transport expenditure by Southampton City Council.

The project is linked to the Solent Future Transport Zone programme, undertaken in collaboration with Solent Transport, a partnership between Hampshire County Council, Isle of Wight Council, Portsmouth City Council and Southampton City Council, and funded by the Department for Transport.

Solent Future Transport Zone programme area

Comparative Economic Assessment of Urban Transport Infrastructure Options in Low- and Middle-Income Countries (PhD Studentship, from April 2017, funded by the Vietnamese Government and Faculty of Engineering and Physical Sciences), Minh Tam Vu. *Supervisors:* Prof J.M. Preston, Dr S.P. Blainey. **Awarded 2022**

Powered two wheelers (PTWs) are dominant in mixed traffic environments in developing countries and in particular in East Asia. Furthermore, significant increases in PTWs and Demand Responsive Rapid (e.g. Taxi and Uber) in urban areas pose a challenge to planning authorities and policy makers. A popular solution is to invest in urban public transport (PT) schemes such as Bus Rapid Transit (BRT), Urban Rail Transit (URT) and Monorail. However, many investments in PT have been ineffective. Additionally, there seems to be very little evidence on evaluation methods of motorcycles, cars and public transport to analyse feasibility of a new PT mode. Hence, the main aims of this thesis are to (i) Analyse the feasibility of new PT technologies in mixed traffic environments with a dominance of PTWs; and (ii) Identify the most cost-effective mixed transport system.

To achieve these aims, the research develops a comparative economic assessment for comparing public transport technologies, Demand Responsive Transit and private transport for a local transport corridor. The comparative economic assessment is integrated from four models: Social Cost Model, Incremental Elasticity Analysis Model, Incremental Multinomial/Nested Logit Model and Microscopic Simulation Model.

The completed assessment was applied to compare the existing mixed transport situation and twelve transport infrastructure options with the introduction of new PT technologies (Bus Rapid

Transit, Elevated Metro and Monorail) replacing the whole or part of the existing bus services; and with or without a congestion charge scheme for private transport on the chosen corridor in Hanoi, in terms of three criteria: average social cost, total general demand and PT share. The results show that five options with Bus Rapid Transit or Monorail can be feasible because of lower average social costs. In addition, the Monorail option partially replacing the existing buses in conjunction with a congestion charge scheme might be the optimal alternative based on the three criteria above. Transport planners and decision makers can draw on the findings of this thesis.

Applications of Photonics and Deep Learning in Intelligent Transport Systems – Focus on LiDAR Technology in Vision Zero

(PGR Student from September 2018, EPSRC and DSTL sponsored). Zeina Nazer. *Supervisors*: Prof O Muskens (Physics), Dr B.J. Waterson.

Vision zero for pedestrians is ideal. Vision zero eliminates deaths and serious injuries for pedestrians from roads. Safer roads ensure better living leading to smarter cities. However, vision zero is not being achieved. There are still traffic accidents due to errors caused by human drivers. Autonomous Vehicles could reduce errors if they can 'see' like humans without making mistakes like humans. Current seeing is not good enough to achieve full autonomy and to eliminate human errors. Can we improve it? The gap in knowledge that this research project aims to fill is '*How can the combination of Intelligent Transport Systems (ITS), Photonics and Deep Learning be improved in order to improve pedestrian safety and lead to vision zero?'*

Intelligent Transport Systems (ITS) use advanced sensor technologies, information and communication to provide optimized and sustainable transport systems. ITS help roads, vehicles and cities become safer, smarter and better connected.
Advances in sensor technology (part of Photonics) include imaging, radar, LiDAR (Light Detection and Ranging), electronics, and artificial intelligence have enabled advanced driver assistance systems (ADAS) and automated driving. Sensor fusion enables safety features including collision avoidance, blind spot monitoring and lane departure warning among others. Fully synchronizing the operation of such systems through sensor fusion allows fully autonomous vehicles to monitor their surroundings and warn drivers of potential road hazards and take actions independent of the driver to prevent collision.

Advanced sensor technologies can detect objects in their field of view, including ranging sensors to provide more accuracy, availability, and positioning other road participants, including pedestrians, bicycles and other vehicles. Advanced sensor technologies are crucial for the development and realization of Connected Autonomous Vehicles (CAV). LiDAR, claimed to be the eyes of the vehicle, is an important sensor used in making vehicles autonomous.

Using deep learning, algorithms are structured in layers to learn and make informed decisions, which is what powers the most human-like artificial intelligence thus, making vehicles autonomous. Artificial Intelligence of the vehicle must make the optimal decision in the absence of the driver.

This research will look into exploring Time of Flight (ToF) LiDAR and deep learning in the applications of intelligent transport systems in order to achieve Vision Zero for pedestrians. This research will explore a broader range of applications of time of flight (ToF) LiDAR technology under different scenarios. This project will initially understand, and test Monostatic LiDAR. Data will be collected and analyzed using different analysis tools. Next the project will experiment Multistatic LiDAR using diverging source. Next the project will verify the data gathered from the LiDAR setup and compare with the data produced via simulation using deep learning. Next the project will compare experimental LiDAR to state-of-the-art LiDAR in the lab using deep learning. Next is to experiment state-of-the-art LiDAR in the field combined with camera to test for collision avoidance between vehicles and pedestrians. The results of field data will then be benchmarked to simulated data using deep learning and will draw conclusions.

The outcomes of this research have a significant impact on improving pedestrian safety and paving the way to vision zero using the combination of photonics, ITS and deep learning.

3.7 Human Factors

Anniversary Fellowship: Applying a Socio-technical Systems Approach to Inform Gender-Equitable Future Road Transport Systems (University of Southampton from Nov 2022 – Nov 2025) *Contract Holder:* Dr K.J. Parnell

This research program will apply socio-technical systems theory and modelling techniques, alongside user testing and experimental analysis, to the design and development of gender equitable future road transportation networks. In addition to overcoming the 'default male' bias, these networks will be required to meet strict sustainability targets while also transitioning to automated services. A sociotechnical systems approach draws on complex systems theory, arguing against the importance of individual elements in system performance and instead valuing the interactions between the multiple elements and actors to implement holistic interventions. This research will apply and develop system modelling techniques and methodologies to generate requirements for gender-equitable future transport systems to ensure historic gender biases are not repeated in future transport networks. The inclusion of gender-equitable factors in the modelling of transport systems will enable better representation of all gender-related needs and provide more inclusive travel options.

Gender Equitable e-Micromobility (GEM) Guidelines (EPSRC from June 2022 – March 2023) S.E. Merriman Contract Holders: Dr K.L. Plant. & Dr K.J. Parnell

The GEM Guidelines project will utilise Human Factors methods to conduct a sociotechnical systems analysis of the gender factors relating to the use of electric micro-mobility (e-scooters and e-bikes), informed by user-centred data collection (interviews and focus groups with users and non-users or e-mircomobility). This will review the electric micro-mobility system as a whole unit of analysis, rather than taking its behavioural components in isolation (e.g. individual users). It will produce guidelines for researchers, practitioners, and industry who are responsible for implementing policy and increasing the uptake of the mobility platforms in

response to public health and climate concerns.

XHS: eXplainable Human-swarm Systems - A human-swarm teaming can make use of fault-tolerance of the swarm as well as the human critical decision making. (EPSRC Trustworthy Autonomous Systems Hub (TAS) from Nov 2022 – Nov 2023) Dr K.J. Parnell, Dr M. Naiseh (external). Contract Holder: Dr M.D. Soorati

Our previous agile project, Human-swarm Partnerships in Extreme Environments, listed the requirements for trustworthy human-swarm interaction. Based on that, our main goal is to enable the system to assess the criticality of a given situation and decide what needs to be displayed, how, when and why.

We will:
1. Co-design the interface with experienced drone operators (how & when);
2. Use probabilistic model checking to verify, predict and explain the behaviour of the swarm (what & why).

Understanding Informal Rules of the Road and Incorporating this Knowledge into a Communication System for Autonomous Vehicles (PhD Studentship from September 2020): Peter Youssef. *Supervisors:* Dr B.J. Waterson, Dr K.L. Plant.

With autonomous vehicles (AVs) likely to be on our roads in the next few decades, drivers will become passengers in their vehicles. As such, a growing area of research has developed looking at how these vehicles will interact with human road users. This is due to concern that AVs will not have the capabilities to properly communicate their intentions to other road users, with explicit communication techniques, such as eye contact and gestures, no longer a feasible option. A common school of thought to remedy this problem, is to investigate how road users currently communicate with each other, so that AVs can be better designed in order to replace the existing communication modes. As such, this PhD will begin by conducting an exploratory study that looks at how different users generally communicate with each other in cooperative situations to convey their intentions. It will then progress by analysing the critical factors of driver decision-making in cooperative interactions through a series of naturalistic and simulator experiments, before proposing a generic framework for the interaction.

Decision Making in Human Machine Teaming for the operation of uncrewed Maritime Autonomous Surface Ships (funded by Thales and the Engineering and Physical Sciences Research Council, PhD Studentship from September 2020), Kirsty Lynch. Supervisors: Dr K.L, Plant, Dr D. Taunton, Dr. A.P.J. Roberts (external), Dr V.A. Banks (external).

The PhD is investigating decision-making in human-machine teams, to explore how systems can be designed to support accountable decision-making at remote control centres. The human-machine team that is the focus of the PhD is human operators and Maritime Autonomous Surface Ships (MASS). As MASS systems are gaining higher levels of autonomy as technology becomes more advanced, it has made it possible for the automated systems to carry out more tasks without the direct involvement of the human operator and it's enabling the ships to be operated uncrewed.

This is changing the nature of the operator’s role to a supervisory role, as

they will monitor the automated systems rather than directly operating the ship, and the operator will lack proximity to the ship as they will be monitoring it from a remote control centre. This has the potential to change the decision-making process within the human-machine team and the operator's decision-making ability may be affected by a reduced situational awareness as they will no longer be on board the ship and have the same environmental cues. Therefore, it will be necessary to understand the issues with operating uncrewed MASS from remote control centres and how MASS systems can be designed to support operator decision-making. To ensure that operators are able to maintain appropriate oversight of the automated systems and intervene and take back control from the automated system when necessary.

Training Implications for Drivers of Automated Vehicles (funded by IAM RoadSmart and the Engineering and Physical Sciences Research Council, from September 2019), Siobhan Merriman. *Supervisors:* Dr K.L. Plant, Dr K.M.A. Revell (external).

Automated Vehicles are expected to bring a huge number of benefits to society. These include improved safety (fewer accidents and traffic law violations), efficiency, and mobility on the road; however, these benefits will only be realised if drivers are trained in how to use them.

When AVs are introduced onto the market, the driver's role will change from an active role of vehicle manoeuvring and control to a passive role of supervising and monitoring the vehicle and the road environment and only intervening (manually controlling the vehicle) when required (e.g. when the automation fails or reaches its limitations). However, the research literature and recent AV collisions suggest that these tasks are challenging for drivers to perform well. For example, in The United States of America, there have been five high-profile collisions involving Automated Vehicles and in the investigations that followed, the driver's inattention to the driving task, the road environment and the operation of the vehicle, their lack of response to the imminent collision and their complacency and over-reliance on the automation were identified as significant causal factors. Therefore, driver training is required to ensure drivers have the appropriate skills to perform their role as a 'co-driver' of an Automated Vehicle.

Most manual driver training programmes are based on the IPSGA (Information, Position, Speed, Gear and Acceleration) system of vehicle control. However, as the nature of the driving task will change when Automated Vehicles are introduced onto the market (see above), a new driver training programme needs to be developed. This PhD project will attempt to address these issues by designing, developing, testing and validating a new training programme for drivers of Automated Vehicles.

Interacting with an Automated Vehicle

Alternative Safety Management Techniques for Air Traffic Management (funded by NATS, PhD from September 2017 – part-time). Craig Foster. *Supervisors:* Dr K.L. Plant, Dr R. McIlroy.

Air Traffic Management (ATM) exists to support the safe and expeditious flow of aircraft through the world's airspace. However, safety in ATM presents unique challenges due to it being a complex and highly coupled socio-technical system of systems. Despite this, ATM has achieved an ultra-safe level of performance. However, ATM is undergoing unprecedented change and a number of new challenges face the industry. New regulations and regulators, new technologies, changing roles for the human, the desire to reduce the environmental impact of air travel and a demand for further cost efficiencies and commercialisation could all affect the ATM industry's commitment to safety. Against this backdrop, ATM needs to ensure that how safety is understood and managed remains appropriate and safety data continues to deliver information about how safe the operation is and provide an alert to changing risks to inform action. This PhD examines the challenges that arise from the way safety is currently thought about in ATM and considers recent advances in safety science as providing an alternative approach which focusses on successfully harnessing the adaptations present within complex socio-technical systems. A review of the safety literature identifies a need to further elaborate how organisations are to practically apply these emerging ideas within the context of an industry which is characterised by standardisation, procedures and regulation.

Whilst the introduction of new technology presents challenges to safety it also presents an opportunity to marry this alternative safety management approach with the use of data generated from the delivery of the ATM service to better understand the adaptations that produce safety. The PhD is expected to explore and contribute to research in this area and bridge the gap between grounded safety theory for complex socio-technical systems and novel techniques for understanding data generated by humans adapting whilst doing work in safety-related domains.

Maritime Command and Control Human-Machine Interaction (sponsored by DSTL and BAE Systems, PhD (part-time) from 2014). Daniel Fay. *Supervisors:* Dr K.L. Plant, Dr V.A Steane (external)

Future maritime control rooms will be tasked with handling increased data with potentially less crew. User interfaces have evolved to meet current requirements, but this iterative process has propagated legacy design paradigms that may be unsuitable for future requirements. A new design paradigm for user interfaces may be required to maintain effective performance. Ecological Interface Design (EID) is being explored as a theory-based approach to design new interfaces. Novel user interfaces will be designed and tested to assess their applicability for future maritime command and control.

The Problem of emergence in Sociotechnical Systems: Exploring Individual and Group Dynamic Risk Analysis (DRA) in a Military Diving Fatality (Funded by the Royal Navy, PhD from January 2018) Mark Sanderson. Supervisors: Dr K.L. Plant, Dr R. McIlroy

Workplace safety risk management utilises both static and dynamic

methodologies. While the former is conducted prior to an event or activity, the latter is customarily performed live and in the moment. Where the preparatory risk assessment is routinely completed by the management or organisational specialists, the onus for dynamic risk analysis rests predominantly with the worker undertaking the activity. Previous research identified seven factors common to DRA and subsequently established a network model. These factors have now been applied to a recent UK military diving fatality through a deductive thematic analysis. Although the post-mortem attributed the cause of death to an undiagnosed heart anomaly, the case illustrates the necessity for DRA in even the most well prepared of activities. The case shows how and where the knowledge of the DRA factors could have helped in coping with the emergent risks. It also offers wider utility and reveals how they could also be used in considering risk in advance of an activity or when reviewing events post-incident. Ultimately, it is important not to perceive the DRA factors as just another set of rules to be applied. Rather, they complement existing safety management systems and represent considerations to be used when analysing dynamic risk.

4. TRANSPORTATION RESEARCH GROUP PUBLICATIONS 2022

1. Abu Saq, HFH, Kaparias, I & Waterson, B 2022, 'Detecting shockwaves on motorways from inductive loops: A microscopic simulation based analysis', Paper presented at 54th Annual Conference of the Universities' Transport Study Group (UTSG) , Edinburgh, United Kingdom, 4/07/22 - 6/07/22.
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