Professor Lucelia Rodrigues, Dr Julie Waldron, Joseph Walters, Dr Gabriele Gradoni, Haicang Li and Dr Anne Touboulic, University of Nottingham – Written evidence (TTS0058)

1. Introduction

This document was compiled as a response to the Call for Evidence: Public transport in towns and cities.

The University of Nottingham (UoN) is a leading international institution that teaches 43,000 and is ranked 8th in the UK on a measure of 'research power' and 4th for research grant income from private industry according to the Research Excellence Framework 2014. UoN's research portfolio is worth over £600M and the team involves more than 2,800 researchers in addition to 1,800 academics and 3,000 postgraduate research students.

UoN is at the forefront of smart transport and mobility innovation within a future city context. The research activities of the Transport Mobility and Cities (TMC) spans the whole University, and includes the Faculty of Engineering and the Schools of Computer Science, Psychology, Philosophy, English, History as well as the Business School. TMC is concerned with creating knowledge for a better understanding of, and response to, the challenges cities and citizens face. The aim is to make cities and their systems smarter, greener, sustainable and more efficient, through research that is innovative, challenge-oriented and useful to a range of stakeholders. UoN's particular and unique focus is the challenge of placement and movement of people and goods, and their consequent impact on city planning, energy use, carbon emissions and citizens' health.

In this document, we outline our response to some of the questions presented on the call for evidence on public transport in towns and cities based on our research experience. The members of the Transport, Mobility and Cities group from the University of Nottingham who authored this document participated in several relevant projects including:

- EV-elocity [2018-2022, funded by Office for Zero Emissions Vehicles (OZEV) and Department for Business, Energy and Industrial strategy (BEIS), delivered through Innovate UK (IUK), £1.7m]: a project looking at increasing the uptake of EVs through helping consumers to monetise their investment using vehicle-to-grid innovation, enabling the optimisation of energy use and the decarbonisation of cities and communities;
- AMiCC (2019-2022, funded by OZEV, delivered through IUK, £1.5m): a project aiming to demonstrate how wireless technology can unlock a range of the blockers to the market transitioning to electric vehicles and decarbonized cities;
- Human Switch [2018-2020, funded by European Space Agency, £6.3m]: a project that looked at developing a platform providing an owner interface for electric vehicle management and integration into the energy market;
- The Active Building Centre [2018-2022, funded by Engineering and Physical Sciences Research Council (EPSRC), £42m]: a project aiming to

transform the UK construction and energy sectors through the deployment of active buildings contributing to more efficient energy use and decarbonisation of communities;

- Project SCENe [2016-2018, funded by IUK and the Energy Research Accelerator, £8m]: project SCENe (Sustainable Community Energy Networks) at Nottingham's Trent Basin looked to accelerate the adoption of community energy systems, reducing costs and increasing efficient use of distributed renewables, ultimately reducing the overall carbon emissions from the energy system;
- Project SENSIBLE [2015-2018, funded by the European Horizon 2020 programme, £8.9m]: a Project exploring 'Storage Enabled Sustainable Energy for Buildings and Communities';
- Creative Energy Homes [2000- current, various funders]: a research/educational 8-house showcase of innovative energy efficient solutions for sustainable homes and communities, including the integration of multi-vector energy generation, storage and deployment and the demonstration of V2X technology;
- Smart Campus Initiative [2016- current, various funders]: various projects using our campuses to test, examine and evaluate smart concepts and systems, particularly in the energy and mobility domains;
- Smart Nottingham [2018- current, various funders]: Nottingham's SMART City programme;
- Project RISE-6G [EU H2020 ICT52 RIA]: Innovative solutions that capitalize on the latest advances in the emerging technology of Reconfigurable Intelligent Surfaces (RISs), enabling the concept of the wireless environment as a service
- CoDRIVE [2020]: Delivering High Accuracy, Ubiquitous Positioning Through Combined Radio Navigation and Inertial Sensing Technologies

The answers were given to be best of our knowledge.

2. Public Transport Demand

What are the current and anticipated levels of public transport demand and capacity in towns and cities in England?

What influences public transport travel patterns?

How does the choice of public transport vary across different demographic groups?

We have little to add here other than the obvious change we all observed in travel patterns since the start of the COVID-19 pandemic (we looked at Official Statistics: Transport use during the coronavirus (COVID-19) pandemic, Transport Statistics Great Britain 2019 and Statistical data set: Ad-hoc National Travel Survey analysis).

These changes have highlighted the importance of trips for food sourcing. Therefore, we suggest there is a need to connect policy agendas on the realms of food poverty, public transport and sustainability so systematic solutions that address the complete supply chain are found. This is particularly important in relation to urban food deserts, which reduce the access of low-income households to healthy food and increases the need to travel. The identification of such areas should allow policy makers and local authorities to rethink planning in order to provide better public transport connectivity and better support to ensure these households have access to local whole and fresh food. This will also have a positive impact on health outcomes.

Our publications in the field

Touboulic, A. , McCarthy, L., Matthews, L. (2020), "Re-imagining supply chain challenges through critical engaged research", *Journal of Supply Chain Management: a global review of purchasing and supply*, Vol.56(2), 36-51.

Touboulic, A.; Matthews, L.; Marques, L. (2018), "On the road to carbon reduction in a food supply network: A complex adaptive systems perspective", *Supply Chain Management: An International Journal*, Vol.23 (4), pp. 313-335.

Touboulic, A. & Walker, H, (2016), "A relational, transformative and engaged approach to sustainable supply chain management: The potential of action research.", *Human Relations*, Vol.69(2), 301-343.

3. Public Transport Patterns

How might public transport travel patterns shift in the next 10 years?

What impact could digitalisation and the COVID-19 pandemic have on travel patterns in the long term?

We believe some changes in travel patterns that have occurred as a result of the COVID-19 pandemic will remain. For example, remote working has become a reality quickly and has reasons to stay at least in part – currently most places of work have adopted a hybrid mode (part remote part in person). Similarly, the need to shop online has forced many new consumers into a world that was alien to them but is now familiar.

We expect public transport travel patterns to continue to change in the next decade due to several reasons, such as technology developments (e.g., integration of micro mobility, autonomous vehicles, last-mile delivery vehicles), economic activities (e.g., remote working or delivery of goods), or unexpected events such as pandemics. Therefore, developing systems that can continually refine the predictions of travel based on observed behaviour will be strategically essential to add resilience to a system that will be highly exposed to changes.

The use of big data and online machine learning to allow refining predictions of vehicles' behaviour could support estimating information such as: transport demand, vehicles location, electric vehicles battery state of charge (to store energy from renewable sources), electric vehicles capacity to share energy with the grid (Vehicle-to-X), transport carbon emissions, among others. In simple terms, we can design algorithms that take all these data and give us answers in return, such as where to invest in infrastructure to get the best return, how to manage energy demand and use in order to reduce our carbon emissions, etc.

Intelligent traffic systems (ITS) refers to the use of information and communication technologies to make mobility safer, more efficient and more sustainable. ITS enables rapid reporting of issues such as traffic jams and accidents and collects data such as vehicles journeys and user requirements through digital signal processing technology, and is therefore an essential part of our mobility future. Smart surface radio environments will enable ITS connectivity by providing the wireless infrastructure to create stable signals with extended coverage.

It is estimated that the electrification of the transport system will add pressure to the energy grid. Therefore, data integration using Machine Learning to understand and predict vehicles usage, location, energy required for the next journeys and storage capacity of the electric vehicles' batteries will be needed to balance the energy and transport systems and to allow the optimisation of the carbon emissions of the entire system.

Finally, we have also observed a change in what users look for in properties. Since the pandemic, the location of properties has in many cases become less important than other items that impact on quality of life, such as access to green spaces. We have started to experience an exodus of people from city and town centres to rural areas. in longer, less-frequent commutes from rural areas to towns and cities, which in turn require more flexible rural-urban public transport services.

Our publications in the field

TUBELO R., NAGHIYEV E., GILLOTT M., RODRIGUES L., SHIPMAN R., 2022. Assessing the Impact of Lockdown Due to COVID-19 on the Electricity Consumption of a Housing Development in the UK. In: Littlewood J.R., Howlett R.J., Jain L.C. (eds) Sustainability in Energy and Buildings 2021. Smart Innovation, Systems and Technologies, vol 263. Springer, Singapore. https://doi.org/10.1007/978-981-16-6269-0_4

Shipman, R., Roberts, R., Waldron, J., Naylor, S., Pinchin, J., Rodrigues, L., & Gillott, M. (2021). "*We got the power: Predicting available capacity for vehicle-to-grid services using a deep recurrent neural network*". Energy, 221, https://doi.org/10.1016/j.energy.2021.119813

Shipman, R., Naylor, S., Pinchin, J., Gough, R., & Gillott, M. (2019). "*Learning capacity: predicting user decisions for vehicle-to-grid services*". Energy Informatics, 2(1)

Shipman, R., Roberts, R., Waldron, J., Rimmer, C., Rodrigues, L., & Gillott, M. (2021). "*Online Machine learning of Available Capacity for Vehicle-to-Grid Services during the Coronavirus Pandemic*". Energies, 14(21), https://doi.org/10.3390/en14217176

Gradoni, Gabriele, et al. "Smart Radio Environments." arXiv preprint arXiv:2111.08676 (2021).

E. C. Strinati et al., "Wireless Environment as a Service Enabled by Reconfigurable Intelligent Surfaces: The RISE-6G Perspective," 2021 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit), 2021, pp. 562-567, doi: 10.1109/EuCNC/6GSummit51104.2021.9482474.

4. Transport Nodes

What can be done to improve connectivity across public transport modes?

How could better integration be delivered in urban areas outside London?

Multimodal transport is key to enable us to deliver a better connected, sustainable future. The seamless integration of modes should enable cleaner, more sustainable journeys without loss of service or comfort. Apps in personal devices should offer a range of options that include trains, buses, trams, tube, cycling on public bikes, car clubs, micro electric mobility such as scooters, perhaps even car sharing, and these should come with the carbon (and why not health) footprint of each choice. Informing decision making in real time is the single most powerful to change our transport system.

Vehicular network including vehicle-to-vehicle (V2V) communication, vehicle-to-infrastructure (V2I) communication and vehicle-to-anything (V2X) communication is a key approach to improve connectivity across public transport modes as these can implement information sharing of vehicles within the network and help to build up traffic management protocol in specific areas of cities. V2X communications capabilities are critical to supporting Demand Responsive Transport (DRT) and Mobility as a Service (MaaS) digital transport service platforms.

In our experience, the usage of global navigation satellite systems, terrestrial network (5G, LTE, Wifi) and multisensors such as IMU (inertial measurement unit) and LiDAR can improve the localization for V2X connectivity and traffic control significantly (see CoDRIVE).

In order to get better integration and improve the safety levels and efficiency, traffic management protocols are necessary. According to the road traffic accidents data, roundabouts and junctions are considered as the place where accidents usually occur. A safe and reliable spatio-temporal ITS management algorithm for roundabout and road intersections has been designed by us, which can control the traffic flow safely and efficiently within roundabout and crossroad scenarios.

Our publications in the field

H. Li and R. Tiwari, "Safe and Reliable Spatio-temporal Model for Roundabouts and Road Intersections using Vehicular Communication System," 2018 16th

International Conference on Intelligent Transportation Systems Telecommunications (ITST), 2018, pp. 1-7, doi: 10.1109/ITST.2018.8566865

Lakatos, A.; Tóth, J.; Mándoki, P. Demand Responsive Transport Service of 'Dead-End Villages' in Interurban Traffic. Sustainability 2020, 12, 3820.

Dianin, A.; Ravazzoli, E.; Hauger, G. Implications of Autonomous Vehicles for Accessibility and Transport Equity: A Framework Based on Literature. Sustainability 2021, 13, 4448.

Enoch, M. Mobility as a Service (MaaS) in the UK: Change and Its Implications; Government Office for Science: London, UK, 2018.

Roberts, S.; Meng, X.; Xu, C.; Wang, X.; Cui, Y.; Ye, G.; Bonenberg, L. CoDRIVE – Delivering High Accuracy, Ubiquitous Positioning Through Combined Radio Navigation and Inertial Sensing Technologies. Preprints 2020, 2020090037 (doi: 10.20944/preprints202009.0037.v2).

5. Innovation

What are the likely areas of innovation in urban public transport over the next 10 years?

How should public policy be shaped considering both incremental and transformational innovations?

How could data help transport services meet consumer demand?

The likely areas of innovation in transport over the next 10 years are:

- New and established micromobility services, particularly electric vehicles;
- Shared mobility and the increase use of pool cars and car clubs;
- Connected and autonomous vehicles for transport of goods and people;
- Innovative charging technology such as wireless charging;
- Improved and greener vehicle technology;
- Using vehicles' batteries as energy storage through bidirectional charging;
- Modelling and forecasting through machine learning, informed through historical and live data;
- Real time data informing multimodal journeys.

We discussed the use of data in detail above. However, worth highlighting that data can allow us to get a full understanding of our transport systems and current pain points, and be used for forecasting outcomes (eg more efficient, or more financially viable, or greener) to inform decision making with regards to investment strategies. Modelling and prediction through machine learning to address complex multifaceted problems are a key innovation that can shape the future of transport.

Urban charging infrastructure for public transport is an area where changes will occur not only to the vehicles but also to the cities' infrastructure, energy provision and data management. For instance, Wireless Electric Vehicle Charging (e.g. Project AMiCC) represents an opportunity for short dwell and high utilisation vehicles and disabled users of electric vehicles to do the transition to electric mobility. This technology works as static wireless charging where the vehicles need to be parking over a pad to get charged. This system can be integrated to taxi fleets by being installed at taxi parking bays, or in 24/7 fleet by identifying the areas of the city where the vehicles are usually parking. Shared charging infrastructure between institution is also likely to be a part of our transport future to maximise investment.

Other area of innovation is using the electric vehicles' (EVs) batteries to store energy and send it back to the grid using Vehicle-to-Grid (V2G), Vehicle-to-Building (V2B) or Vehicle-to-anything (V2X). This technology has been demonstrated on buses and large fleets (e.g., EV-elocity) finding that aggregating EVs storage capacity can contribute to reduce carbon emissions from the energy grid and transport.

Public policies will need to aim high but be implemented incrementally. For example, consider a future when all public transport is carbon neutral and set up time-appropriate targets towards reaching that goal by 2050. Support cities and towns centres for people not vehicles, establishing steps to get to that goal but not forgetting inclusivity. Determine the need to establish corelations between the need for transport and the distribution of goods, such as food.

Our publications in the field

Waldron, J., Rodrigues, L., Gillott, M., Naylor, S., & Shipman, R. (2020). "*Decarbonising our transport system: Vehicle use behaviour analysis to assess the potential of transitioning to electric mobility*". In J. Rodríguez Álvarez, & J. C. Soares Gonçalves (Eds.), Planning Post Carbon Cities: 35th PLEA Conference on Passive and Low Energy Architecture, A Coruña, 1st-3rd September 2020: Proceedings., (689-694). https://doi.org/10.17979/spudc.9788497497947

Shipman, R., Waldron, J., Naylor, S., Pinchin, J., Rodrigues, L., & Gillott, M. (2020). *Where Will You Park? Predicting Vehicle Locations for Vehicle-to-Grid*. Energies, 13(8), https://doi.org/10.3390/en13081933

6. Local Power

Are local authorities well equipped with appropriate funding and powers to deliver high-quality public transport services?

Would further devolution of transport policy contribute to better outcomes?

Local authority planners display generally positive attitudes towards emerging transport technologies but do not have the capacity to effectively implement them. Better education/understanding is needed to support the implementation of innovation, such as connected and autonomous vehicles, as these technologies can contribute to high-quality public transport services.

Local authorities in rural areas are not yet well equipped with funding and power to deliver high-quality transport services. Rural communities require support from urban local authorities for better public transport to connect communities through urban and rural transport hubs. These need to deliver for a range or communities in order to make financial sense.

Local authorities need more opportunities to engage with industry and academic institutions to develop understanding and implementation strategies for future transport systems. The importance of data was discussed above; academic institutions can turn data into answers that can help decision making. Funding that enables research and development in the area with engagement of policy makers is needed.

Consider a future integrated public transport strategy supported by digital applications where multimodal is the majority of the trips. Provide a range of options including micro and shared mobility.

In many cases one local authority alone cannot justify the investment in a major hub or on innovative mobility. Further devolutions could support urban-rural integrated public transport services resulting in better connected communities.

Our publications in the field

Walters, J.G.; Marsh, S.; Rodrigues, L. Planning Perspectives on Rural Connected, Autonomous and Electric Vehicle Implementation. Sustainability 2022, 14, 1477. https://doi.org/10.3390/su14031477

Hammarsten, A.; Ohlsson, E. Future Technology in Public Transportation—A Qualitative Study Based on Public Transportation Authorities Attitudes; University of Boras: Boras, Sweden, 2019.

7. Policy Coordination

Could better policy coordination across government departments, and between central and local government, improve public transport outcomes?

If so, how can this be achieved?

Yes is the simple answer. For example, investment in active mobility modes can be justified by better health outcomes. Batteries in electric vehicles can help support the energy grid. Life data streaming can provide more efficient decision making for every trip. Higher density neighbourhood can attract local services reducing the need to travel.

How to achieve this is a difficult question to answer. Perhaps the use of data and machine learning can help to start bringing together the various needs of each department and start to address the complex questions above. Enabling and supporting multi-disciplinary research is essential.

Our publications in the field

Walters, J.G.; Marsh, S.; Rodrigues, L. Planning Perspectives on Rural Connected, Autonomous and Electric Vehicle Implementation. Sustainability 2022, 14, 1477. https://doi.org/10.3390/su14031477

Bosworth, G.; Price, L.; Collison, M.; Fox, C. Unequal futures of rural mobility: Challenges for a "Smart Countryside". Local Econ. 2020, 35, 586–608.

Prioleau, D.; Dames, P.; Alikhademi, K.; Gilbert, J.E. Barriers to the Adoption of Autonomous Vehicles in Rural Communities. In Proceedings of the 2020 IEEE International Symposium on Technology and Society (ISTAS), Tempe, AZ, USA, 12–15 November 2020; pp. 91–98.

8. Barriers for Improvement

What are the barriers to improving urban public transport, in terms of delivering the necessary infrastructure, increasing connectivity and improving the consumer experience?

Investment in infrastructure, such as charging hubs, new public transport routes, innovative technology such as autonomous vehicles, is very substantial and therefore a major barrier. This is particularly problematic if it cannot be justified across geographic areas and/or authorities.

The time that it takes for policies to be developed and implemented and the difficulties with predicting investment outcomes upfront. Lack of engagement between academics and policy makers can be a barrier for change. Often, there is also a significant delay between research development and its implementation, reducing our ability to be pioneers on the use of innovation in transport.

Monitoring and sensing are essential in order to build robust datasets that can enable us to answer questions that will help improve urban public transport. However, the collection of data can be impaired by a number of reasons, as can be the storage and integration of meaningful datasets.

In order to implement ITS and autonomous traffic, infrastructure prescribing connectivity to on-road sensors and on-board units are necessary. However, due to the huge number of public transports, expenses may be high and shifting procedure may take longer than we expected, which could be a barrier. Localisation of vehicles and user terminals can be assisted by reflective intelligent surfaces to reduce the number of sensors deployed within the territory.

Customer experience requires real-time connectivity, which requires reliable digital infrastructure. Infrastructure barriers include inconsistent digital connectivity between an individual service (eg. a bus), the whole transport system, and individual users. Connectivity can also support positioning and localisation required for real-time demand-based public transport services. Denser urban environments may suffer from Global Navigation Satellite System positioning loss and errors due to multi-path.

Public acceptance can be a barrier, particularly in relation to autonomous vehicles.

Our publications in the field

C. L. Nguyen, O. Georgiou, G. Gradoni and M. Di Renzo, "Wireless Fingerprinting Localization in Smart Environments Using Reconfigurable Intelligent Surfaces," in IEEE Access, vol. 9, pp. 135526-135541, 2021, doi: 10.1109/ACCESS.2021.3115596.

Walters, J.G.; Meng, X.; Xu, C.; Jing, H.; Marsh, S. Rural Positioning Challenges for Connected and Autonomous Vehicles. In Proceedings of the 2019 International Technical Meeting of The Institute of Navigation, Reston, VA, USA, 28–31 January 2019; pp. 828–842.

Walters, J.G.; Marsh, S.; Rodrigues, L. Planning Perspectives on Rural Connected, Autonomous and Electric Vehicle Implementation. Sustainability 2022, 14, 1477. https://doi.org/10.3390/su14031477

LARGE, D. R., CLARK, L., BURNETT, G., HARRINGTON, K., LUTON, J., THOMAS, P. and BENNETT, P., 2019. "It's Small Talk, Jim, But Not as We Know It." Engendering Trust through Human-Agent Conversation in an Autonomous, Self-Driving Car *In:* 1st International Conference on Conversational User Interfaces (CUI2019), Dublin, Ireland.

LARGE, D. R., HARRINGTON, K., BURNETT, G., LUTON, J., THOMAS, P. and BENNETT, P., 2019. To Please in a Pod: Employing an Anthropomorphic Agent-Interlocutor to Enhance Trust and User Experience in an Autonomous, Self-Driving Vehicle *In:* Automotive User Interfaces and Interactive Vehicular Applications (AutoUI2019), Utrecht, Netherlands.

LARGE, D. R., CLARK, L., QUANDT, A., BURNETT, G. and SKRYPCHUK, L., 2017. Steering the conversation: A linguistic exploration of natural language interactions with an autonomous digital driving assistant Applied Ergonomics. 63, 53–61

9. Further thoughts

Are there other important changes, not covered elsewhere in these questions, which would improve matters?

We appreciate this is difficult job and there are no clear answers; however, we hope our contribution can be of help.

March 2022