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Workshop synthesis: Virtual reality, visualization and interactivity in travel survey, where we are and possible future directions

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Abstract

This paper summarizes the discussion of the workshop B16 "Virtual reality, visualization and interactivity in travel survey, where we are and possible future directions". The workshop involved three sessions over the course of the conference. First two sessions discussed the current state of research, challenges, and possible future directions. The last session focused on synthesis of a research agenda for the next five years. It was concluded that the VR/AR tools and platforms provide a unique opportunity to proactively investigate the travel behaviour changes that are expected to happen due to the development and adoption of disruptive mobility technologies and services as well as virtual worlds and digital twins.

Keywords: travel behaviour; experimental design; stated preferences, virtual reality

1. Introduction

Over the past decade, to study the emerging transportation technologies (e.g., automated vehicles and urban air mobility) and services (e.g., ride-hailing and micro-mobility), researchers have been investigating the use of new survey tools and methods to appropriately capture the associated human behaviour. In recent years, travel survey research has particularly focused on incorporating experience, immersiveness, and interactivity in the experiments to

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account for issues like the absence of a well understood prior reference choice, capturing the heterogeneity of behaviour, and lack of realism in conventional survey tools.

Patterson et al. (2017) compared text-only and visualization-based survey tools for stated preference experiments in the context of neighbourhood choice. The study reported that visualization resulted in more focused participants and the resulting choice model had more significant parameters than the model based on text-only tool. Farooq et al. (2018) used Virtual Reality (VR) headsets, traffic microsimulator, and stated preference survey design to study the interaction between pedestrians and automated vehicles. The study completely immersed the participants in a futuristic scenario, where the virtual objects could respond to the actions of the participant. The study compared the VR experiment with text-only and visualization-based experiments and reported that the VR tool captured the heterogeneity of responses better than other tools. Several studies have been dedicated to investigating the appropriateness and validity of these emerging survey tools. Rossetti and Hurtubia (2020) established the ecological validity of 3D videos projected using VR headsets and reported no significant differences between VR and reality in the context of perception about the safety of a neighbourhood. Feng et al. (2022) reported the face validity, content validity, construct validity and usability of the use of their VR tool for experiments on pedestrian route choice, evacuation exit choice, wayfinding.

VR tools provide the flexibility to develop more complex and detailed experiments. For instance, Djavadian et al. (2019) used a VR headset, driving-rig, and traffic microsimulator to study the choice behaviour of the drivers in the context of giving-up and taking-back control of a partially automated vehicle. More recently, VR tools have been used to collect novel and rich behavioural data (e.g., trajectory, head orientation, and neurophysiological state) to develop advanced discrete choice models. Kalatian and Farooq (2021) used the trajectory and head orientation data from VR experiments to develop interpretable deep learning model for pedestrian wait-time decisions when crossing urban streets with automated vehicles. Bogacz et al. (2021) combined VR and ElectroEncephaloGraphy (EEG) data from cycling experiments to develop an Integrated Choice and Latent Variable (ICLV) model where the conventional self-reported psychometric indicators were substituted by the EEG measurements, incorporating the direct brain activity into the model. Mudassar et al. (2022) combined data from Galvanic Skin Resistance (GSR) sensors and VR to study the stress level of a pedestrian when interacting with automated vehicles on urban roads.

In this context, the aim of the workshop was to first look back at the literature developed in the past decade that incorporated Virtual Reality (VR), visualization, and interactivity on travel survey methods. The discussion focused on the understanding of how such emerging tools have helped in improving survey methods; what are the situations, where they are useful and where they are not; what are the challenges associated with the large-scale adoption of such tools and how such challenges can be addressed; and how the resulting observations are used in developing advanced behavioural models. This effort was assisted by five research papers presented and discussed in this workshop, including, Barthelmes et al. (2022), Daziano (2022), Farooq et al. (2022), Kasraian et al. (2022), and Yin and Cherchi (2022). These papers set the scene for the discussion and provided the necessary background to the attendees on the state-of-the-art. The workshop then focused on defining possible future research directions that can best serve the research community. Here the research needs, open questions, and challenges were discussed, with an aim to collaboratively advance the state of the travel survey research.

The first two sessions started with the oral presentations where the presenting author introduced their work. After the presentations, the workshop chairs organized a structured and interactive discussion with defining key questions and inviting participants to reflect on them. The third session focused on the synthesis of the discussion into a well-organized workshop output and setting out a collaborative research agenda for the next five years. The workshop was attended by researchers from a wide variety of background, who were enthusiastic about developing new research in the use of VR, visualization, and interactivity for travel behaviour surveys.

2. Key challenges

The workshop discussed in detail the key challenges associated with the mainstream adoption of VR/AR tools in travel behaviour analysis.

2.1. Technological expertise behind interactivity experiments

The majority of the workshop participants defined the technological expertise, software development, and hardware required to enable interactivity as the major barriers to adoption. It was pointed out that the research projects that were able to introduce interactivity, did so by collaborating with industry partners, having access to specialized software (e.g., cityengine), and having access to researchers with prior programming background in visualization and gamming tools (e.g., Unity3D). See for example the discussion in Kasraian et al. (2022) and Yin and Cherchi (2022) where a highly multidisciplinary participation with software industry involvement was needed for the development of the interactive survey tool. Such barrier could be overcome by encouraging open access collaborative projects with well-maintained code and data by the community. Strong focus must be given to transferability of the scenes, environments, and the software.

2.2. Response accuracy and comparative analysis

The immersive and interactive nature of VR/AR based survey tools have the potential to introduce bias as the participants may lose focus from the choice task and are distracted by the novelty, excess information, and factors unique to such tools. An approach suggested was to make the environment as neutral as possible so that the focus remains on the choice talk (as reported in Kasraian et al., 2022). A comparative analysis of various level of details in the environment could be useful in measuring the bias introduced. The level of realism in the interactions of other avatars in the environment (e.g., virtual cyclists in Bogacz et al (2021), crowd in public transport as in Daziano (2022), and vehicles in the traffic as in Farooq et al. (2022)) also have the potential to introduce bias and their influence must be systematically evaluated. It was also pointed out that the type of avatars in the scene is critical and should be representative of the real population. The current focus of VR/AR based tools have been on bringing as much realism as possible, but it is not well understood at what point the gains due to the introduction of realism plateau. Another important aspect of VR/AR experiment is the physical and mental workload experienced by the participants and their influence on accuracy of the responses. Yin and Cherchi (2022) reported that participants were willing to spend longer times (e.g., 45 minutes) in VR/AR based experiments. The “wow” effect of VR/AR has the potential to increase the participation rate in the experiments, but then it is important to investigate the effect of wow-factor on the collected data (a systematic evaluation is required to quantify these effects) or to start with a familiarization session to normalize the wow effect (Yin and Cherchi, 2022).

2.3. Validity and transferability of VR/AR tools

Various key issues around the validity of these emerging VR/AR tools are currently not very well understood. There is a strong need for a systematic effort focused on the construct, content, face, and criterion validity of various VR/AR tools developed by the community, comparative analysis, and understanding of the differences in performance (as discussed for example in Barthelmes et al., 2022). Furthermore, the transferability and validity of the experiments in various geographical locations is needed for a more ubiquitous adoption. The transferability would require easy customization of the experiments based on the norms, culture, and rules of each location. For instance, in a recent effort, Newcastle University and Toronto Metropolitan University developed two experiments in VR, one on the choice of normal versus automated taxis and other on pedestrian crossing behaviour, customized for Newcastle and Toronto, and conducted them at these two locations (Nazemi et al., 2022; Yin and Cherchi, 2022).

2.4. Use of neurophysiological sensors in VR/AR

The controlled and immersive environment enabled by VR/AR tools have the potential to collect data on participant's neurophysiological state using sensors like Galvanic Skin Resistance (GSR), electroencephalogram (EEG), and electrocardiogram (ECG). See discussion in Farooq et al. (2022) where they used GSR sensor to measure the changes in stress level during pedestrian's interaction with an automated vehicle in VR. The challenges here include the definition of base state, accounting for noise/interference, and definition of appropriate temporal scale to collect the data. For achieving a good base state, the participants could be asked to sit and relax for a while with calming music being played in the background. In VR/AR tools, the participants are performing actual physical tasks e.g., walking, cycling, or using an e-scooter (Kalatian and Farooq, 2021 and Bogacz et al. 2021). The learning effects in such talks may need to be properly incorporated in the analysis. There is also a potential to collaborate with cognitive scientists to understand these effects better in travel behaviour related situations.

3. Research roadmap

In addition to the challenges faced, the workshop also defined a five-year roadmap for the research community to enable a more wide-ranging use of VR/AR technologies and tools for travel behaviour analysis.

3.1. Determining the appropriateness of VR/AR in travel behaviour

For a comprehensive investigation, the community could focus on selecting a range of well understood choice scenarios and replicating them in VR/AR tools in addition to other conventional tools (e.g., web survey). These experiments must be performed with a range of sub-populations and in various geographical regions. A systematic analysis could be performed on what is gained in terms of information, efficiency, and behaviour and in which choice scenario the gains out way the required effort and cost.

3.2. Open access approach

To overcome the technological challenges in terms of adoption of VR/AR tools, the community may consider the open-source approach. For the greater adoption, the tools, protocols, data, and analyses must be made available as open access resources for the community. This will also encourage a greater emphasis on reproducibility of the data and analysis in the community. Special importance should be given to the long-term sustainability, maintenance, and archival of tools and data. A common ontology must be developed so that the interoperability between various open access projects could be possible. The community can develop new collaborations with information scientists in this regard.

3.3. VR/AR experiment as a new category

VR/AR experiments overlaps with both stated and revealed preference experiments. Like stated preference experiments, the scenarios are hypothetical and environment is completely controlled. The available choice options are clearly predefined. Similarly, like revealed preferences, the participants may also perform a physical talk of choosing a choice (e.g., a pedestrian may take steps to turning left or right in an intersection). The VR/AR experiments have features that are neither present in stated nor revealed preference experiments. The protocols of VR/AR experiments have several unique features (e.g., preparation proposes for the participants). Therefore, the community may consider defining VR/AR experiments a new category of experiments and develop specific methodologies for their designs.

3.4. Engaging other senses in VR

Visual realism may not be enough to capture several choice situations, such as choice preference in an overcrowded subway or route choices when cycling on a windy day. Such situations may require engaging other senses, for instance,

sense of smell and physical impact. Recent advanced in haptic technologies, wind control, and artificial smell could be used to further improve the realism and evaluate the improvement in the quality of the data collected. Previous studies have reported that the lack of realism can further increase the chance of motion sickness in VR experiments. Adoption of these technologies can also reduce the motion sickness and further improve the performance of participants in the VR experiment.

3.5. VR/AR to incorporate needs of marginalized communities

The general travel surveys focus on the representativity of the population and may not include the travel behaviour of marginalized communities. VR/AR tools have the potential to be customized to the needs of such communities and can be used to collect detailed data based on their specific needs and circumstances. In this regard VR/AR surveys can also improve the representativity of conventional surveys via data fusion process.

3.6. Scalability of VR/AR experiments

Most of current studies have focused on VR/AR experiments performed on a relatively small sample of participants, involving less than 100 participants. This could mainly be due to the unique factors associated by VR/AR tools, e.g., effort required to collect the data, availability of the hardware and space to conduct the experiment, and expertise required to manage the large amount of data collected in the VR/AR environment. In future, the community could focus on the scalability aspects of these experiments and involve a more heterogenous population to make the resulting data more representative.

3.7. VR/AR based virtual worlds and digital twins

So far, the VR/AR technologies have primarily been used for the collection of travel behaviour data in controlled environments. However, there is an increasing trend of the use of such technologies for the development and participation in virtual worlds (e.g., Metaverse and Fortnite) and digital twins. Engagement in activities such as socialization, remote work, and virtual entertainment in such platforms will have strong consequences on travel behaviour. The research community could use these platforms to design experiments that can help us understand the future travel behaviour changes. In near future, several interesting research questions will arise due to the adoption of these platforms. For instance, who will be the earlier adopters of this move, and if embracing such platforms is a factor of personal preferences, features of the platform, and/or type of work, education, shopping, and recreation activities? Will embracing such platforms be a complete or partial move for an individual, what factors will define this move, and what will be the resulting activity participation pattern? Virtual worlds and digital twin usage is expected to impact vehicle ownership, home location, and personal travel patterns. In this context, will travel time saved by not travelling to work induce travel for other activities? Will the urban sprawl and move to rural and small towns increase due to adoption of these platforms? What will be the consequences of travel surveys and activity-based travel demand models?

4. Conclusions

The VR/AR technologies and survey and engagement tools for travel behaviour analysis are rapidly maturing and their adoption is gaining a strong momentum. The VR/AR based software and technology development remains a significant challenge, which can be addressed by an open sourced and cooperative approach by the community. Such an approach can also encourage and support reproducibility in travel behaviour research. Systematic comparative analysis and large-scale validation of the VR/AR tools on a set of well-known choice tasks can inform the community on the value such emerging tools can bring in the understanding of travel behaviour. VR/AR tools can be useful in designing experiments to capture the travel behaviour of marginalized communities that may not be represented well in the conventional surveys. Using VR/AR tools, the research community has a unique opportunity to proactively investigate the travel behaviour changes that are expected to happen due to the development and adoption of virtual worlds and digital twins.

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References

Bogacz, M.; S. Hess; C. Calastri; C.F. Choudhury; F. Mushtaq; M. Awais; and A. Erath, (2021). Modelling risk perception using a dynamic hybrid choice model and brain-imaging data: an application to virtual reality cycling. Transportation research part C: emerging technologies, 133, 103435.

Barthelmes, L.; J. Kübler; L. Bönisch; M. Kagerbauer and P. Vortisch, (2022). An interactive travel diary for web-based trip reporting (paper 182). Paper presented at the 12th International Conference on Transport Survey Methods, Portugal, March 20-25.

Daziano R., (2022). Virtual environments for analyzing travel behavior during the COVID-19 pandemic (paper 195). Paper presented at the 12th International Conference on Transport Survey Methods, Portugal, March 20-25.

Djavadian, S.; B. Farooq and R. Vasquez, (2019). Should I give or should I take? Choice issues in automated vehicle control, in: International Choice Modelling Conference 2019. URL: https://litrans.ca/projects/virtual-reality/Djavadianetal_Give_TakeControl_VIREStudy.pdf.

Farooq, B.; A Kalatian and R. Vasquez, (2022). Virtual Immersive Reality for Choice Experiments: Scope, Opportunities, and Challenges (paper 122). Paper presented at the 12th International Conference on Transport Survey Methods, Portugal, March 20-25.

Farooq, B.; E., Cherch, and A., Sobhani, (2018). Virtual immersive reality for stated preference travel behavior experiments: A case study of autonomous vehicles on urban roads. Transportation research record, 2672(50), 35-45.

Feng, Y.; D.C., Duives and S.P. Hoogendoorn, (2022). Development and evaluation of a VR research tool to study wayfinding behaviour in a multi-story building. Safety science, 147, 105573.

Mudassar, M.; A., Kalatian and B., Farooq, (2022). Analysis of pedestrian stress level using GSR sensor in virtual immersive reality. Collective Dynamics, 6, 1-18.

Nazemi, M.; T., Zhao; D., Ramos, D.; B., Farooq; H., Yin; M., Bektas and E., Cherchi, (2022). The Role of Social Conformity in Pedestrian-Autonomous Vehicles Interaction. 16th International Conference on Travel Behaviour Research December 11 - 15, 2022 – Santiago, Chile.

Kalatian, A. and B. Farooq, (2021). Decoding pedestrian and automated vehicle interactions using immersive virtual reality and interpretable deep learning. Transportation research part C: emerging technologies, 124, 102962.

Kasraian, D.; S. Adhikari; D. Kossowsky; M. Luubert; B. Hall; J. Hawkins; K.N. Habib; J. Bowes; S. Diamond; P. Hess; M. Wolfe; J. Farvolden; E.J. Miller and M.J. Roorda, (2022). Evaluating complete streets with a 3D stated preference survey (paper 71). Paper presented at the 12th International Conference on Transport Survey Methods, Portugal, March 20-25.

Patterson, Z.; J. Mostofi-Darbani; A., Rezaei and J., Zacharias, (2017). Comparing Text-only and Virtual Reality Discrete Choice Experiments of Neighborhood Choice. Landscape and Urban Planning, 157, 63-74.

Rossetti, T. and R. Hurtubia, (2020). An assessment of the ecological validity of immersive videos in stated preference surveys. Journal of choice modelling, 34, 100198.

Yin H. and E. Cherchi, (2022). Conducting Stated Choice Experiments within a Virtual Reality Environment: an application to the choice of automated taxi (paper 131). Paper presented at the 12th International Conference on Transport Survey Methods, Portugal, March 20-25.

Yin Hao and E. Cherchi (2022). A stated choice experiment embedded in immersive virtual reality to estimate preference for fully automated taxis. 16th International Conference on Travel Behaviour Research December 11 - 15, 2022 – Santiago, Chile.