Accessibility of urban regions on a low car diet – A research agenda for digital twins

van Arem, Bart; Sharif Azadeh, S.; Snelder, Maaike; Hoogendoorn, Serge

DOI
10.1016/j.commtr.2022.100077

Publication date
2022

Document Version
Final published version

Published in
Communications in Transportation Research

Communications in Transportation Research 2 (2022) 100077

Contents lists available at ScienceDirect

Communications in Transportation Research

journal homepage: www.journals.elsevier.com/communications-in-transportation-research

Editorial

Accessibility of urban regions on a low car diet – A research agenda for digital twins

1. Introduction

Worldwide, cities and urbanised areas attract more people and economic activities. In addition, new ways of working, shopping and recreation, mobility and 'ownership' are introduced – all influenced by digitalisation. The United Nations (2018) expect the world-wide population living in urbanised regions to grow from 55% to 68% by 2050. However, concentration of residential, industrial, commercial, and recreational activities leads to an increasing pressure on land use and accessibility, potentially causing adverse environmental, health and liveability effects. Increasing housing density and decreasing space for transport infrastructure and parking call for new smart mobility approaches to ensure sustainable and inclusive accessibility.

2. Problem statement

Cars have proven to be attractive modes of transport, because of a perceived low marginal trip cost and elevated level of comfort compared to other modes of transport. However, cars occupy space when idle. In areas with high housing density, the road transport system is reaching the limits of what is physically possible in terms of usage of space and desirable in terms of externalities. Grand expectations therefore rest on smart mobility modes based on flexible combinations of walking and cycling, shared electric vehicles (including micro-mobility), passenger and freight transport hubs and smart traffic management. Smart mobility modes do not depend on the possession of a private car and have a great –but still under explored-potential to complement or replace private car mobility at a much lower occupation of space.

Understanding the demand for travel, its determinants and (smart) mode preferences are important to get a grip on the extent to which smart mobility modes can contribute to sufficient accessibility. Travel demand increases with the density of housing, commercial areas, schools, etc., and depends on personal, attitudinal, cultural, and socio-economic characteristics as the availability of travel modes and their levels of services. Travel restrictions during the Covid 19 pandemic have led to an accelerated development and understanding of the pros and cons of online shopping, education, meeting, etc. The future development of travel demand promises increased flexibility and awareness of smart mobility modes, but it is also highly unpredictable.

Transportation models have been widely used to study the interaction in space and time between travel demand, transport networks, their levels of services and interventions based on policy, infrastructure, and management. Presently, advanced models derive travel demand from activity scheduling of a synthetic population and use agent-based models for the individual and collective behaviour of travellers and flows in transport networks and modelling of interventions. Important challenges of transportation models in relation to smart mobility modes in dense urban areas are: (1) data driven adaptation to changes in travel demand and smart mobility modes; (2) better understanding of user needs, travel behaviour and response to intervention; (3) better modelling of the interaction between local (street) and network level processes; (4) better facilities for visualisation and interpretation of results.

3. A digital twin modelling federation

We propose a digital twin modelling federation as basis for a research agenda to develop a new generation of transportation models for the development of smart mobility modes in 'car-low' urban areas. Digital twins may be considered as a next step made possible by data and Artificial Intelligence (AI) driven research approaches. A digital twin is commonly defined as a digital representation of a corresponding physical twin, that uses sensor data, mathematical models and a model updating mechanism. A digital twin is used not only to mirror, but also predict the behaviour of its physical twin (Wright and Davidson, 2020). An important property of a digital twin is its capability to adjust based on data and information about changes in the physical system at different time scales.

Fig. 1 outlines a digital twin modelling federation to study both real-time management and strategic planning of smart mobility and infrastructure applications and interventions. Rather than imaging an (over-) ambitious all comprehensive digital twin, we envisage a federation of different digital twin instances that can be embedded in a classic feedback-control loop in which real-life and virtual reality data will be combined with model-based scenario development, implementation of interventions, monitoring, and analyses.

Digital twin models for car-low areas will require significant development, based on building blocks from existing lines of research such as data analytics and visualisation and agent-based transport modelling. By closing the loop between data and modelling in an integrated and iterative research approach, it will enable researchers and practitioners to address the following fundamental research challenges that are key to the development of sustainable and accessible car-low urban areas.

4. Research challenges

4.1. Mobility data analytics

The first scientific challenge is propelled by novel sensor technology (including social data, chatbots, but also AR and VR), sensor network design for key smart mobility applications such as smart active modes, smart shared services, and multi-modal traffic management. It needs to

https://doi.org/10.1016/j.commtr.2022.100077
Received 22 June 2022; Received in revised form 1 July 2022; Accepted 5 July 2022
Available online xxxx

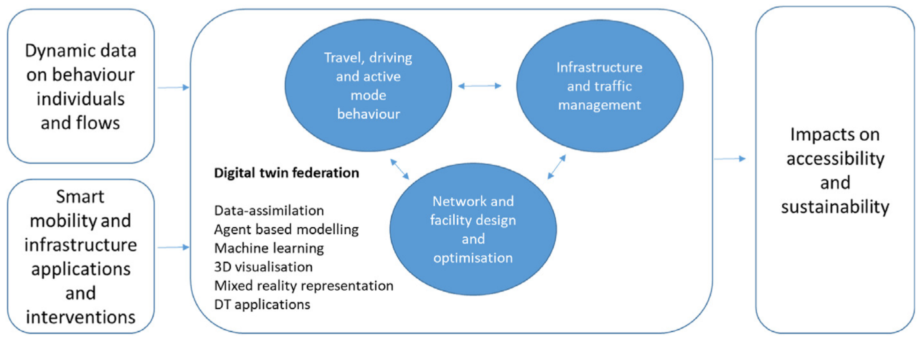

Fig. 1. Digital twin modelling federation.

address data enhancing services such as data cleaning methods, data fusion technology, prediction using AI to enhance or contextualize the data. It is aimed at designing a cost-efficient sensor network, including 5G edge-technology that will be privacy and data secure. Important research topics are observability and controllability, data utility and combined work on sensor network design and data enhancing services.

4.2. Behavioural impacts

Citizens are the ultimate users of smart mobility solutions. A mismatch between mobility services and demand is often observed in transportation systems, which yields an imbalance between available resources with the corresponding willingness or need in the market. Therefore, it is crucial to incorporate individual or group preferences/choices in designing, planning and management of these new mobility services (Pacheco Paneque et al., 2020). This integration is scientifically challenging yet operationally rewarding to make sure these multimodal transport systems provide the required service level. However, measuring the acceptability level of new mobility options by users is a challenging task. The main reason is the absence of data for innovative solutions. This calls for new methodological developments to accurately predict the market share of sustainable and innovative mobility options as current methods either heavily depend on the available historical data or survey results that may not be realistic due to lack of user experience.

4.3. Physical and digital infrastructure

Future car-low areas will provide new opportunities to radically redesign public space to support active mode traffic, facilitate hubs that provide access to shared vehicles and public transport, thus providing accessibility using less space. Car-low areas will also be rich with information technology and dynamic data. This will enable intelligent traffic management and control algorithms that can dynamically provide safe, efficient, and sustainable mobility in shared space. It will also provide wireless networked intelligence to constantly feed a real-time digital twin with up-to-date information regarding for instance people, shared smart bicycles, and self-driving vehicles.

4.4. Network and location planning and design

The increasing interconnected nature of infrastructure networks has provided opportunities for reshaping the decision-making process, enabling new opportunities for stimulating sustainable and inclusive urban infrastructure in smart cities. In literature, the design of networks is known as the Network Design Problem (NDP) in which the upper-level deals with the optimization of the design variables based on an objective function and restrictions, given the network performance. The lower level of the NDP evaluates the impacts of the designs with impact assessment models. Key questions that need to be addressed are how multimodal networks can be designed in interaction with stakeholders while considering multiple objectives like accessibility, sustainability, liveability, safety, and inclusiveness and considering uncertainties with respect to disruptions and uncertainties with respect to future developments and new mobility systems.

4.5. Impact assessment

To assess the impact of smart mobility alternatives for private cars, small scale pilots and experiments are needed to study user responses. At the same time, there is a need for a new generation of models that accurately capture these user responses and assess the network-wide impacts of large-scale introduction of smart mobility solutions on land use, accessibility, sustainability, liveability, safety, and inclusiveness (Snelder et al., 2019). On the hand this calls for highly detailed multimodal activity and agent-based demand and assignment models in combination with optimization models that allocate trips to shared vehicles and services. On the other hand, this calls for more aggregate models that are fast yet accurate enough to be used in an optimization context of network design and to cope with disruptions and long-term uncertainties regarding the introduction and adoption of the smart mobility solutions.

4.6. Digital twin realisation

Although high expectations rest on the use of digital twins to support research by design approaches of car-low mobility, the road toward a federation of digital twins is paved with technical challenges. These challenges pertain to temporal and spatial data synchronization of the real and virtual world, interfacing between digital twins at different network levels, real-time communication and visualisation, data integrity and security, and privacy conservation.

5. Conclusions and call for action

Digital twins as data driven replicas of transport systems will open important research lines to address fundamental challenges that are connected to the questions how smart mobility can provide sustainable accessibility in car-low urban areas. We expect that public and private actors, together with researchers, will be the first to use the digital twins. This potential of digital twins for urban mobility was shown by Dembski et al. (2020), who developed a prototype urban digital twin in a VR visualisation platform for the town of Herrenberg in Germany, including a 3D model of the built, a street network model and mobility simulation. A survey amongst urban planners and designers and the public confirmed the added value in participatory and collaborative processes, but also revealed the need for reliable behavioural models of travellers and flows in the network.

We encourage researchers world-wide to explore, develop and exchange digital twins for urban-car-low mobility to help improve the sustainability and accessibility of urban regions. Society will experience changes through pilots and interventions taken on the basis of these digital twins. Eventually, the public will also be able to use the digital twins to co-design the mobility system.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The work in this paper was funded by Delft University of Technology.

References

Dembski, F., Wössner, U., Letzgu, M., Rudda, M., Yamu, C., 2020. Urban digital twins for smart cities and citizens: the case study of Herrenberg, Germany. Sustainability 12, 2307.

Pacheco Paneque, M., Bierlaire, M., Gendron, B., Sharif Azadeh, Sh, 2020. Integrating advanced discrete choice models in mixed integer linear optimization. Transp. Res. Part B Methodol. 146, 26–49.

Snelder, M., Wilmink, I., van der Gun, J., Bergveld, H.J., Hoseini, P., van Arem, B., 2019. Mobility impacts of automated driving and shared mobility: explorative model and case study of the province of north Holland. Eur. J. Transport Infrastruct. Res. 19, 4282.

United Nations, 2018. World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). Retrieved from. https://www.un.org/development/desa/pd/content/world-urbanization-prospects-2018-revision.

Wright, L., Davidson, S., 2020. How to tell the difference between a model and a digital twin. Adv Model Simulat. Eng. Sci. 7, 13.

Bart van Arem is a full professor of Transport Modeling and pro voice rector magnificus for Doctoral Affairs at TU Delft. He received the MSc and PhD degrees in applied mathematics from the University of Twente, the Netherlands, in 1986 and 1990, respectively. From 1992 to 2009, he was a Researcher and a Program Manager at TNO, working on intelligent transport systems, in which he has been active in various national and international projects. Since 2009 he is a Full Professor of Transport Modelling at TU Delft, focusing on the impact of intelligent transport systems on mobility.

Shadi Sharif Azedeh is an assistant professor of Smart and Sustainable Mobility at TU Delft. She received her PhD degree in Mathematics from Polytechnique Montreal. Prior to joining to TU Delft, she held an assistant professorship position at Erasmus University Rotterdam, and a postdoctoral position at Civil and Environmental Engineering at EPFL. Her areas of expertise include integration of operations research with behavioural models for transport, mobility and logistics networks. She develops efficient algorithms to design sustainable and smart transport options and incentivize travellers to use them. Her research focuses on efficient urban spatial usage and energy efficiency of transport systems.

Maaike Snelder is part time associate professor at TU Delft and principal scientist at TNO. She completed her study Econometrics in 2003 at Erasmus University Rotterdam and her PhD research about robust road network design in 2010 at TU Delft (Cum Laude). Her research interest focusses on the development of next generation traffic and transport models and the development of interactive network design methods.

Serge Hoogendoorn was appointed a full professor Traffic Operations and Management in 2006 at TU Delft. He has been the chair of the department Transport and Planning since 2018. He is currently (one of the four) Distinguished Professor of Smart Urban Mobility at TU Delft His current research evolves around Smart Urban Mobility, with focal areas such as theory, modelling, and simulation of traffic and transportation networks, including cars, pedestrians, cyclists and novel public transport services

Bart van Arem*
Department of Transport & Planning, Faculty of Civil Engineering and Geosciences, Delft University of Technology, P.O. Box 5048, 2600 GA, Delft, the Netherlands

Shadi Sharif Azedeh
Department of Transport & Planning, Faculty of Civil Engineering and Geosciences, Delft University of Technology, P.O. Box 5048, 2600 GA, Delft, the Netherlands

Maaike Snelder
Department of Transport & Planning, Faculty of Civil Engineering and Geosciences, Delft University of Technology, P.O. Box 5048, 2600 GA, Delft, the Netherlands
The Netherlands Organisation for Applied Scientific Research (TNO), P.O. Box 96800, 2509 JE, The Hague, the Netherlands

Serge Hoogendoorn
Department of Transport & Planning, Faculty of Civil Engineering and Geosciences, Delft University of Technology, P.O. Box 5048, 2600 GA, Delft, the Netherlands

* Corresponding author.
E-mail address: b.vanarem@tudelft.nl (B. van Arem).