Journal of Urban Mobility 2 (2022) 100034

Contents lists available at ScienceDirect

Journal of Urban Mobility

journal homepage: www.elsevier.com/locate/urbmob

Assessing the influence of connected and automated mobility on the liveability of cities

Gillian Harrison[a,*], Joseph Stanford[b], Hannah Rakoff[b], Scott Smith[b], Simon Shepherd[a], Yvonne Barnard[a], Satu Innamaa[c]

[a] Institute for Transport Studies, 36-40 University Road, University of Leeds, Leeds, LS2 9JT, United Kingdom
[b] United States Department of Transportation, Volpe Center, 55 Broadway, Cambridge MA 02142 United States of America
[c] VTT Technical Research Centre of Finland Ltd, P.O. Box 1000, FI-02044 VTT, Finland

ARTICLE INFO

Keywords:
Connected & automated mobility
Automated driving systems
Liveability
System dynamics
Causal loop diagrams

ABSTRACT

In this work we are concerned with how the introduction of connected and automated mobility (CAM) will influence liveability in cities. We engaged with city and transport planners from both Europe and the U.S. and adopted a system dynamics approach to capturing the discussions and exploring potential outcomes. There are two aims in doing this: (1) to identify the concerns of city planners and how they differ from the traditional focus of transport researchers; but also (2) to develop a causal loop diagram (CLD) that can both explore the potential systemic effects of CAM and help to communicate those effects and the underlying mental models. Addressing these aims can inform policy design related to both CAM specifically and urban mobility more generally. In a change from previous related studies, we allowed the participants to establish their concept of liveability in cities and did not define a specific CAM scenario. This broad scope was critical in capturing the high-level view of what really matters to city stakeholders. We have established that a focus on a more holistic understanding of interactions related to sustainability is required rather than on specific transport modes or technology. A key insight that emerged was that quality of life (QoL) was the dominant concern of city planners, regardless of how it is achieved. The specifics of new services or technologies (such as CAM) are secondary concerns - which are important only insofar as they support the higher goal of improving QoL. As a result, we have produced a high level CLD that can be used as a starter for any future research in the area of CAM and liveability in cities and which may resonate better than previous CAM models have with city planners and policy makers—those who will ultimately play a key role in recommending and then implementing changes affecting QoL.

1. Introduction

Mobility is central to liveability (Anciaes and Jones, 2020). Particularly in an urban context, our understanding of both mobility and liveability is evolving as these concepts undergo a period of profound change. We are entering the era of the 'smart city', increasingly integrating and relying upon digitalisation and connectivity (Abu-Rayash and Dincer, 2021), set within a recent background of COVID-19 travel restrictions and social distancing. Looking forward, sustainable, healthy, and socially inclusive poly-centric cities are a commonly stated goal—to be achieved, for example, through development of "15-minute neighbourhoods" and "liveable streets". Many cities hope to encourage the uptake of active forms of transport (cycling and walking) and shared micro-mobility while dependence on individual motorised vehicles (e.g., personally owned cars) is phased out. The introduction and integration of connected and automated mobility (CAM) within this paradigm could either help or hinder, depending on how individual citizens, businesses, and policymakers respond to the new technology (Milakis, 2019). On the one hand, a move towards CAM that uses certain models of vehicle and ride-sharing could open the way for an efficient, inclusive, and sustainable transport system (with several assumptions, including a zero emission, renewably powered fleet). At the other extreme, if the current model of individual vehicle-ownership and -use persists, we risk making our transportation system even less sustainable, while deepening societal inequalities with respect to accessibility, mobility, and liveability.

The central research question we are addressing is: *"How will the introduction of connected and automated mobility (CAM) influence liveability in cities?"* By answering the question we hope to be able to inform urban policy design. In order to do so, we carry out the following tasks:

- Explore the key concepts related to visions for 'liveability' in a city, identifying the elements required for attaining a good quality of life (QoL).

* Corresponding author.
E-mail address: G.Harrison@leeds.ac.uk (G. Harrison).

https://doi.org/10.1016/j.urbmob.2022.100034
Received 9 February 2022; Received in revised form 7 June 2022; Accepted 2 July 2022

Acronyms

ADS	Automated Driving Systems
CAM	Connected and Automated Mobility
(C)AV	(Connected and) Automated Vehicles
CLD	Causal Loop Diagram
PAV	Private Automated Vehicles
POV	Privately Owned (human-driven) Vehicles
PT	Public Transport
QoL	Quality of Life
SAV	Shared Automated Vehicles (fleet vehicles that are used either privately or as a ride-share)
SD	System Dynamics
VMT	Vehicle Miles Travelled

- Determine the potential system influences of CAM on urban liveability and how the vision of liveability held by city and regional planners may be affected.

We start with a conventional view of transport systems, then incorporate additional narratives that have recently come to light. Recognising that the systems involved are complex and dynamic, we use a system dynamics (SD) approach to examine them, with the goal of developing a high-level causal loop diagram (CLD), through group model building.

We engaged with metropolitan areas in the United States and Europe to gain a better understanding of what matters to them with respect to QoL and liveability in cities, and how these factors relate to CAM. Recognising that automation is being integrated into a complex transport ecosystem, this allowed us to collate perspectives from professionals who work within that existing system. Previous work (Rakoff et al., 2020) focused on the impacts of CAM scenarios that were developed in advance, mostly direct impacts on traffic from different developments in automated driving, with a strong emphasis on automotive technology. However, our goal here was to broaden the focus with respect to CAM to obtain perspectives we had not thought of before, thus getting the best value from having participants who work in different aspects of transportation than we do, especially including those who are closer to city planning and management and less focused on automation and research. To do so, we engaged in a group model building exercise during a workshop with city, metropolitan area and regional planners and modellers to discuss these complex systems in a meaningful way and capture new insights. The CLD we develop in this work is the first application of an SD approach to understanding the effect of CAM on liveability. It is generalised and high-level, so it can be readily adapted for use by others seeking to apply the framework to their particular circumstances and concerns.

The workshop also took advantage of new developments in virtual group model building to bring together city planners and modellers from regions that, in pre-COVID times, would not have found it feasible to send multiple staff to international in-person conferences. The session allowed fifteen technical-level professionals from five U.S. metropolitan areas and regions (in two states), and four European cities (in four countries), as well as a representative of the European network POLIS, to exchange and interact with each other's ideas and observations in real time.

In the next section of this paper, we provide a brief review of the concepts of CAM, liveability in cities, and the traditional transport system. We also explore the complex interactions among those concepts. Building on this context, in Section 3 we introduce our methodology, describing the system dynamics approach and the workshop activities as well as how the model was developed and refined after the workshop. We present the results (including the workshop output and resultant CLD) in Section 4 then in Section 5 we discuss key insights from the CLD in relation to CAM and liveability as well as reflecting on the methodological process. Finally, Section 5.7 is our conclusion summarising outcomes in relation to the research question.

2. Background

2.1. Connected and automated mobility (CAM)

Connected and automated mobility (CAM) has the potential to transform the world's road transportation system. Benefits could include (Milakis et al., 2017, Aittoniemi et al., 2020, Nahmias-Biran et al., 2021):

- Improved traffic safety (automobile collisions are a leading cause of accidental deaths)
- Higher transport network efficiency (most cities experience significant traffic congestion)
- Reduced energy use and emissions (oil consumption, air pollution and greenhouse gas emissions are of worldwide concern); and
- Improved personal mobility and accessibility (drivers and non-drivers alike may enjoy new mobility options).

For the purposes of this paper, we have chosen to use the term "connected and automated mobility" (or "CAM") to express the full range of potential mobility options enabled by connected vehicles and those with automated driving systems (ADS), including those with the ability to operate in a cooperative manner. This includes both private and shared vehicles, as well as public transport (PT) provision. We chose not to use other common terms, such as connected and/or automated vehicles (C/AVs) (except where a more restricted meaning is desired), as readers are likely to associate them with only private individual passenger vehicles, not the broader range of mobility services (such as public transport, fleet ownership and ride-sharing) where our interest lies.

CAM includes technologies enabling a vehicle to handle the dynamic driving tasks with increasingly limited human interaction and at the most extreme stage to operate completely without any human intervention whatsoever. There are six levels of driving automation recognised over this range, where Level 0 has no automation and Level 5 is fully automated in all situations (SAEI, 2021). At the time of writing, driver assistance technologies are already widely available in existing vehicles on our roads – such as (adaptive) cruise control, automatic parking and lane assistance, and there are a significant number of ADS being tested around the world. However, it is likely still many years before we would expect wide-spread market penetration of automation which completely frees the human from the driving task in a wide operational design domain, as even though technology may be maturing the socio-legal systems required to support any transition are still under discussion (Bellet et al., 2019, Pattinson et al., 2020, Milakis and Müller, 2021). The claimed benefits of CAM include safer, more efficient and inclusive travel. However, these benefits may not be fully realised under the model of individual ownership and car dependence that currently exists within our established transport systems (Chase, 2016).

While the benefits of CAM are potentially transformative, it is important to realise that it is being introduced into a complex transportation system, with highly uncertain outcomes. Second order impacts, such as the possibility of increased travel leading to more congestion and emissions, are of significant concern (Aittoniemi et al., 2020). Other farther-removed and longer-term effects, including potential feedback effects, could have significant impact on outcomes as well. Feedback effects occur when a system responds to initial changes in ways that either reinforce those changes (*reinforcing* feedback effects, which can drive "vicious" or "virtuous" cycles) or limit the effect of those initial changes (*balancing* feedback effects, often manifested as policy resistance) (Sterman, 2006). As a result, the impacts of CAM may be wide-ranging, and are very difficult to assess.

2.2. The trilateral working group on automation in road transportation (ART)

The Trilateral Working Group on Automation in Road Transportation (ART) is an initiative of the European Commission, the United States Department of Transportation and the Japanese Ministry of Land, Infrastructure, Transport and Tourism. Building on a long history of research collaboration and information exchange related to intelligent transportation systems (ITS), three bilateral agreements formalised ITS knowledge exchange activities between the parties in 2009-2010 (Dreher et al., 2019). These activities are coordinated by a Steering Group which established four working groups, one of which is ART, established in 2012. ART's mission goals are to "support shared learning, develop solutions to shared challenges, and harmoni[s]e approaches where appropriate. The working group seeks to achieve these goals by (Fischer et al., 2018):

- Allowing each region/country to learn from one another's programs
- Identifying areas of cooperation where each region will benefit from coordinated research activities; and
- Engaging in cooperative research and harmoni[s]ation activities.

When it comes to ADS, public authorities, industry, research institutions, and citizen groups struggle to comprehend the potential consequences of wide-scale implementation. It is challenging to have meaningful conversations about which impacts may be desirable, which ones should be avoided, and which ones might be mitigated by other measures. In order to structure discussions and further investigate these issues, ART established a sub-working group on Impact Assessment. The Impact Assessment sub-working group started to collaborate in 2015 in the development of a high-level framework for assessing the impacts of road traffic automation (Innamaa et al., 2018, Innamaa et al., 2017). The goal was to facilitate the impact assessment work in projects performing field tests with ADS in the three regions and beyond. With a harmonised approach, tests and studies can be designed to maximise the insight obtained and to arrange complementary evaluation across the world. Harmonisation also facilitates meta-analysis. The framework provides recommendations on how to describe impact assessment studies in such a way that the user of the results understands what was evaluated and under which conditions. In addition, a detailed series of key performance indicators was developed.

During the development of the trilateral framework mentioned above, several workshops were organised, both with experts in the field and with a wider public during international transport conferences, one of which had a public open day. One of the difficulties encountered was that the complexity of the impacts and their interrelationship made it difficult to engage in structured and meaningful discussions. For example, it is very difficult to discuss one impact area, such as mobility, without also considering what the effects would be on the environment. If CAM would make car use easier and more comfortable, would that mean that there would be more cars on the road? Although these workshops produced very useful ideas and insights, we began to realise that the participants in these discussions were usually coming from the transport sector, with a strong focus on the effects on transport. Some participants had a rather strong interest and belief in the beneficial impacts of road automation, and in any case, we framed the workshops to look largely at impacts of automation on travel demand and mode choice, rather than higher-order impacts on QoL. However, we realized that there are other important perspectives to consider. During one workshop, a representative from a large city remarked that they were very interested in CAM, but that one of their primary goals was to significantly reduce individual motorised transport in favour of public and active transport. They felt that if CAM could help to realise that objective, it was great; if not, then they were no longer interested. After the publication of the impact assessment framework, the trilateral group started to look for new, innovative ways of discussing impacts and helping decision makers address the wider issue of liveability. This paper describes how we used system dynamics modelling, in particular the use of group model building and CLDs, to establish a conceptual framework for assessing the potential impacts of CAM for cities.

2.3. Liveability and mobility

Urban sustainability is an increasingly global concern, indicated by "sustainable cities & communities" being one of the United Nations' sustainable development goals (UN, 2021). In the last half of the 20thcentury, urban areas in European Union member states grew by 80% while urban population grew 35% (Ferreira et al., 2021). By 2015, around half of the population of OECD (Organisation for Economic Co-operation and Development) countries lived in metropolitan areas, and it was projected that by the end of the 21st century, the global urban population will be around 9 billion, 85% of the total population (OECD, 2015). As we face this era of urbanisation we need to ensure that cities are "liveable", as an essential element of long-term urban sustainability.

There are many definitions and different ways to understand the concept of liveability. The annual Global Liveability Index ranks all cities in terms of five key factors: Stability, Healthcare, Culture & Environment, Education and Infrastructure (EIU, 2021). As suggested by Appleyard et al. (2014), liveability is "*best understood as an individual's ability to access opportunities to improve his or her quality of life"*, and those opportunities can be limited by conflicting desires and competition for resources across large populations. This raises the issue of ensuring equal access for all. Other researchers have attempted to define liveable communities in more detail, such as: "*safe, attractive, socially cohesive and inclusive, and environmentally sustainable; with affordable and diverse housing linked to employment, education, public open space, local shops, health and community services, and leisure and cultural opportunities; via convenient public transport, walking and cycling infrastructure"* (Lowe et al., 2013). At a local level, liveability may also be characterised by community identity. The sustainability and liveability of cities are also strongly affected by the form of urban development, which generally follows one of two approaches: dense with high-rises, or low-density and sprawling (Nieuwenhuijsen, 2020), each of which has transport and planning implications. In addition, there is a strong association of liveability with health (Khomenko et al., 2020, Lowe et al., 2015, Nieuwenhuijsen, 2020, Badland and Pearce, 2019).

There is no single recognised definition of liveability, as it is highly context-specific. Ultimately, liveability consists of multiple socio-physical and socio-cultural factors, with variations in assessment approach, but generally is used as a reference to the standard of living (or living standards) or overall wellbeing of those who live in a city (DoT, 2011, Barry, 2010, AARP, 2005, Paul and Sen, 2020). In this work we take a general definition of liveability, drawing from the literature outlined above:

> *Liveability in cities relates to the physical, social and cultural factors that can lead to equal access to opportunities, ensuring a sustainable and satisfying quality of life (QoL) for all inhabitants.*

Transport, or more specifically, the access it provides, is an integral part of QoL, whereas the externalities of transport negatively affect health and well-being. The liveability benefits provided by transport can be related to provision of (safe and sustainable) accessibility (DoT, 2011) or the facilitation of independence and choice (Barry, 2010, AARP, 2005). Anciaes and Jones (2020) suggest that there are nine dimensions of liveability related to transport, which fit under the three broad categories of "movement", "place", and "society".

Vitale Brovarone et al. (2021) recognise from the literature that CAM may have both positive impacts on urban liveability (reduced collisions, improved accessibility, increased capacity) and negative ones (increased VMT, congestion, and sprawl, with reduced active travel and public transport). However, using a back-casting visioning process, they believe that it is possible for CAM to positively contribute to liveability, but that requires regulation of circulation and parking, as well as integration into the existing transport system. Agreeing with Vitale Brovarone et al. to some extent, González-González et al. (2020) emphasise that a model of like-for-like replacement of current conventional private vehicles with connected and automated vehicles would not help to achieve goals of liveability and sustainability, but such vehicles could support those goals with a move towards shared use and restriction of motorised transport to certain areas.

3. Methodology

3.1. System dynamics

System dynamics (SD) is a methodology for understanding complex systems, and in particular identifying effective interventions to make them perform better. The purpose is to capture all relevant variables, relationships and feedbacks that characterise the behaviours of the systems (Sterman, 2000). SD has both qualitative and quantitative aspects. Qualitatively, we build causal loop diagrams (CLDs) that represent key aspects of the system, consisting of variables connected to each other by causal links. These causal links can be positive (or "same") or negative (or "opposite"). A positive link means a change in the cause variable will lead to a change in the *same* direction in the effect variable (i.e., an increase in the first leads to an increase in the), whereas a negative link means the change will be in the *opposite* direction (i.e., an increase in the first leads to a decrease in the second). A closed sequence of these links form feedback loops that can be either reinforcing (ultimately resulting in exponential growth or decline) or balancing (which inhibit growth or decline). These can be used to then develop quantitative dynamic simulation models that capture both linear and non-linear effects. Liveability has been recognised as an outcome of complex systems, for which we need to develop our understanding of interactions, feedbacks and non-linear responses (Badland and Pearce, 2019), thus, making SD an appropriate method for considering the subject.

SD has been widely applied to transport (Shepherd, 2014) and in particular to the uptake of alternative fuel vehicles (Gómez Vilchez and Jochem, 2019). There are a few efforts to date that have used SD to examine CAM, but there have been no studies where an SD approach has been applied directly to understanding the influence of CAM on liveability. Qualitatively, CLDs have been developed to examine impacts on total vehicle distance travelled (Stanford, 2015) and vehicle use and modal shift (Gruel and Stanford, 2015). These papers concluded that predictable, linear transitions are unlikely, and while positive outcomes are possible in some scenarios, a key insight was that CAVs alone (in the absence of other interventions) are unlikely to lead to a sustainable transport system, so early policy intervention to avoid the dominance of privately owned CAVs is likely to be necessary. Focusing on socio-economic impacts of CAM, a group of international experts developed a high-level consensus causal loop diagram through a group model building workshop and conceptualised a general qualitative framework for CAM stakeholder interactions (Rakoff et al., 2020).

Five quantitative SD-based models addressing CAM have been identified in the literature, all concluding that there are high levels of uncertainty and risk. All of these studies were carried out using traditional transport indicators, rather than considering the wider QoL approach that was adopted in our study. Technology development and car sharing across all levels of automation were explored by Nieuwenhuijsen et al. (2018), who identified that positive economic and social acceptance conditions were required for high market share of highly automated vehicles. Three studies incorporated Nieuwenhuijsen et al. (2018) work into their own. Puylaert et al. (2018) and May et al. (2019) utilised the outputs in their own SD models and both found that total vehicle distance travelled may increase following the introduction of automated driving, though shared and connected mobility may mitigate this to some extent, but not enough to remove all increased distance. Harrison et al. (2021) further developed Nieuwenhuijsen et al.'s model to focus on the role of services linked to connectivity, finding that they could contribute to a 20% increase in Level 5 market share by 2050. Finally, using the region of Copenhagen as a case study, Legêne et al. (2020) applied SD and exploratory modelling and analysis to establish twelve key uncertainties of CAV on urban development and lead to the conceptualisation of two distinct scenarios, indicating that shared CAV ownership will be critical in reducing congestion and urban sprawl.

3.2. Workshop

We organised a virtual workshop in early 2021, using the Zoom platform City representatives and transport planners from four European cities, one U.S. state, and four U.S. metropolitan areas participated[1], and the session was jointly facilitated by the authors (from the U.K., U.S., and Finland)[2]. The U.S. attendees were invited to participate due to their partnership in ongoing related projects. In Europe, we invited cities representing specific region/city sizes, supplemented by an open invitation distributed to members of the POLIS network.[3]

The workshop, which lasted 3 hours, was titled "Liveability of Cities: A System Dynamics Perspective", and participants were told that we would be exploring the dynamics of improving liveability in the urban system and that a key consideration would be the role of automated mobility in improving liveability. They were also told that they would learn how to use system dynamics concepts to identify the key relationships and points of leverage among the causal factors in city transportation.

Through the workshop we develop a CLD for understanding the impact of CAM on Liveability, involving a three stage process as described in Fig. 1 and Sections 3.2.1 and 3.2.2.

Prior to the workshop, participants were asked to contribute to two online collaborative engagement boards (using the platform "Padlet"[4]). This important step in the process allowed the workshop organisers to start collating key concepts and building a causal loop diagram as a starting point for discussion in the workshop.

The first Padlet focused on identifying key elements related to liveability in cities, and asked, *"What are the most important elements for attaining a good quality of life in your City?"*. Participants were requested to provide their top three elements, along with a short description, and to add any links to other elements already posted. Respondents also had the ability to up-vote or down-vote elements proposed by others. In the second Padlet, the question was "*How might the introduction of automated vehicles impact quality of life in your City?"* Participants could add up to three "hopes" and three "fears" regarding this question, and could again vote for existing posts. This "hopes and fears" exercise is a standard activity in group model building[5]. The project team took the results of the pre-workshop QoL exercise to create a simple CLD in advance (see section 4.1 and Fig. 3 later), using the online tool "Loopy"[6].

[1] From Europe: Vienna, Austria; Gothenburg, Sweden; Madrid, Spain; Oslo, Norway; a representative from POLIS. From the U.S.A.: Oregon Department of Transportation [ODOT, the state DOT] ; Mid-Willamette Valley Council of Governments [MWVCOG, the metropolitan planning organization for Salem, Oregon metropolitan area] ; Oregon Cascades West Council of Governments [OCWCOG, the metropolitan planning organization for Corvallis and Albany in the region of the Oregon coast and Willamette Valley mountainous region] ; Central Transportation Planning Staff [CTPS, the staff to the Boston Region Metropolitan Planning Organization] ; Metropolitan Area Planning Council [MAPC, the regional planning agency for the 101 cities and towns of metropolitan Boston]

[2] One author (Jospeh Stanford) was not involved in the workshop facilitation. One facilitator (Hitesh Boghani, University of Loughborough) was not involved in the writing of this paper.

[3] POLIS is a network of European cities and regions working together to develop innovative technologies and policies for local transport. https://www.polisnetwork.eu/.

[4] www.padlet.com.

[5] https://en.wikibooks.org/wiki/Scriptapedia/Hopes_and_Fears.

[6] https://ncase.me/loopy/.

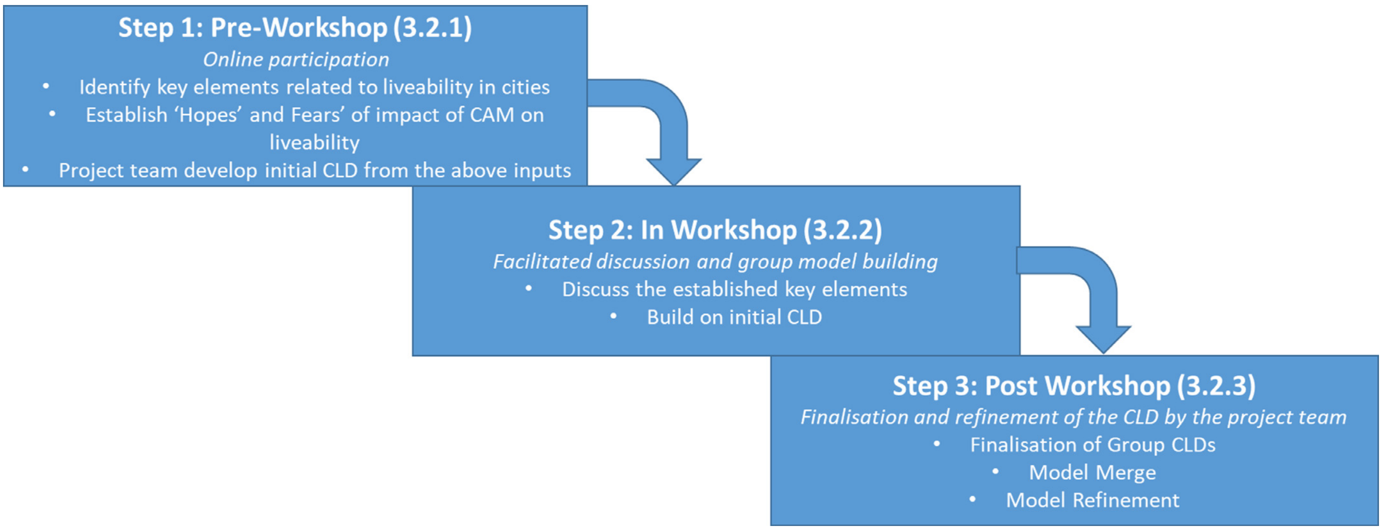

Fig. 1. Methodological process

What influences quality of life (starting from Loopy CLD, referring to QoL padlet)?

- Establish consensus of definition of the variables
- What metrics could be used to measure them?
- Do you agree with the variables currently included?
- Are there any key variables missing?
- What is the nature of the relationships between variables (+/-, strength, delays)?
- What are the key feedback loops that describe system behavior?
- Causal relationships among transportation, land use, and other factors
- Equity aspects: how different groups are affected

What role (if any) might automated driving play (Hopes and Fears padlet)?

- Establish consensus on definitions
- Which variables in the QoL CLD will be influenced, and how – establish the links in Loopy
- What is the relative strength of the influences?

Fig. 2. Prompt questions for the facilitators

3.2.1. In-workshop CLD development

During the workshop, the participants were first given a short introduction to the theory of system dynamics and causal loop diagrams. They were then divided into two breakout groups, each group comprising a balanced mix of European and U.S. participants. Each group built upon the initial simple QoL CLD in two tasks within the session. First, they discussed the existing CLD and QoL Padlet, and the facilitation team captured the consensus of the group regarding the key variables, relationships and feedback that characterize liveability of cities, with a focus on transport. Secondly, the groups identified what influences automated driving may have on these variables, including causal relationships and feedback. These sessions were facilitated by the project team, with three people working with each breakout group, taking the following roles: *Facilitator,* who guided the discussions (see Fig. 2); *Modeller*, who recorded the suggestions on the Loopy CLD; and *Note-taker*, who took written notes of the discussion. The notes taken at the workshop are available as supplementary information to this paper. A seventh member of the project (*Floater*) moved between the two groups to make further suggestions and to get an overview of both discussions.

During a short break in the workshop, the project team discussed the two respective CLDs that had been developed by the groups, and after the break presented the findings back to the whole group, followed by an overview of insights garnered by the Floater, and a round-table discussion that gathered feedback on the process from all participants. The topics raised in this discussion were also noted down for further work.

3.2.2. Post-workshop CLD development

Following the workshop, the project team continued to work on refining and merging the CLDs, building on the workshop notes and existing literature. The aim was to develop a high-level CLD that reflects conventional understanding of how transport systems work and incorporates potential impacts from CAM on the liveability of cities—and includes new insights regarding direct and indirect effects on liveability that were brought to light in the workshop discussion. This work consisted of three stages (see sections 3.2.2.1, 3.2.2.2 and 3.2.2.3).

3.2.2.1. Stage 1: finalization of group CLDs. The CLDs and notes for each group from the workshop were reviewed by the project team, in order to more adequately capture the discussions carried out, the knowledge of the project team and wider literature on CAM. In the first instance, the three members involved with each breakout group discussion worked together and agreed on a final version of the CLD for that group. In some cases, this involved editing variable names and relationships to make them more accurately reflect the concepts that had been discussed in the meeting.

3.2.2.2. Stage 2: model merge. Following finalisation of the Group CLDs in Stage 1, the project team set about merging the findings of the two

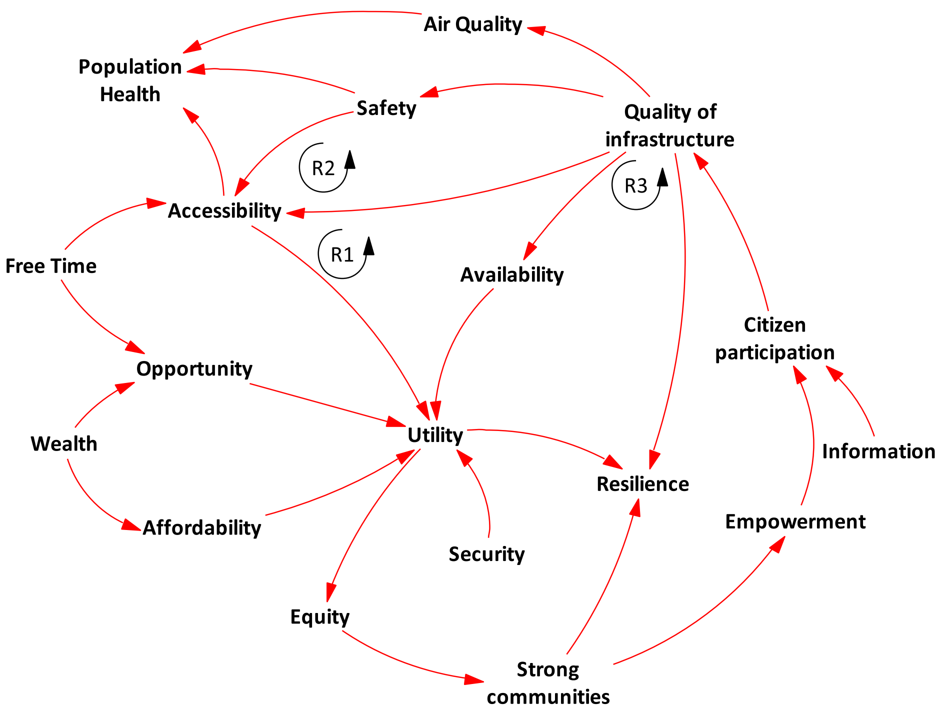

Fig. 3. Initial QoL CLD built from Padlet responses (Note: all links have been identified as positive (same) and there are three positive (reinforcing) feedback loops, all passing through Utility – see Table 1.

Table 1
Loops of the initial CLD.

Loop	Pathway
R1	Utility ->+ Equity ->+ Strong communities ->+ Empowerment ->+ Citizen participation ->+ Quality of infrastructure ->+ Safety ->+ Accessibility ->+ Utility
R2	Utility ->+ Equity ->+ Strong communities ->+ Empowerment ->+ Citizen participation ->+ Quality of infrastructure ->+ Accessibility ->+ Utility
R3	Utility ->+ Equity ->+ Strong communities ->+ Empowerment ->+ Citizen participation ->+ Quality of infrastructure ->+ Availability ->+ Utility

separate models into one final model that addresses the research question.

3.2.2.3. Stage 3: model refinement. At this point, another round of refinement was needed to fully integrate the two models. This consisted of four main tasks:

- Resolving inconsistencies and incompleteness in language and logical structure;
- Identifying and closing additional feedback loops;
- Improving visual arrangement and presentation; and,
- Creating a high-level summary.

4. Results

4.1. Pre-workshop

4.1.1. QoL padlet

We used workshop participants' perspectives on a vision for liveability from the QoL padlet, identifying the most important elements for relating to QoL, to construct a causal loop diagram, shown in Fig. 3[7] (with loops set out in Table 1). This served as a starting point for the group modelling during the workshop. The terms used in this CLD were drawn from the original QoL Padlet content from the participants (see Appendix 1). Some match exactly those used by participants (e.g. "safety", "accessibility"), whereas others were adjusted from suggested terms to terms felt to be more appropriate by the team (e.g. "utility' was chosen to be used in the CLD over "choice" as written in the Padlet, as utility is a more tangible/understood term which is well used within transport planning). Additional links were also added at the discretion of the project team with the objective of creating a coherent CLD which communicated the overall themes which emerged from the Padlet.

4.1.2. Hopes and fears padlet

Participants' hopes and fears relating to vehicle automation for liveability in cities that emerged from the Padlet exercise, are set out in Table 2. The original Padlet content is also available in Appendix 1. The hopes and fears broadly align with previous studies and conventional thinking as set out in Section 2.1, such as the focus on utility and accessibility, though do bring in some new concepts such as equity and community involvement.

4.2. Workshop outputs

Here we present a summary of the group discussions. The full workshop notes and resultant Loopy diagrams for each group are available as supplementary information.

4.2.1. Group 1 discussions

The CLD arising from the discussions of Group 1 is shown in Fig. 4. Group 1 recognised that liveable cities need to be sustainable (in a broad sense) and identified that most elements included in the presented CLD were linked to sustainability, The group added the variable *sustainability*, to explicitly recognise this. Furthermore, the *vision* of the city was raised as a crucial driver of key decisions. Although it could be argued that *vision* would influence all elements within city control, Group 1 specifically identified the links to *changing modes, competition for space/funds*

[7] Originally "Equality" was used rather than "Equity", but in post-workshop discussions it became apparent that "equity" was the correct term to use to describe the concepts discussed in the workshops eg. provision of resources for an equal outcome rather than providing equal resources to all.

Table 2
Hopes and Fears related to the impact of Automated Vehicles on liveability in cities.

HOPES	FEARS
• Improved travel comfort	• Reduced active travel and PT use
• Better compliance with traffic laws	• Increase in individual motorised vehicle kilometres travelled (VKT) as car travel comfort increases, cost decreases and due to empty miles,
• Decreased travel costs	• Increased congestion (especially at peak hours)
• Enjoying less noise	• Increased roadway maintenance, infrastructure and related costs
• Reduced parking needs	• Increase in energy consumption
• Improved safety	• Increased inequity
• New revenue opportunities	• Increased urban sprawl
• More accessibility for vulnerable individuals	• Decreased safety for other road users
• Increased energy efficiency	• Private companies putting profit above societal good
• Optimisation of road space and traffic flow	• Increased inequity – in road space use, accessibility, safety
• Increased road safety	
• Lower car ownership	
• More useful travel time	
• Advanced electrification	

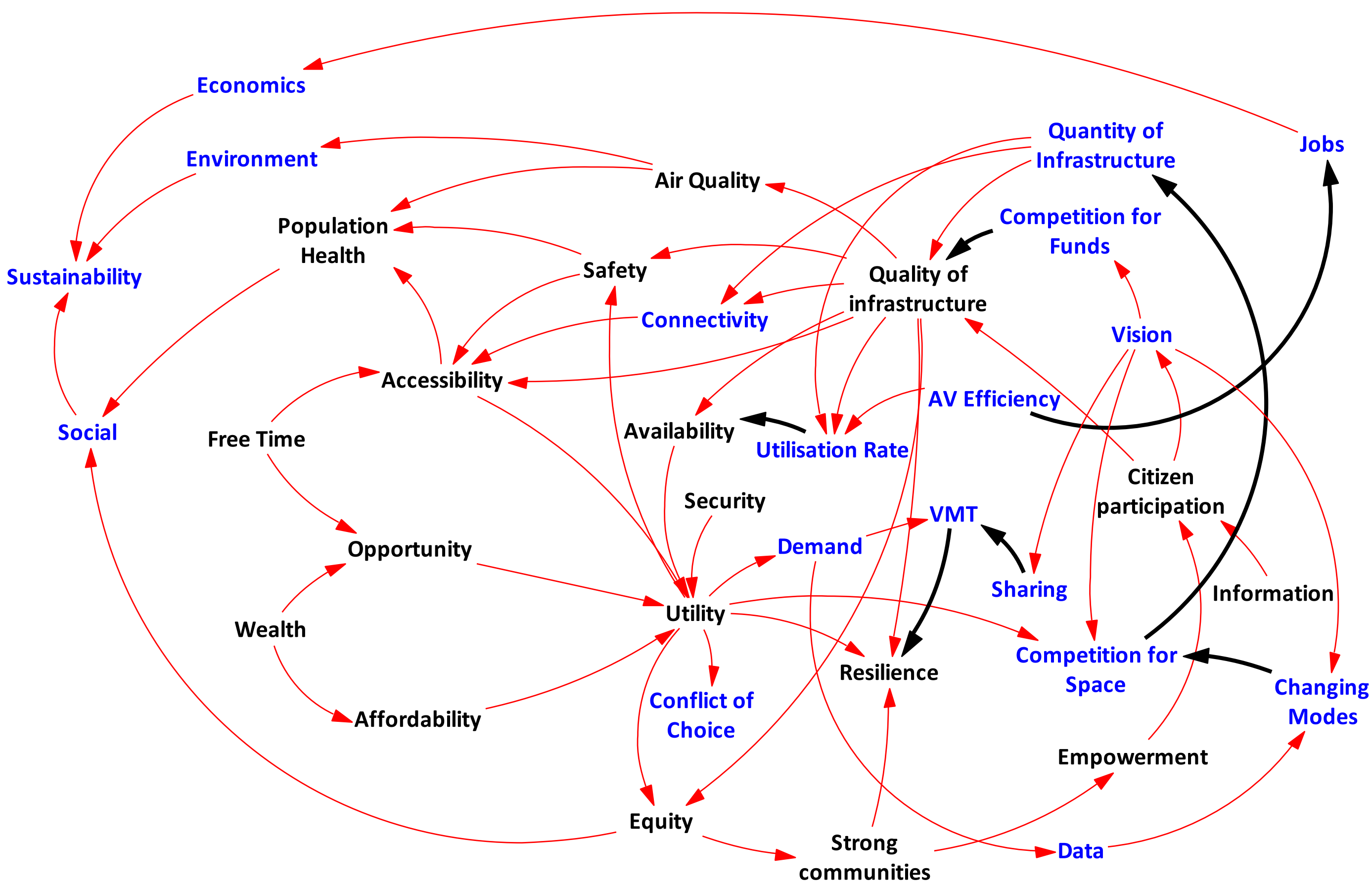

Fig. 4. Final Group 1 CLD: There are 36 variables and 39 feedback loops. Variables added to the initial CLD from the Group 1 discussion are in blue. For ease of viewing, negative links are thick black, positive links are thin red.

and *sharing* as being important in the context of this discussion. We did not actively pursue discussions regarding city visions related to intermediate variables, focusing instead on *vision* for outcomes that cities identified as key, such as sustainability; *population health;* and *strong communities*. Subsequent discussions were in three broad areas: public transport, personal choice and land use. Although public transport has been widely addressed in previous (transport-based) discussions around CAM, the latter elements, in particular personal choice, are relatively novel concepts within this domain.

4.2.1.1. Public transport. Public transport (PT) was discussed in terms of *quality of infrastructure*, which was already in the CLD, but also *quantity of infrastructure*. The *quality of infrastructure* is linked to the physical environment, (*accessibility* and *availability*) and installation and maintenance costs (*competition for funds)*,whereas the *quantity of infrastructure* is focused on the volume of PT available to users, such as the network coverage and frequency (*connectivity* – to desired destinations*)*. It is constrained by the *competition for space* and contributes to determining the *quality of infrastructure*. Both *quality* and *quantity of infrastructure* influence the *utilisation rate,* which is also important as demand for PT services is required, or else even a high-quality service is left unused.

There is a lot of uncertainty involved in the introduction of CAM into PT, especially in the transition phase. An increase in demand increases *VMT* but CAM may also increase *AV efficiency*. Lower *VMT* can provide many benefits, such as better safety, better air quality, and more space for other activities. An increase in simultaneous ride sharing (rather than consecutive vehicle-sharing) has positive impacts, by allowing more person-travel to be provided per unit of vehicle-travel. Although not explicitly captured in the CLD, pricing models can influence the system; digital connectivity (e.g. vehicle-to-infrastructure communication) creates *data* (such as who is driving where) that can be used to develop pricing models and better services. For example, combination of parking fees and dynamic road pricing can be ways to have CAVs compete less with PT. An authority could charge more for CAV trips that are parallel to a major PT corridor or have only a single occupant. Furthermore, when no driver is required, this may enable a lower PT price, which may open up the possibility of new pricing models by the public authority. This said, CAM will have an equity impact on employment. Professional driving (in PT) is a major employment option for people with lower levels of education. If these *jobs* are no longer present, the city needs to consider what other options are open to these citizens.

4.2.1.2. Personal choice. Personal choice played a strong role in initial discussions, with participants acknowledging that, while choice of where to live, work, play and shop is a goal for many cities, unlimited choice of destinations and travel modes (within given time/cost thresholds) is simply unworkable. Providing services and networks that deliver this would be highly costly, complicated and lead to use of land for transport assets overwhelming space available for the destinations themselves. Attempting to do so may result in creating a poorly-functioning transport system and too much choice could lead to sub-optimal quality of life (people find difficulty in dealing with too many choices). In any case, although aspirational, it may be unrealistic to assume everyone would be able to access everywhere and be completely satisfied. *Conflict of choices* arises from *competition for space (via quantity of infrastructure)* and *funds(via quality of infrastructure)*. However, funding is not an absolute constraint but is, rather, a policy decision. Some other constraints are also more political than absolute, such as *information, jobs* and *quality of infrastructure*. The freedom to make choices enables choices that may not lead to system-optimal outcomes. Regulation and rules are there to limit these effects. Unlimited choices link negatively to air quality, safety, etc. Competition will also produce negative effects (e.g., not enough space for all desired uses; all parts of a city cannot be made equally attractive), thus not all connections are positive, providing some nuance to the initial model built from the pre-work Padlets (Fig. 3). Limiting factors include space, climate impacts, costs and political ability to manage towards a consensus that everyone can agree with. Different sub-groups experience different impacts. Cities have an obligation to manage towards consensus, but also for equity (access, equal distribution of infrastructure for different activities, and equity of different regions).

4.2.1.3. Land use. CAM could reduce required parking capacity, releasing space for other activities, but could also reduce city revenues if parking fees are currently levied. New revenue sources could arise with new land use. Public authorities manage space; introduction of demand management and pricing are levers they often hold. Group 1 also acknowledged the reality that, while cities may aspire to move space to higher uses than parking, parking fees are a significant source of municipal revenue in many places. Discussion turned to policy levers which can both nudge travellers towards less energy- and space-intensive modes, and form replacement sources of city revenue. There was a recognition of the importance of understanding foremost the desired transport and land use system, rather than allowing unregulated development – in other words, what is the city *Vision*. That said, although there are policy instruments that can affect consumer demand, there are also elements over which cities have limited control, such as *wealth* or *free time* (outside of travelling).

4.2.2. Group 2 discussions

The discussion held by Group 2, whose final CLD is presented in Fig. 5, was much broader than that of Group 1, though with focuses on two similar areas: public space and personal choice. Other areas of discussion included mobility services, and safety and security. The group recognised that a multi-functional city is more attractive for *Active Travel*, with less dependence on long commutes.

4.2.2.1. Mobility services

The transition towards mobility services (e.g., *Ride-hailing, Micromobility*) could significantly influence liveability in cities both positively and negatively. Mobility services can contribute to a reduction in *private vehicle use* (and subsequent negative externalities) and promote *equity*. On the other hand, they may compete with *active travel*, which in itself may have a greater positive influence on liveability. The success of mobility services may depend on CAM being used for shared (rides and/or vehicles), rather than individual private use.

4.2.2.2. Public space. Similar to Group 1, Group 2 recognised the important relationship and competition between *urban transport* and *use of public space*. For example, *pedestrianisation* can aid with *active travel, safety* and *equity*. However, there are business models (particularly in relation to mobility services) of commercialising public space, such as placement of *micro-mobility Hubs*, which could have both positive consequences (improved access, increased income to the city) and negative ones (reduction of public space; increased nuisance).

4.2.2.3. Personal choice. The group identified that a liveable city offers choice, which they viewed as *utility*, which also flows from *affordability* and *accessibility*. Choices include good availability of transport and employment options. Diversity and access to information are important in (equity of) choice. CAM can make cities more accessible but may diminish the sense of community if private trips allow quicker access to essential needs. CAM could help non-motorists and those who cannot access PT by providing a lower-cost mobility option than a taxi. On the other hand, if rides are not shared, CAM can be used to avoid human interaction. If a door-to-door service is provided, active and PT trips may also be avoided, and the additional convenience could lead to increase in trips. It is important that authorities introduce appropriate policies to mitigate negative effects. This could include access regulations such as congestion charging, which could also increase city revenue (with questions on where these funds may be directed. Authorities could also introduce mobility hubsto supplant door-to-door service.

4.2.2.4. Safety and security. Many cities are auto-centric. To improve *equity* and *population health*, the city needs to be safer (and be perceived to be so) for both non-motorised modes and PT. Use of these modes also depends on a certain level of security, with differing effects across the population. Linking back to personal choice, increased *safety* and security increases utility. If travellers feel less safe and secure on non-motorised modes or PT, they will be more likely to drive personal cars, which has negative externalities. More broadly, a sense of *safety* and security helps to strengthen local communities, improving their *resilience*.

4.3. Post-workshop CLD development

4.3.1. Stage 1: finalization of group CLDs

The CLDs that resulted from this stage of work were presented in Fig. 4 and Fig. 5. Although both CLDs have a similar number of variables, many more links were made by Group 1, resulting in many more feedback loops.

4.3.2. Stage 2: model merge

Following finalisation of the Group CLDs, the ambition of the project team was to merge the two models. As both models were built from the same base model (Fig. 3), we initially thought that this could be a

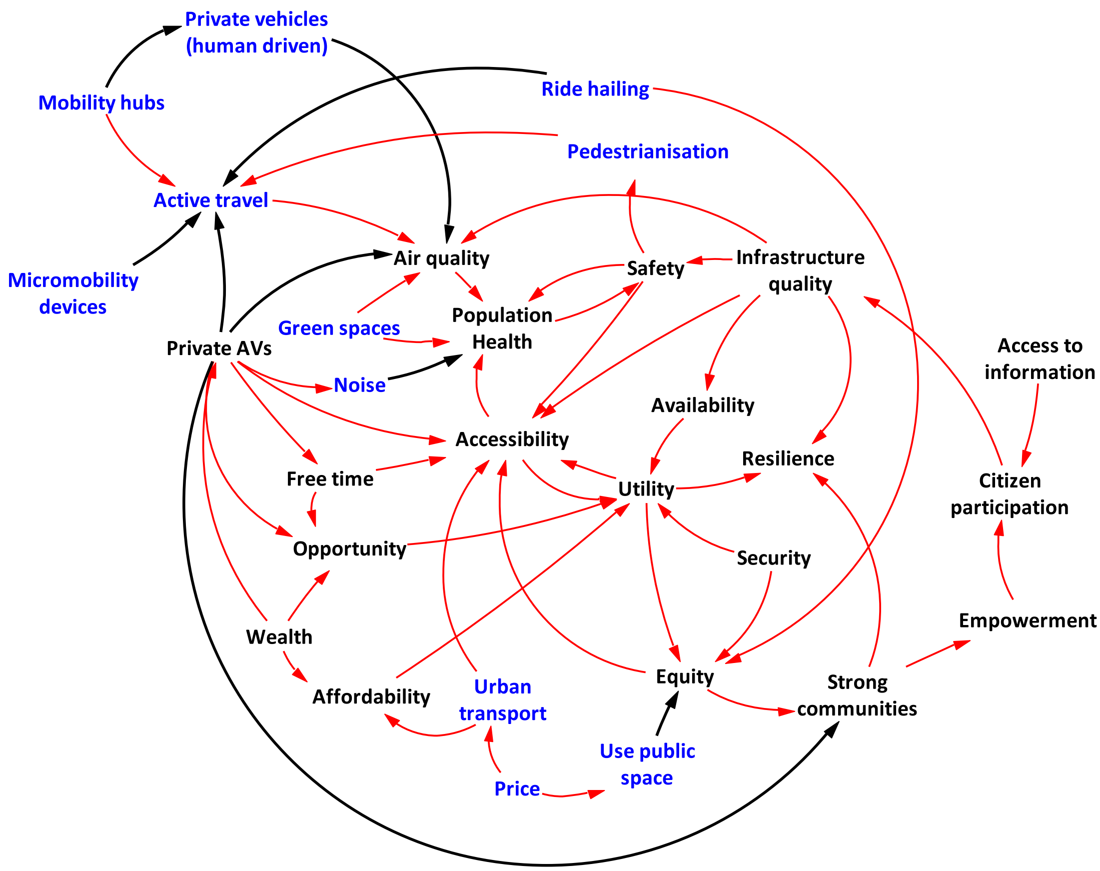

Fig. 5. Final Group 2 CLD: There are 30 variables and 9 loops. Variables added to the initial CLD from the Group 2 discussion are in blue. For ease of viewing, negative links are thick black, positive links are thin red.

straightforward exercise. However, interestingly, as the two groups had such different discussions, it quickly became apparent that the merging process would not be so simple if we were to adequately reflect the views of both groups. Therefore, the decision was taken to start with the Group 1 CLD and build the differences that were discussed by Group 2 into that CLD. We recognise that this may somewhat bias the final CLD towards the discussions of Group 1. With the two models merged, some of the larger causal pathways become clearer - showing connections from key input variables to key physical, social and cultural factors related to urban liveability.

4.3.3. Stage 3: model refinement

4.3.3.1. Resolving inconsistencies and incompleteness in language and logical structure. These resulting changes were mostly minor, and primarily made for clarity—for example, we changed *strong communities* to *community cohesion/strength*. In other cases, variables were re-worded to ensure they support the logical structure of the model—for example, *accessibility for everyone* became *attractiveness of city for disadvantaged populations*. Furthermore, some minor structural revisions were required, where causal links were removed when the logic was not fully supported, or where causal pathways could be better connected elsewhere.

4.3.3.2. Identifying and closing additional feedback loops. One of the benefits of the iterative revision process is that feedback loops may become apparent that were not initially identified. For example, the variable *support for public projects* was added to connect *community cohesion/strength* to *tax rate* (Fig. 6). This completes (“closes”) a reinforcing feedback loop and supports a key insight—that a city only survives when there is public will to pay for it and the very vitality of any city is defined by community cohesion/strength, which both supports and is supported by public spending. Similarly, another potentially powerful feedback loop emerged with the addition of the variable *economic vitality*: as *accessibility* increases, *economic vitality* improves, which grows *tax collection* and *revenue,* which further support *quality of PT infrastructure*, which ultimately reinforces *accessibility*, and so on.

4.3.3.3. Improving visual arrangement and presentation. While this final step is not essential to the underlying logic (or ultimate operability) of the model, it can be essential for the value of the model as an external communications tool, by making it more accessible to unfamiliar audiences and by telling clear, compelling stories. Improving visual arrangement can also play an important role in sustaining the model as an internal systems-thinking tool. Improved visual clarity helps the project team identify feedback effects and draw new connections that establish new feedback effects. This step did not involve significant structural changes but was more a matter of arranging variables and links in a way that reveals the underlying structure of the model. The rearrangement helped establish a general flow of cause and effect from the left side to the right (see Fig. 7 and Appendix 5), to help illustrate the effect of different levels of quality and availability for different mobility options on ultimate liveability outcomes. In other words, this clear flow helps the model communicate its answer to the question:

How will the “Key Primary CAM Variables” affect “Key Liveability Outcomes”?

When mapped onto our research question, this yields:

“How will the introduction of CAM (Private AV ownership, Shared AV service provision, and PT service provision) influence liveability in cities (Environmental Sustainability, Public health, Community cohesion/strength, and Economic vitality)?”

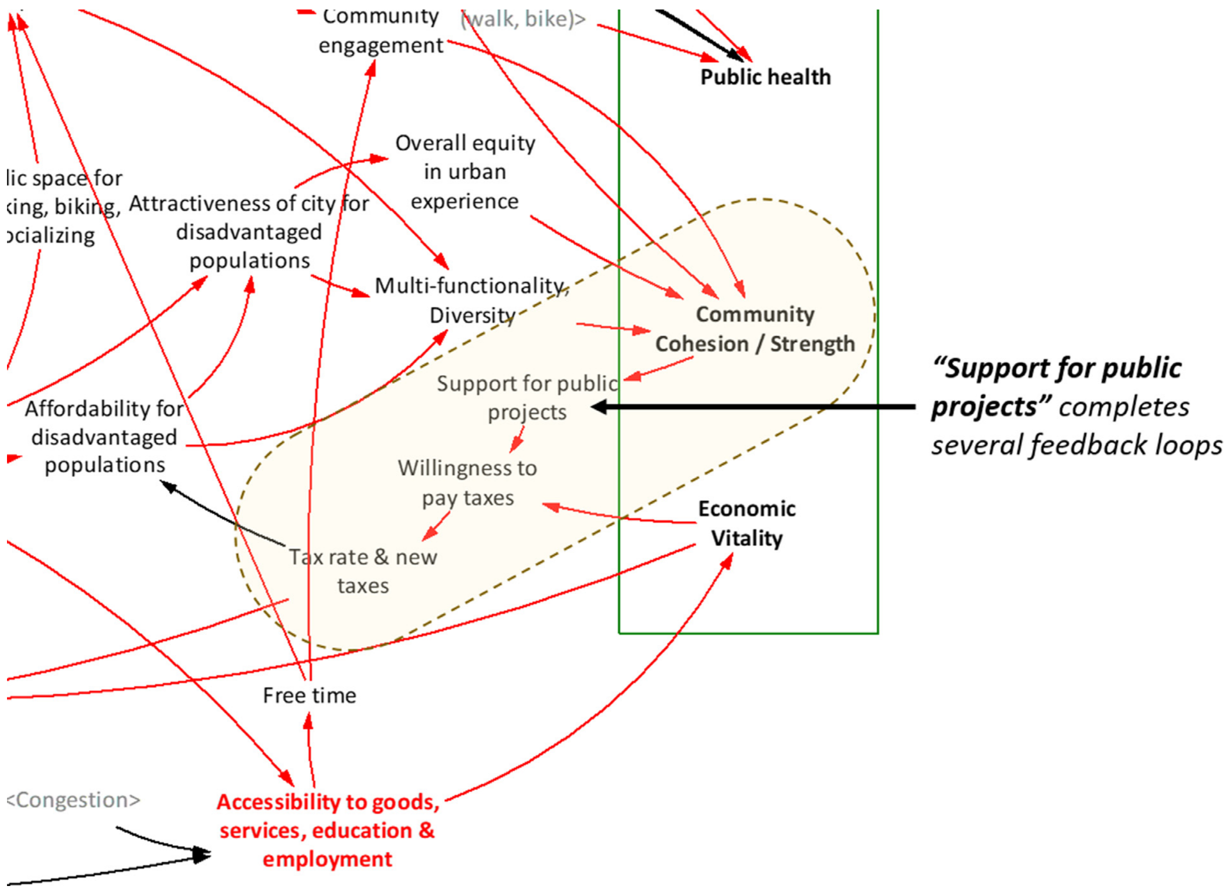

Fig. 6. Detailed view of key new variable, which connects several feedback loops.

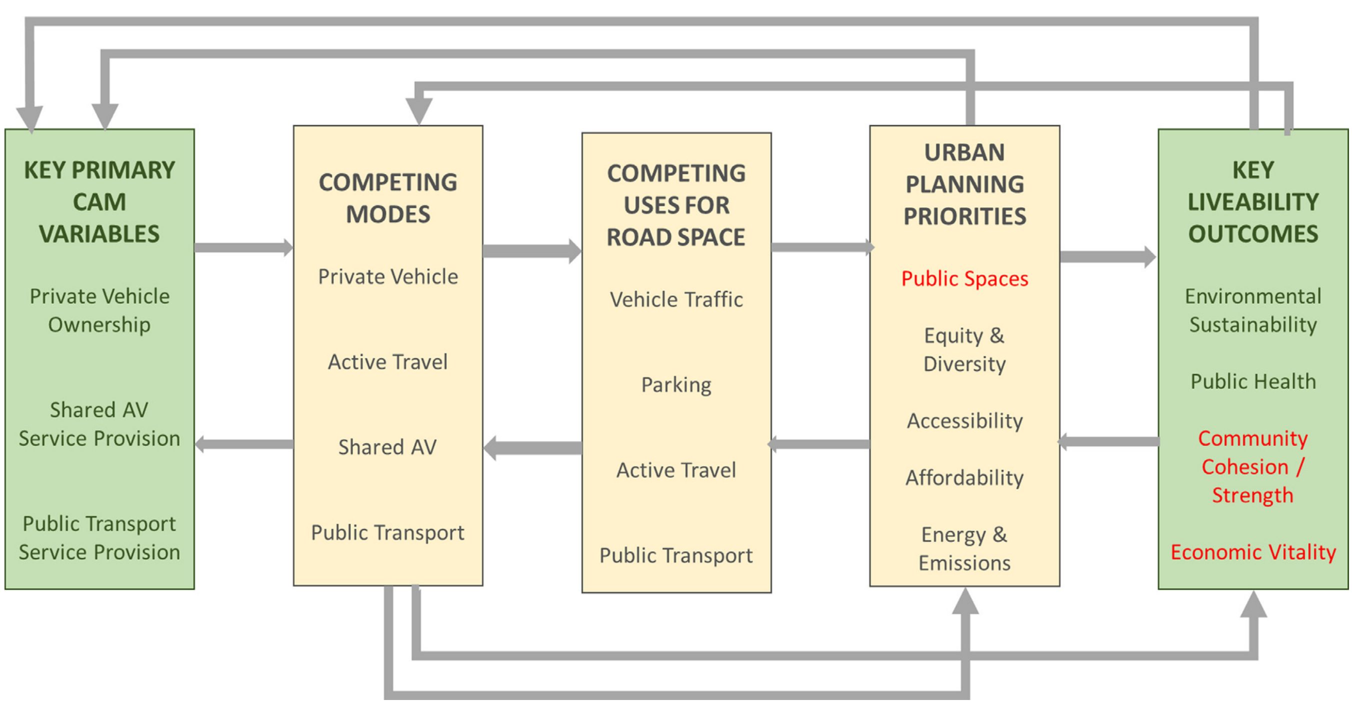

Fig. 7. High level summary of the fully integrated and refined CLD (full CLD in Appendix 5). Urban planning insights which differ from traditional transport perspectives are highlighted in red.

To further clarify the message of the model, the complex interactions among two clusters of variables were reduced and simplified, and we took liberty with certain conventions used in drawing CLDs. The clusters represent: (i) the competition among modes and (ii) competing uses for road space. Modelling the detailed mechanisms of these interactions would involve several more variables and links, making the model less readable, less accessible to external audiences, and less valuable as a systems-thinking tool. Therefore, instead of completing all the logical connections between the variables, they were labelled in yellow boxes. Finally, we drew a final clear box around the variables representing urban planning priorities that were revealed in the workshop and went beyond traditional transport perspectives.

4.3.3.4. Creating a high-level summary diagram. The resultant diagram is highly complex and may be difficult to interpret for a non-SD practitioner. Therefore, we further simplified the full final CLD in order to make it more understandable to planners and policymakers. We removed all intermediate variables other than the main clusters (competing modes, competing road space and urban planning priorities), as well as the causal link polarity. Thus, the high-level narrative of the CLD can be easily introduced before delving into the complexities of the full CLD.

4.4. Final CLD

Fig. 7 shows the high-level summary diagram, with the full final version of the CLD available in Appendix 5. It should be noted that the full CLD is a reflection of what was said during the workshop, and does not include every possible relationship. We capture our **key primary CAM variables** on the left, and the resultant **key liveability outcomes** on the right. Of these outcomes, two of the four are not traditionally considered in transport planning (community cohesion and economic vitality).

In both diagrams the main intermediate transport variables are the **competing modes** (which will all be strongly affected by the initial service provision variables) and the **competing uses for road space** (which will be largely determined by the outcome of competition among modes, although also by quantity and quality of infrastructure, as this competition is affected by the competition of road space overall with non-travel uses of the public space). These capture the 'traditional' transport perspectives we would perhaps expect, though also hinting towards a wider understanding of competition for public space . The elements of competition relate to the personal choice aspects which both workshop groups captured in their discussions. The focus on space, and on competition between transport and non-transport uses of space, was much more salient here than in traditional transport-focused workshops on CAM.

Exploring this wider perspective further, we remark that the "penultimate variables" (the proximate causes to the "key outcomes") are **urban planning priorities**, to which transport-focussed studies of CAM have paid little attention as a comprehensive group. Again, the interaction between city vision and urban transport planners' leverage in use of public space marks this work as distinct from most transport-focused work on CAM. For example, while there is an emerging literature on societal aspects of CAM (Milakis and Müller, 2021), and CAM studies attempt to determine the effects of CAM on energy and emissions (e.g. Brown and Dodder (2019), Stephens et al. (2016), Wadud et al. (2016)), model the effects of CAM on accessibility and equity in travel options (e.g. Nahmias-Biran et al. (2021), Cohn et al. (2019)) and even look at equity aspects of emissions from induced demand (Ezike et al., 2019), they tend not to link all of these aspects to use of the public space, instead focusing on policy decisions relating to use of vehicles (e.g. ride pooling) and technology (e.g. electrification). While pooling was a topic of discussion in the QoL workshop, a wider set of city-controlled levers was the greater focus.

5. Discussion & conclusions

The following sections discuss four key areas of insights regarding CAM and liveability from the full final CLD (Appendix 5), alongside illustrative extracts in which several variables and links have been moved and/or omitted for clarity. We focus on public benefits, reflecting the findings of Milakis and Müller (2021) that 'societal implications' are one of three key dynamics (alongside governance and acceptance) reflecting the societal dimension of ADS technology transition. In section 5.1 we focus on the key revealed 'urban planning priority', Public Space, then in the next two sections we focus on the two highlighted liveability outcomes of Community Cohesion and Economic Vitality. We then combine these insights for wider system perspectives in section 5.4. These are by no means the only areas of insight regarding CAM from this model, but seemed to us to be most relevant to understanding workshop participants' perspectives on liveability and how those go beyond the 'traditional' transport perspective. We then set out our thoughts on model quantification and our methodological reflections, before a final summary of our findings and conclusions.

5.1. Public space

Private automated vehicles (PAVs) share many of the same disadvantages as privately owned (human-driven) vehicles (POVs), in that they consume more shared resources than either the non-motorized or shared modes. If the service provided by shared automated vehicles (SAVs) can be good enough to lead to a reduction in private vehicle ownership, the reduction in private vehicle use may lead to additional benefit in terms of land use, energy and air pollution (Fagnant and Kockelman, 2014). There are four ways captured in the final CLD to decrease *private vehicle use* and thereby mitigate undesirable effects: through *road use pricing,* and by improving competing mobility options through policies and investments aimed at making *active travel, SAV use*, and *PT use* more attractive. This affects several key outcomes, as shown in Fig. 8, including some potentially powerful effects involving non-transportation uses of public space, beyond the land-use change relating to road and parking space focused on by previous authors (González-González et al., 2020, Soteropoulos et al., 2019).

For example, greater private vehicle use leads to more *air pollution, noise*, and the *traffic barrier effect* of having to cross a busy road to reach an attraction such as a park or waterfront. All of these reduce the *attractiveness of public spaces*, thus leading to less *social use of public spaces*, a diminished feeling of *security*, and potentially less *community engagement* (loss of informal meeting places). These weaken *public health*, and *community cohesion/strength* (Macmillan et al., 2020, Roe and McCay 2021). Other undesirable impacts include decreased *sustainability* (due to increased energy consumption and air pollution) and decreased *economic vitality* (due to traffic congestion reducing accessibility).

As shown in Fig. 9 below, the model also clearly identifies a feedback loop here, similarly identified by Macmillan et al. (2020) in relation to active travel, which would be driven as a vicious cycle with an increase in VMT: As *VMT* grows, *air pollution, noise*, and the *traffic barrier effect* all increase, which reduces the *attractiveness of public space*. As the *attractiveness of public space* decreases, the *social use of public space* decreases, reducing the *feeling of security in public space*, further decreasing the *attractiveness of public space,* and so on.

5.2. Community Cohesion/Strength

Both privately owned automated vehicles (PAVs) and (more importantly) SAVs, provided they are affordable, may lead to improved *mobility options for non-motorists*, leading to improved *community cohesion/strength*. Fig. 10 is an extract from the full CLD, which illustrates the relationships driving this outcome.

Firstly, as personal mobility is one of the key components of QoL identified by Aittoniemi et al. (2018), increased *mobility options for non-*

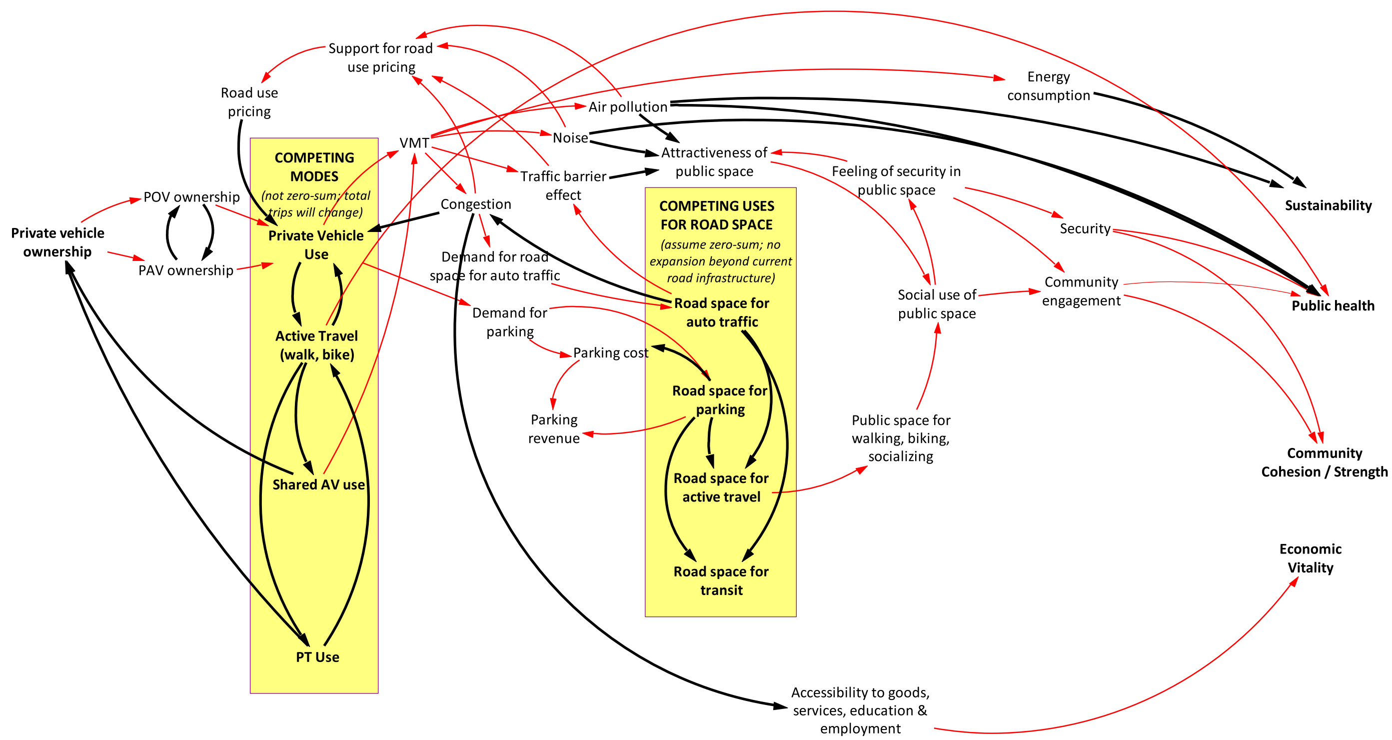

Fig. 8. Effects of private vehicles on public space(extract from full CLD—several variables and links have been moved and/or omitted for clarity)

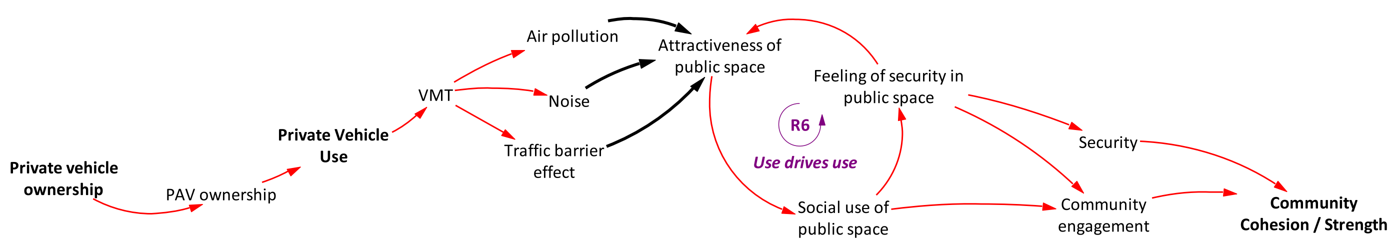

Fig. 9. Detailed view of feedback effect related to public space

motorists make the city more *affordable* and *attractive for transportation-disadvantaged population* (non-motorists – more likely to be lower income and/or elderly/disabled) (des Cognets and Rafert, 2019, Harper et al., 2016). This improves *overall equity in urban experience* as well as the city *multi-functionality/diversity*. Both of those factors improve the urban *community cohesion/strength*, as the population generally experiences the city on a more equal footing and fewer citizens feel "left out." Indeed, Macmillan et al. (2020) have already captured feedbacks between attractiveness of public space and community empowerment and Paddeu et al. (2020) have identified that equity and social inclusion were strong considerations regarding social acceptance of CAM.

Secondly, increased *mobility options for non-motorists* also has the potential to increase *accessibility to goods, services and employment*. We recognise though that this accessibility may not be evenly distributed (Milakis et al., 2018, Cohen and Cavoli, 2019). Improving *accessibility* can also increase the amount of *free time* which individuals have (Ezike et al., 2019). Though this may vary between socio-demographic groups (Pudāne et al., 2021), low income households have been found to take a substantial number of ride-hailing trips to avoid longer PT trips (Gehrke et al., 2018). The role of *free time,* often overlooked in more purely transport-focused workshops, is significant, and tells a compelling story that burdening a population with poor transportation options has harmful distal effects on *community cohesion/strength.* Put plainly, making everyone so busy just getting from place to place may mean that citizens can't connect with their neighbours, don't have time to go to community meetings, don't develop attachment to their city, and lack interest in investing in it, which may result in even poorer travel options, longer travel times, and so on: potentially driving vicious cycles of urban decline. Though we have captured the importance to urban planning of time outside the vehicle, often a focus of transport planners, another influence on *free time* not currently captured could be that of the in-vehicle value of time savings (Steck et al., 2018, Bjorvatn et al., 2021).

There are also a number of potentially significant feedback effects, which might drive *community cohesion/strength* much farther than the initial linear arrangement of causal links might suggest. For example, in Fig. 11, by adding three intervening variables (shown in purple in the diagram) we show how two reinforcing effects (R1 and R2) can emerge: *SAV service provision* may ultimately increase *community cohesion/strength*, which is likely to increase citizens' *comfort with ridesharing* (i.e., their willingness to take trips with people they don't know), which will increase the number of *SAV trips with ride-sharing*, as well as the number of *trips by PT.* Both of these factors will ultimately drive more service provision in both modes (PT and SAVs), completing two virtuous cycles which could compete with concerns that CAM may induce a mode shift from PT to AV (Lehtonen et al., 2021). This 'sharing breeds sharing' feedback loop mirrors previously understood 'safety/normality in numbers' feedbacks for walking and cycling (Jacobsen, 2003, Macmillan et al., 2014).

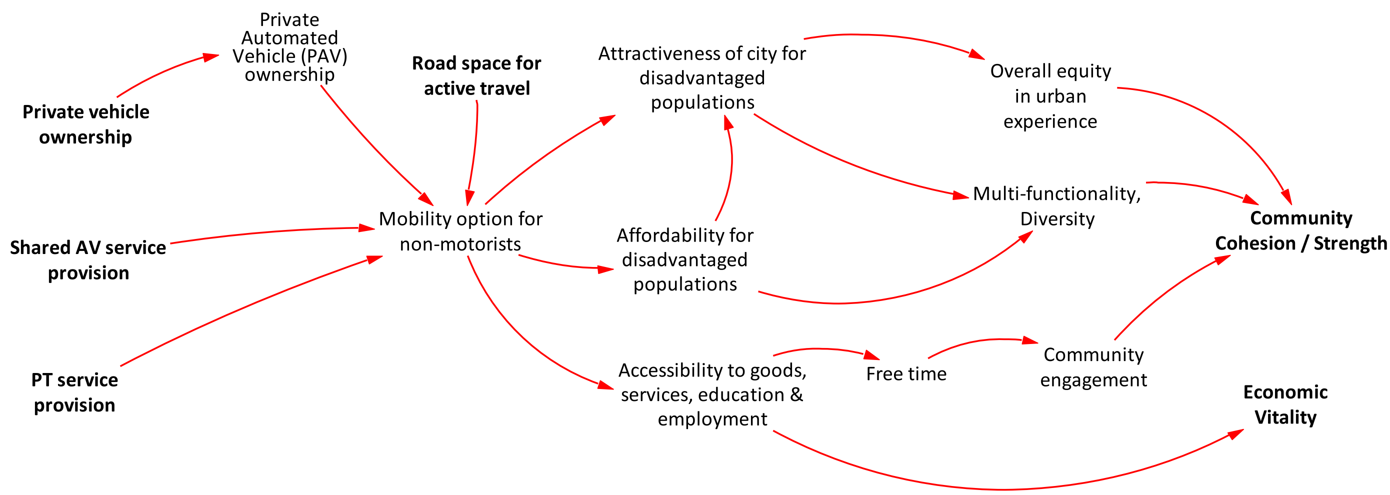

Fig. 10. Effect of improved mobility for non-motorists

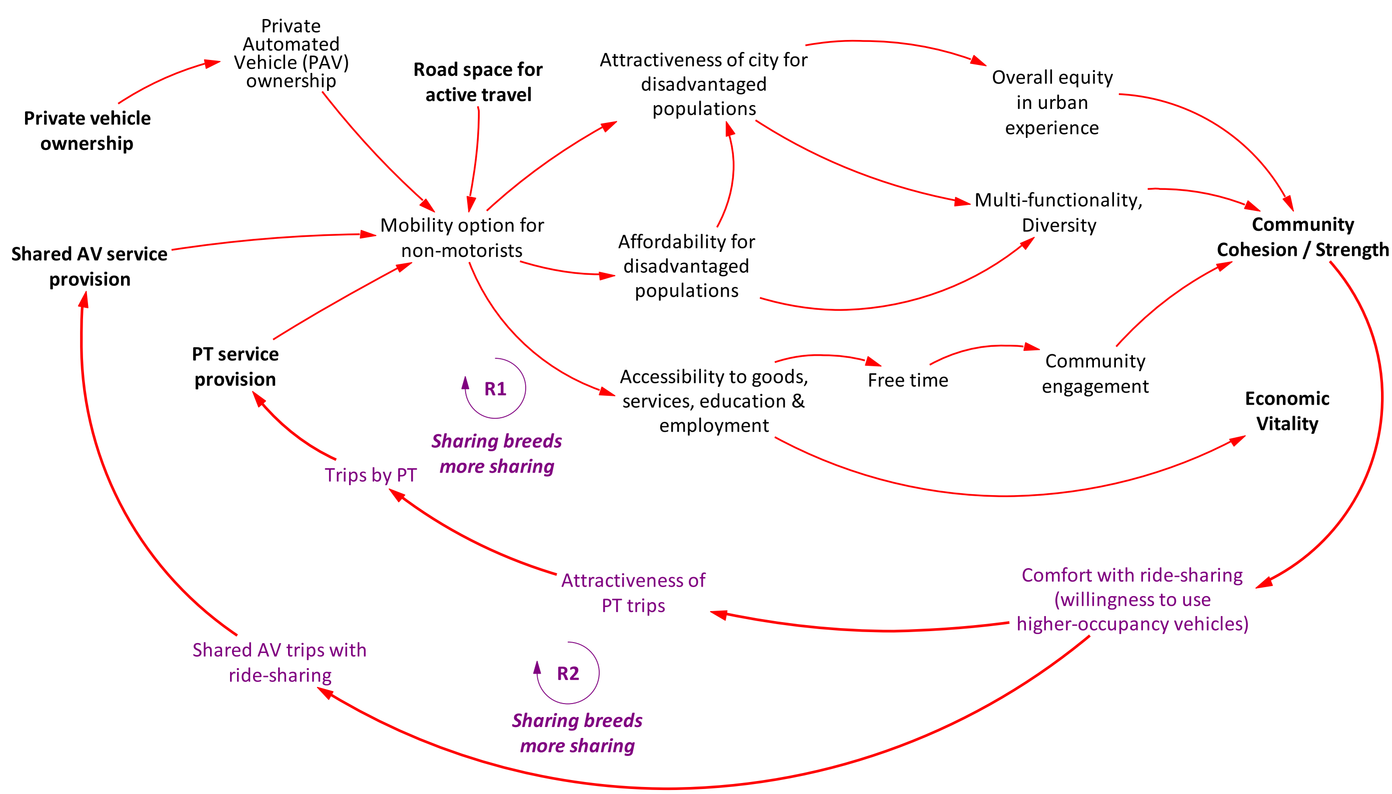

Fig. 11. Detailed view of potential feedback effects related to increased willingness to share rides (purple variables have been added to illustrate feedbacks not captured in the CLD).

Fig. 12 builds off the example in and includes one of the fundamental feedback effects that is key to PT service behaviour (R3). By adding the variable *attractiveness of PT trips*, we are able to connect *comfort with ride-sharing* to an increased number of *trips by PT,* which eventually (through links shown in the larger model) drives additional *PT service provision.* Although this may be in conflict with feedbacks suggested by other authors that AV could divert PT funds (Emory et al., 2022), it would increase higher-frequency service (with reduced headways and wait times), thereby further increasing the *attractiveness of PT trips*. These causal links complete the feedback effect R3, which in this example is shown as a virtuous cycle (note that this reinforcing effect, when it is driven in the opposite direction, is also commonly referred to as the "PT death spiral"). In addition, if SAVs are used as a first-mile/last-mile solution to supplement PT, we can capture this effect through the addition of the variable *mobility options for first-mile/last-mile.* Lau and Susilawati (2021) found that first/last mile SAVs could improve PT use, though this is dependent on the SAV waiting time. If successful, this will directly improve the *attractiveness of PT trips,* which, as noted above, could drive a virtuous cycle for PT (R3).

5.3. Economic vitality

Both groups discussed city finance, noting that in some locations, revenue from road use pricing and parking may be significant sources of city income. Previous authors have suggested that introducing road pricing and increasing parking fees may be required to constrain potential increases in VMT from the introduction of AVs (Shatanawi et al., 2021, Cohen and Cavoli, 2019). Higher *city revenue* may enable improved *PT*

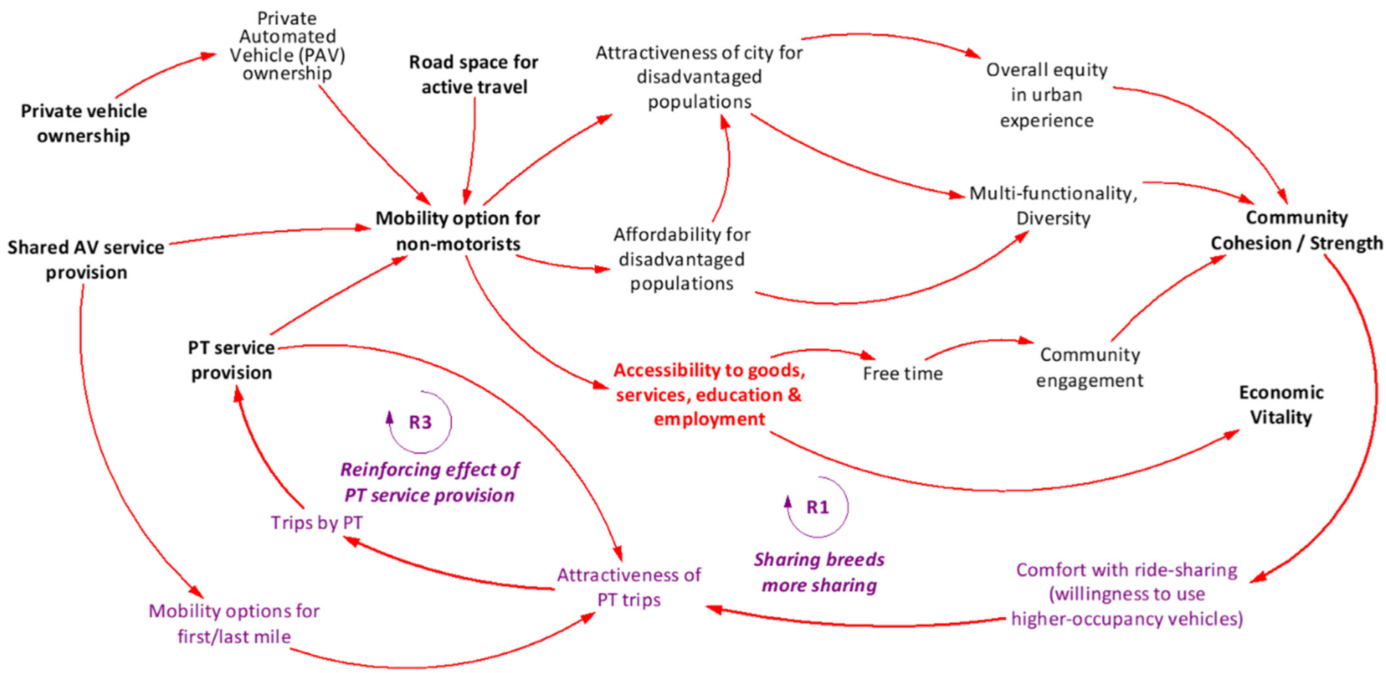

Fig. 12. Detailed view of additional feedback effects related to increasing the attractiveness of PT trips

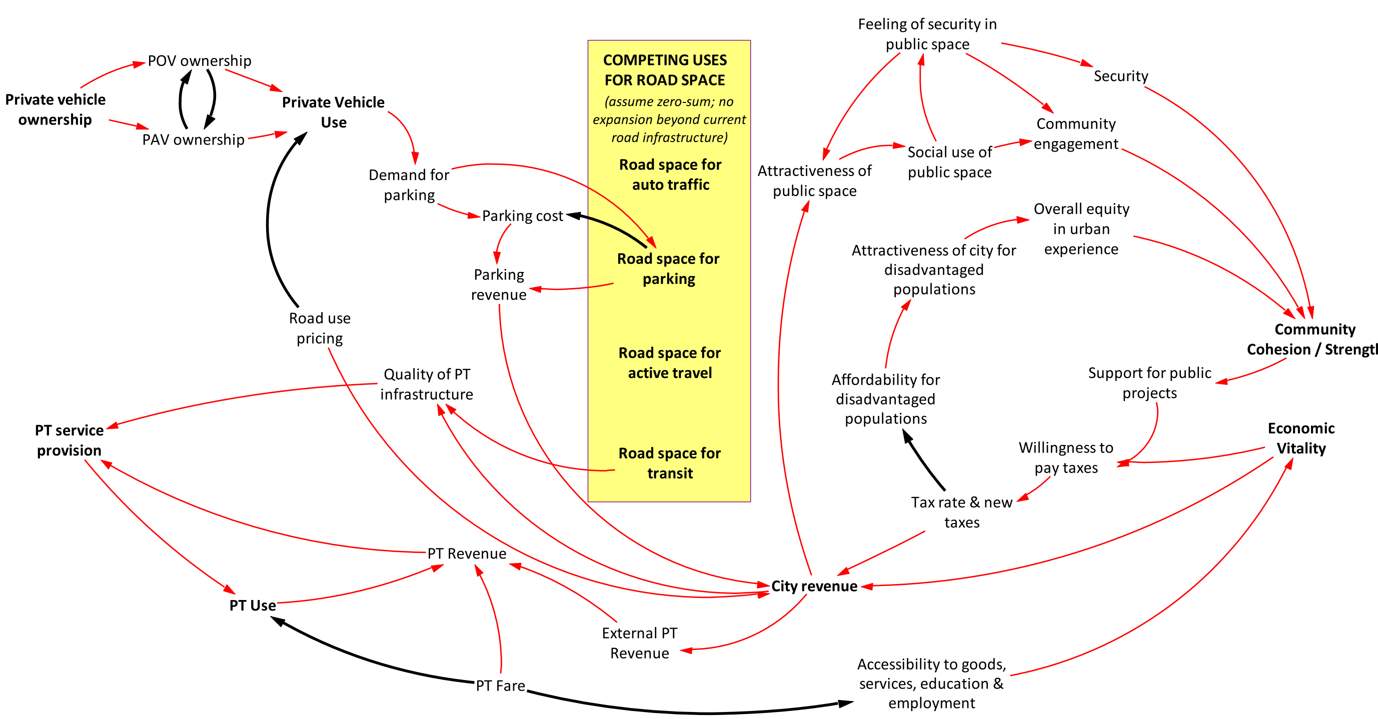

Fig. 13. Financial impacts

service provision and an investment in the *attractiveness of public spaces*. A stronger and more cohesive community is likely to have higher property values (Harnik and Welle, 2009) and is thus more likely to support investment in public projects (Putnam, 1995), so when initiatives arise that require raising revenue (through taxes or other means), they are more likely to be supported, which will allow the city to provide more funding for public space and PT services. That additional funding will lead to further improvements, thus completing a reinforcing cycle. Fig. 13 is an extract from the full CLD (Fig. 7) which illustrates these relationships. However, it should be noted that an increase in the tax rate may have a negative effect on the affordability for disadvantaged populations, and thus on equity objectives.

Fig. 14 highlights a few of the potentially relevant feedback effects related to city finances. The reinforcing loop R7 suggests that increases in city revenue driven by higher parking fees (*parking revenues*) and *road use pricing* could (at least partially) be committed to projects that improve the *attractiveness of public space.* Such investments (if done efficiently and effectively) could be self-reinforcing, as increasing *attractiveness of public space* will improve the *social use of public space,* which will drive *community engagement,* which should improve *community co-*

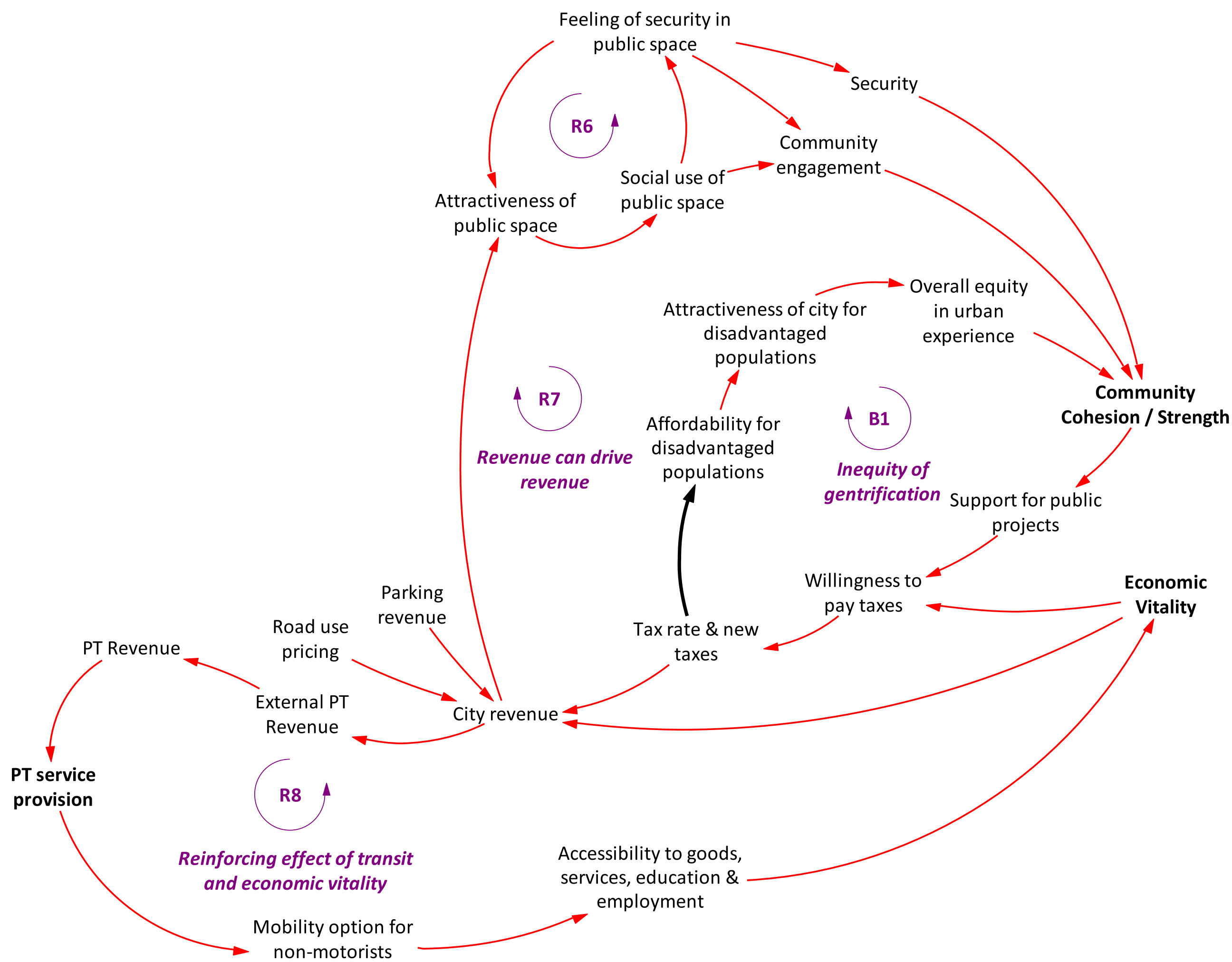

Fig. 14. Detailed view of a few key reinforcing effects related to city finances

hesion/strength. (Note that the reinforcing loop R6, discussed earlier, will further strengthen this larger reinforcing effect, R7). From there, we see that improvements in *community cohesion/strength are* likely to increase *support for public projects,* which will support citizens' *willingness to pay taxes*, which will allow for increases in *tax rates* and *new taxes,* further increasing *city revenue.* We recognise that these loops capture arguments for gentrification schemes, which may be criticised for their potentially negative impacts on social equity as poorer communities may be forced from the area, reducing social connection (Macmillan et al., 2020) (loop B1). Future development of these parts of the CLD may wish to also consider the wider costs of urban living such as housing and food. Furthermore, the loop identified in R8 suggests that increases in city revenues could trigger an additional virtuous cycle: if some of the extra *city revenue* is used to support PT (thereby increasing *PT revenue*), we'll see an increase in *PT service provision,* which will improve *mobility options for non-motorists,* which ultimately improves the city's *economic vitality*, further driving growth in *city revenue.* This loop illustrates the potentially powerful (and often-observed) relationship between effective public transportation and a city's economic vitality, although this also can feed into gentrification.

5.4. Combined effects (involving multiple areas of the larger model)

Each of the prior discussion sections examined key feedback effects associated with certain features of the overall model. However, there are also a number of significant feedback effects that can be identified when we consider the model in its entirety. For example, Fig. 15 identifies three such effects that might be triggered by the introduction of privately owned automated vehicles. As shown below, these appear to behave as "vicious cycles" if we assume an initial increase in *PAV ownership.*

5.4.1. R9 ("Vicious cycle of VMT, public space, and PT")

The (assumed) increase in *PAV ownership* increases *Private vehicle use*, which causes growth in *VMT.* As noted in section 5.1, increased VMT will harm public spaces, and ultimately reduce *community engagement*; this drives a series of causal relationships (as discussed above) that can reduce *city revenue*. If such a reduction in revenue persists and results in reduced *PT service provision, PT use* is likely to fall, as many travellers will respond to poorer service by switching to *Private vehicle use*, even further driving increases in *VMT*, and so on. This loop suggests that use of PAVs could drive a potentially powerful feedback effect involving VMT, the quality of public spaces, and the quality of a city's public transport system, adding a distinct space aspect to arguments for increased investment in PT in work such as Ezike et al. (2019)

5.4.2. R10 ("Vicious cycle of congestion and community cohesion")

As noted above, an increase in PAV ownership is likely to increase *VMT*. In addition to harming public spaces, this will also increase *congestion*, which will reduce *accessibility*, reducing the amount of free time citizens have to engage with their communities, which will erode *community cohesion/strength,* which—as noted previously—can drive causal

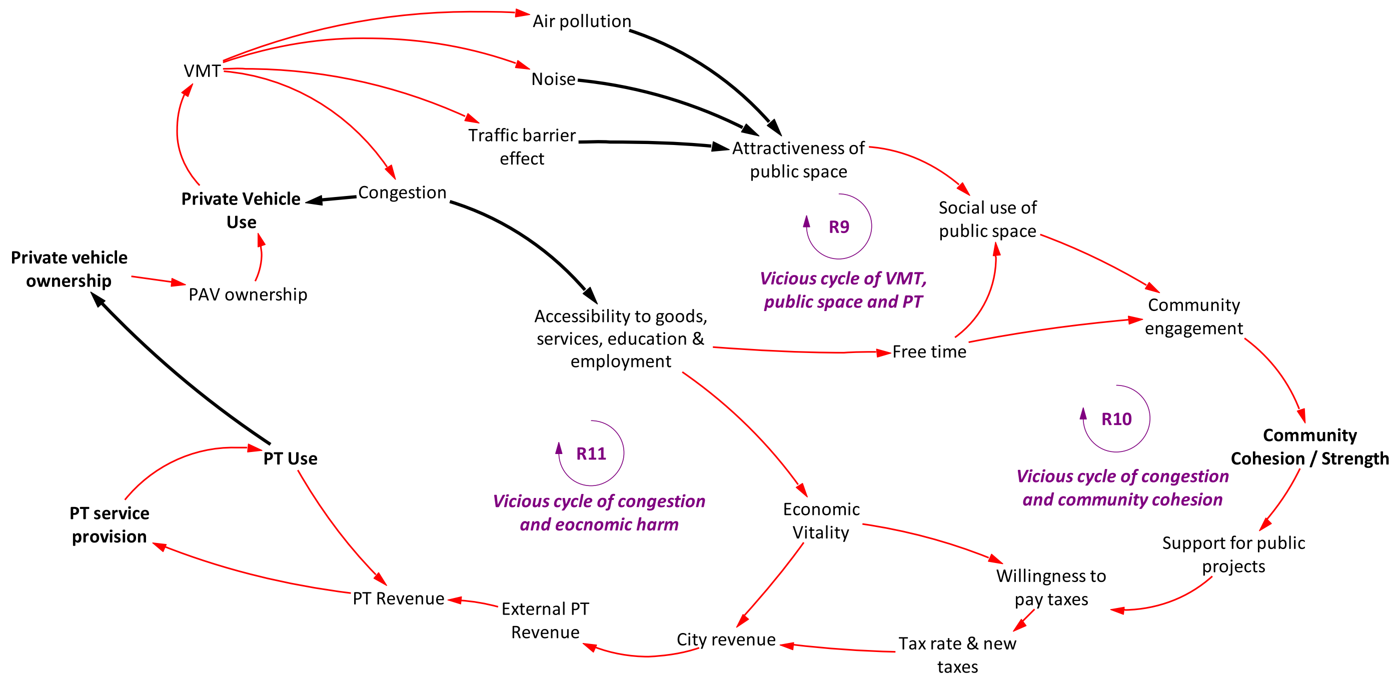

Fig. 15. Detailed view of feedback effects related to increased VMT and congestion (extract from full CLD—several variables and links have been omitted for clarity)

relationships that are essential to sustaining city revenues and providing essential services, such as public transportation. As identified in the discussion of R9, a sustained reduction in *PT service provision* can further drive increases in *VMT* and *congestion*, and so on.

5.4.3. R11 ("Vicious cycle of congestion and economic harm")

.As noted for loop R10, the introduction of PAVs is likely to increase *VMT* and *congestion* and reduce *accessibility*. The reduction in *accessibility* will also harm a city's *economic vitality*. As noted above, this drives a chain of causality that results in reduced *PT use* in favour of more *private vehicle use*, more *VMT*, and so on.

5.5. Model quantification

This particular stage of research was focused on the development of a qualitative CLD, without intention to develop a quantitative stock-flow model. It would be a large task to do so, considering all the linkages we found. However, this CLD, or parts of it, can be used in future research as the basis of development of a quantitative model. The variables and relationships identified can be further developed in order to construct simulation models by establishing the dynamic relationships either through further engagement with stakeholders or through existing literature. Although there is limited (if any) data currently available regarding CAM, and indeed not in a fully deployed capacity, many of the relationships which have been identified do already exist and so can be operationalised. Indeed, in addition to the CAM SD models already discussed in Section 3.1, there are already existing SD models that capture relationships inherent in active travel and health (Macmillan et al., 2014), transport and land-use (Pfaffenbichler et al., 2008), and urban resilience (Li et al., 2020). Our work here exposes the non-transport linkages (such as those around public space or sharing) and it is these which could be investigated further and added to existing models with some new relationships being imported from the literature or via primary data collection. There is an increasing volume of data available regarding urban mobility, as cities become 'smarter' and connected, proving potentially rich sources for model input and calibration. Development of such models and simulation of policy scenarios could be used to inform policy makers of the potential impacts of the introduction of CAM on liveability in cities.

5.6. Methodological reflections

In addition to our CLD insights, it is also important to reflect on the methodology we have developed and how it could be used in the future. Our methodological findings are in two parts: logistical and strategic.

From a logistical viewpoint, the online format provided a unique opportunity for cross-continental group model building, avoiding significant time, cost and environmental impact of international travel. This may be more commonplace as individuals across the world become acquainted with the online format, and has been the subject of previous papers (Zimmermann et al., 2021, Wilkerson et al., 2020, Jittrapirom et al., 2021). Furthermore, in our experience, online working has the potential to allow more perspectives to take part equally. A virtual workshop allowed cities, regions and PT agencies to send technical professionals, rather than only senior executives as would have been more likely to represent such organizations at international conferences, and also democratised participation for planning and modelling groups with lower budgets for research and external technical collaboration. On the whole, our participants were of a similar position within their respective institutions, making for a relatively comparable set of individuals – though we recognise that more diversity may require 'more sophisticated facilitation techniques' (Wilkerson et al., 2020). Managing dominant and shy participants can be challenging either in-person or online, but online these dynamics can shift as physical clues cannot be read and additional communication tools (raise hand/text chat functions) are available (Zimmermann et al., 2021). That said, we cannot overlook the value of additional informal communications – and even ice-breaking activities - that can be facilitated when meetings are in-person (Morrison-Smith and Ruiz, 2020), in particular in a collaborative process such as group model building, and the fact that power dynamics and biases may still remain in a virtual setting (Dhawan et al., 2021) and speaking time may not be equally distributed. Empirical research shows that required camera use during virtual meetings is more fatiguing for women than for men, and more harmful to women's level of engagement (Shockley et al., 2021); we did not require camera use, but participants may have felt the expectation was there. It is also likely that many participants had previously met, or at least heard of, the other participants from their continent, but were unfamiliar with the participants from the other side of the Atlantic. Common ground from having worked together before, shared experiences, mental models, and even vocabulary have been identified as factors that can make distance collaboration more difficult (Morrison-Smith and Ruiz, 2020). Regarding mental models, a key aspect of group model building, we observed that views about the role of city planners, the levers available to them, and challenges such as displacement of public transport operator roles, may have differed across the Atlantic, but perhaps not as much as is commonly thought. Regarding vocabulary, indeed, a potentially overlooked issue is that of dialect and language between the participants—although EU participants may have been comfortable with using English as a second language in a work environment, the differences between terminology and concepts in European and American planning may have been more significant than we anticipated.

Regarding methodological strategy, we stand by the advantages of avoiding a scenario-based approach. Not leading off with scenarios led, we believe, to a much broader discussion that captured 'big' impacts and allowed greater understanding of complex feedbacks, without masking the complexities that exist in reality. Based on feedback from the participants, we recognise that though we deliberately kept the content broad, so that we would not obfuscate some significant concept, the lack of specific focus or scenario was challenging, with many ideas coming to the fore within a relatively short discussion period. As our background is transportation, and there are reasonably standard SD models regarding transport, we accept that we could have provided a starter model that incorporated these features and into which we built the QoL indicators. This not only could have saved time but also aided understanding and perhaps linked to mental models with which participants were more uniformly familiar. An alternative could be to provide longer workshops, but this itself is hindered by the practicalities of disparate time-zones and limiting screen-time to prevent fatigue. Reflecting on the need to add additional feedbacks to close loops in our CLD refinements, we accept that it is already established that individuals tend to think in short term causal chains but struggle with the concepts of feedback (Sterman, 2006). Without providing dedicated support to the participants in this form of system thinking, in some form of group model building script, closing loops can be challenging. In the case of this workshop, which was limited to three hours, this step was perhaps omitted though has been highlighted as being important in future work. The final reflection we have is regarding how much participants require briefing in SD concepts and methodology in advance of the meeting—and to what level this would aid rather than hinder the freedom of discussion and understanding of the complexities that are being addressed. We chose to provide a short overview at the start of the session of key CLD concepts rather than expect attendees to engage in complex pre-work (though the U.S. participants had some prior knowledge gain from related projects. This may have proved to be insufficient for their complete understanding and engagement, evidenced by the lack of closed loops and uncertain polarities, though that equally may have been due to time constraints.

5.7. Final summary

The objective of this work was to explore the question, *"How will the introduction of connected and automated mobility influence liveability in cities?"* In doing so, we have created a high level CLD that can be used as starting point for stakeholders to understand the key interactions and policy implications that yield insights to this question. Interestingly, the critical elements of our CLD map onto the three broad categories of liveability and mobility identified by Anciaes and Jones (2020): Movement (competing modes), Place (competing uses for road space) and Society (key outcomes).

The workshop revealed some city priorities that are different from what is often discussed in automation circles and in government transport roadmaps. Both groups converged on personal choice and equity, not on scenarios or business models, which is what transport operators tend to focus on. There was no mention by cities of being afraid of being left behind if they do not make it easy for technology developers to deploy in their territory, which is something that was a common discussion topic a few years ago. It was not clear if this was because the overall discourse has moved on, or that cities have a different perspective from those who come at things from the perspective of industrial policy, or frequent transport-focused conferences. Thus, we discovered, as transport researchers engaging with city planners, that the scope of transport policies is much wider than is often credited for in the literature. Although city stakeholders have an awareness that CAM will have an impact on liveability within their regions, they are actually to an extent agnostic about the general concept of CAM—rather, their concerns are directly related to the accessibility and opportunities that it would provide. However, the hopes and fears that arise from CAM are many.

Through the CLD we have gathered a number of reflections on the potential impacts of CAM, which could ultimately be relevant to the design of policies for both CAM and liveability, including the following examples:

- **Public Space:** CAM risks a continued lock-in of negative effects from privately owned vehicles, as there is likely to be an increase in VMT, leading to more air pollution, noise, and a stronger traffic barrier effect. In addition to the direct harm to sustainability, all of these factors will reduce the attractiveness of public spaces, ultimately harming public health and community cohesion. Both of these outcomes would drive several potential feedback effects, potentially greatly magnifying the initial impact of the introduction of PAVs and resulting in uncontrollable negative outcomes: increasing congestion, diminishing accessibility and free time (an effect consistent with the modelling performed in Ezike et al. (2019). The model also clearly highlights interventions that could mitigate these effects, especially if used early on: road use pricing and policies to support active travel, SAV use, and PT use.
- **Community Cohesion and Strength:** By increasing mobility options for non-motorists, CAM has the potential to improve a city's overall community strength and cohesion, through a variety of causal mechanisms, including: improving equity in the urban experience; enabling a more multi-functional and diverse city; and improving community engagement by reducing the time burden of less-effective transportation options. The improvement in mobility options will also improve overall accessibility to goods, services, education, and employment, with consequent benefits for the city's economic vitality. Such improvements in community engagement and economic vitality can drive a number of powerful feedback effects, which—given the right policy interventions—could be harnessed to produce desirable outcomes potentially beyond the scale of the initial investment.
- **Economic Vitality:** Key financial levers, such as road use pricing and parking revenues can drive a virtuous cycle (reinforcing effect with positive outcomes), by enabling investment in improved PT and more attractive public spaces, both of which can improve community cohesion and strength, leading to increased city revenues, driving economic vitality.

It is important to note that the feedback effects discussed here are a few key examples among many such effects that may be identified and articulated by the overall model. The effects discussed here are not intended to represent a comprehensive list—rather, they are intended as examples of the types of insights that such a model can bring to light, and in particular draw out new insights related to urban planning which may be overlooked when approaching this from a traditional transport perspective. While we examined feedback effects involving two of the key outcomes of the model, *community cohesion/strength* and *economic vitality*, we can expect several other feedback effects to exist that involve the other two key outcomes: *sustainability* and *public health*. For example, we would expect that improving *public health* outcomes would improve *economic vitality*, as it would improve worker attendance and reduce the burden of healthcare expenses on individuals and businesses. Similarly, by reducing the need for public spending on healthcare, additional public funds would be available to spend in ways that would further improve *public health* (e.g., investing in infrastructure for non-motorized modes), thereby completing a reinforcing loop. Developing a large, highly conceptual CLD is often a highly iterative process of ongoing refinement and discovery. This is especially true when separate models are merged, drawing on diverse perspectives and fields of expertise, as it may take multiple revisions to fully understand and harmonise the ideas and observations that went into building the initial models. Ultimately, the model is intended as a "living" tool that can be adapted and used by others to continue to explore and generate additional insights.

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

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.urbmob.2022.100034.

References

AARP 2005. Beyond 50.05 A Report to the Nation on Livable Communities: Creating Environments for Successful Aging. Available online: https://assets.aarp.org/rgcenter/il/beyond_50_communities.pdf. [accessed 14/10/21]: American Association of Retired Persons.

ABU-RAYASH, A, & DINCER, I (2021). Development of integrated sustainability performance indicators for better management of smart cities. *Sustainable Cities and Society, 67*, Article 102704. 10.1016/j.scs.2020.102704.

AITTONIEMI, E, BARNARD, Y, HARRISON, G, DE KLEIN, D, KOLAROVA, V, LEHTONEN, E, MALIN, F, NAENDRUP-POELL, L, RAMA, P & TOULIOU, K 2020. AUTOPILOT (AUTOmated driving Progressed by Internet Of Things). D.4.6: Quality of Life Impact Assessment. Available from: https://autopilot-project.eu/deliverables. [accessed 11/10/21].

AITTONIEMI, E, KOLAROVA, V, BARNARD, Y, TOULIOU, K & NETTEN, B 2018. How may connected automated driving improve quality of life, 25th ITS World Congress. Copenhagen, Denmark, 17-21. September 2018: Available from: https://autopilot-project.eu/wp-content/uploads/sites/3/2019/07/Aittoniemi_AUTOPILOT_QoL_ITSWC2018_finalversion.pdf [Accessed May 24th 2022].

ANCIAES, P, & JONES, P (2020). Transport policy for liveability – Valuing the impacts on movement, place, and society. *Transportation Research Part A: Policy and Practice, 132*, 157–173. 10.1016/j.tra.2019.11.009.

APPLEYARD, B, FERRELL, CE, CARROLL, MA, & TAECKER, M (2014). Toward livability ethics: A framework to guide planning, design, and engineering decisions. *Transportation Research Record, 2403*, 62–71. 10.3141/2403-08.

BADLAND, H, & PEARCE, J (2019). Liveable for whom, Prospects of urban liveability to address health inequities. *Social Science & Medicine, 232*, 94–105. 10.1016/j.socscimed.2019.05.001.

BARRY, S 2010. Case Studies on Transit and Livable Communities in Rural and Small Town America. Available from: https://t4america.org/wp-content/uploads/2010/09/Livability-Transit-Rural-Case-Studies-WEB.pdf [accessed 14/10/21]: Transportation for America.

BELLET, T, CUNNEEN, M, MULLINS, M, MURPHY, F, PÜTZ, F, SPICKERMANN, F, BRAENDLE, C, & BAUMANN, MF (2019). From semi to fully autonomous vehicles: New emerging risks and ethico-legal challenges for human-machine interactions. *Transportation Research Part F: Traffic Psychology and Behaviour, 63*, 153–164. 10.1016/j.trf.2019.04.004.

BJORVATN, A, PAGE, Y, FAHRENKROG, F, WEBER, H, AITTONIEMI, E, HEUMM, P, LEHTONEN, E, SILLA, A, BÄRGMAN, J, BORRACK, M, INNAMAA, S, ITKONEN, T, MALIN, F, KARL;, P, SCHULDES, M, SINTONEN, H, STREUBEL, T, HAGLEITNER, W, HERMITTE, T, HILLER, J & GUILHERMINA, T. 2021. L3 Pilot, D7.4: Impact Evaluation Results. Available from: https://l3pilot.eu/fileadmin/user_upload/Downloads/Deliverables/Update_14102021/L3Pilot-SP7-D7.4-Impact_Evaluation_Results-v1.0-for_website.pdf [Accessed 26th Mat 2022]: Horizon 2020.

BROWN, KE, & DODDER, R (2019). Energy and emissions implications of automated vehicles in the US energy system. *Transportation Research Part D: Transport and Environment, 77*, 132–147. 10.1016/j.trd.2019.09.003.

CHASE, R 2016. Self-driving cars will improve our cities. If they don't ruin them. *Wired.* Available from: https://www.wired.com/2016/08/self-driving-cars-will-improve-our-cities-if-they-dont-ruin-them/. [Accessed 26th May 2022].

COHEN, T, & CAVOLI, C (2019). Automated vehicles: exploring possible consequences of government (non)intervention for congestion and accessibility. *Transport Reviews, 39*, 129–151. 10.1080/01441647.2018.1524401.

COHN, J, EZIKE, R, MARTIN, J, DONKOR, K, RIDGWAY, M, & BALDING, M (2019). Examining the equity impacts of autonomous vehicles: A travel demand model approach. *Transportation Research Record, 2673*, 23–35. 10.1177/0361198119836971.

DES COGNETS, J & RAFERT, G 2019. Assessing the Unmet Transportation Needs of Americans with Disabilities. Available from: https://www.analysisgroup.com/globalassets/content/news_and_events/news/assessing_unmet_transportation_needs.pdf. [Accessed 26th may 2022]: Analysis Group.

DHAWAN, N, CARNES, M, BYARS-WINSTON, A, & DUMA, N (2021). Videoconferencing etiquette: Promoting gender equity during virtual meetings. *Journal of Women's Health, 30*, 460–465. 10.1089/jwh.2020.8881.

DOT 2011. The Role of FHWA Programs in Livability: State of the Practice Summary. Available online: http://www.fhwa.dot.gov/livability/state_of_the_practice_summary/research2011.pdf. [accessed 14/10/21]: United States Department of Transport.

DREHER, S, FLAMENT, M, WILSCH, B, INNAMAA, S, MERAT, N, ARRUE, A & LYTRIVIS, P 2019. CARTE: Deliverable 2.4 Overview and status of trilateral exchange and emerging markets. Final edition. Available from https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5c5f46aab&appId=PPGMS. [Accessed 23rd May 2022]: EUROPEAN COMMISSION. DG Research and Innovation. HORIZON 2020 PROGRAMME SOCIETAL CHALLENGES – SMART, GREEN AND INTEGRATED TRANSPORT. Coordination and Support Action – Grant Agreement Number 724086.

EMORY, K, DOUMA, F, & CAO, J (2022). Autonomous vehicle policies with equity implications: Patterns and gaps. *Transportation Research Interdisciplinary Perspectives, 13*, Article 100521. 10.1016/j.trip.2021.100521.

EZIKE, R, MARTIN, J & CATALANO, K 2019. Where Are Self-Driving Cars Taking Us Pivotal choices that will shape DC's transportation future. Available from: https://ucsusa.org/resources/where-are-self-driving-cars-taking-us [Accessed 26th Mat 2022]: Union of Concerned Scientists.

FAGNANT, DJ, & KOCKELMAN, KM (2014). The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios. *Transportation Research Part C: Emerging Technologies, 40*, 1–13. 10.1016/j.trc.2013.12.001.

FERREIRA, C, KALANTARI, Z, & PEREIRA, P (2021). Liveable cities: Current environmental challenges and paths to urban sustainability. *Journal of Environmental Management, 277*, Article 111458. 10.1016/j.jenvman.2020.111458.

FISCHER, S, MACHEK, E, RAKOFF, H & SLOAN, S 2018. European Union – United States – Japan Cooperation on Intelligent Transportation Systems Research and Deployment: 2017 International Accomplishments Summary. *U.S. Department of Transportation report number FHWA-JPO-18-702.* Available from https://rosap.ntl.bts.gov/view/dot/37393 [accessed 17th May 2022]: U.S. Department of Transportation.

GEHRKE, SR, FELIX, A & REARDO, T 2018. Fare choices: A survey of ride-hailing passengers in metro Boston: Report #1. *A Metropolitan Area Planning Council Research Brief.* Available from: https://www.mapc.org/farechoices/. [Accessed 26th May 2022]: Metropolitan Area Planning Council.

GÓMEZ-VILCHEZ, JJ, & JOCHEM, P (2019). Simulating vehicle fleet composition: A review of system dynamics models. *Renewable and Sustainable Energy Reviews, 115*, Article 109367. 10.1016/j.rser.2019.109367.

GONZÁLEZ-GONZÁLEZ, E, NOGUÉS, S, & STEAD, D (2020). Parking futures: Preparing European cities for the advent of automated vehicles. *Land Use Policy, 91*, Article 104010. 10.1016/j.landusepol.2019.05.029.

GRUEL, W & STANFORD, J 2015. Assessing the Long-Term Effects of Autonomous Vehicles: a speculative approach. *European Transport Conference 2015 – from Sept 28 to Sept-30, 2015.*

HARNIK, P & WELLE, B 2009. Measuring the Economic Value of a City Park System. Available from: https://cloud.tpl.org/pubs/ccpe-econvalueparks-rpt.pdf [Accessed 31st May 2020]: The Trust for Public Land.

HARPER, CD, HENDRICKSON, CT, MANGONES, S, & SAMARAS, C (2016). Estimating potential increases in travel with autonomous vehicles for the non-driving, elderly and people with travel-restrictive medical conditions. *Transportation Research Part C: Emerging Technologies, 72*, 1–9. 10.1016/j.trc.2016.09.003.

HARRISON, G, SHEPHERD, S, & CHEN, H (2021). Modelling uptake sensitivities of connected and automated vehicle technologies. *International Journal of System Dynamics Applications (IJSDA)*, 10. 10.4018/IJSDA.2021040106.

INNAMAA, S, SMITH, S, BARNARD, Y, RAIINVILLE, L, HORIGUCHI, Y & GELLERMAN, H 2017. Trilateral impact assessment framework for automation in road transportation, version 1.0. Trilateral impact assessment sub-group for ART.

INNAMAA, S, SMITH, S, BARNARD, Y, RAIINVILLE, L, HORIGUCHI, Y & GELLERMAN, H 2018. Trilateral impact assessment framework for automation in road transportation, version 2.0. Trilateral impact assessment sub-group for ART. Available from: https://www.connectedautomateddriving.eu/methodology/impact-assessment-frameworks. (Accessed 11/11/21).

JACOBSEN, PL 2003. Safety in numbers: more walkers and bicyclists, safer walking and bicycling. 9, 205-209. 10.1136/ip.9.3.205.J.Injury.Prevention

JITTRAPIROM, P, BOONSIRIPANT, S, & PHAMORNMONGKHONCHAI, M (2021). Aligning stakeholders' mental models on carsharing system using remote focus group method. *Transportation Research Part D: Transport and Environment, 101*, Article 103122. 10.1016/j.trd.2021.103122.

KHOMENKO, S, NIEUWENHUIJSEN, M, AMBRÒS, A, WEGENER, S, & MUELLER, N (2020). Is a liveable city a healthy city Health impacts of urban and transport planning in Vienna, Austria. *Environmental Research, 183*, Article 109238. 10.1016/j.envres.2020.109238.

LAU, ST, & SUSILAWATI, S (2021). Shared autonomous vehicles implementation for the first and last-mile services. *Transportation Research Interdisciplinary Perspectives, 11*, Article 100440. 10.1016/j.trip.2021.100440.

LEGÊNE, MF, AUPING, WL, CORREIA, GHDA, & VAN-AREM, B (2020). Spatial impact of automated driving in urban areas. *Journal of Simulation, 14*, 295–303. 10.1080/17477778.2020.1806747.

LEHTONEN, E, MALIN, F, INNAMAA, S, NORDHOFF, S, LOUW, T, BJORVATN, A, & MERAT, N (2021). Are multimodal travellers going to abandon sustainable travel for L3 automated vehicles? *Transportation Research Interdisciplinary Perspectives, 10*, Article 100380. 10.1016/j.trip.2021.100380.

LI, G, KOU, C, WANG, Y, & YANG, H (2020). System dynamics modelling for improving urban resilience in Beijing, China. *Resources, Conservation and Recycling, 161*, Article 104954. 10.1016/j.resconrec.2020.104954.

LOWE, M, C WHITZMAN, H BADLAND, DAVERN, M, D HES, L AYE, BUTTERWORTH, I & GILES-CORTI, B 2013. Liveable, healthy, sustainable: What are the key indicators for Melbourne neighbourhoods, Research Paper 1. https://mccaugheycentre.unimelb.edu.au/research/health_and_liveability. Place, Health and Liveability Research Program, University of Melbourne.

LOWE, M, WHITZMAN, C, BADLAND, H, DAVERN, M, AYE, L, HES, D, BUTTERWORTH, I, & GILES-CORTI, B (2015). Planning healthy, liveable and sustainable cities: How can indicators inform policy? *Urban Policy and Research, 33*, 131–144. 10.1080/08111146.2014.1002606.

MACMILLAN, A, CONNOR, J, WITTEN, K, KEARNS, R, REES, D, & WOODWARD, A (2014). The societal costs and benefits of commuter bicycling: simulating the effects of specific policies using system. *Dynamics Modeling, 122*, 335–344. 10.1289/ehp.1307250.

MACMILLAN, A, SMITH, M, WITTEN, K, WOODWARD, A, HOSKING, J, WILD, K, & FIELD, A (2020). Suburb-level changes for active transport to meet the SDGs: Causal theory and a New Zealand case study. *Science of The Total Environment, 714*, Article 136678. 10.1016/j.scitotenv.2020.136678.

MAY, AD, SHEPHERD, S, PFAFFENBICHLER, P & EMBERGER, G 2019. The potential impacts of automated cars on urban transport: an exploratory analysis. *World Conference on Transport Research - WCTR 2019 Mumbai* Transport Research Procedia.

MILAKIS, D (2019). Long-term implications of automated vehicles: an introduction. *Transport Reviews, 39*, 1–8. 10.1080/01441647.2019.1545286.

MILAKIS, D, KROESEN, M, & VAN WEE, B (2018). Implications of automated vehicles for accessibility and location choices: Evidence from an expert-based experiment. *Journal of Transport Geography, 68*, 142–148. 10.1016/j.jtrangeo.2018.03.010.

MILAKIS, D, & MÜLLER, S (2021). The societal dimension of the automated vehicles transition: Towards a research agenda. *Cities, 113*, Article 103144. 10.1016/j.cities.2021.103144.

MILAKIS, D, VAN AREM, B, & VAN WEE, B (2017). Policy and society related implications of automated driving: A review of literature and directions for future research. *Journal of Intelligent Transportation Systems, 21*, 324–348. 10.1080/15472450.2017.1291351.

MORRISON-SMITH, S, & RUIZ, J (2020). Challenges and barriers in virtual teams: a literature review. *SN Applied Sciences, 2*, 1096. 10.1007/s42452-020-2801-5.

NAHMIAS-BIRAN, B-H, OKE, JB, & KUMAR, N (2021). Who benefits from AVs? Equity implications of automated vehicles policies in full-scale prototype cities. *Transportation Research Part A: Policy and Practice, 154*, 92–107. 10.1016/j.tra.2021.09.013.

NIEUWENHUIJSEN, J, CORREIA, GHDA, MILKIS, D, VAN AREM, B, & VAN DAALEN, E (2018). Towards a quantitative method to analyse the long–term innovation diffusion of automated vehicles technology using system dynamics. *Transportation Research Part C: Emerging Technologies, 86*, 300–327. 10.1016/j.trc.2017.11.016.

NIEUWENHUIJSEN, MJ (2020). Urban and transport planning pathways to carbon neutral, liveable and healthy cities; A review of the current evidence. *Environment International, 140*, Article 105661. 10.1016/j.envint.2020.105661.

OECD 2015. Introduction: The century of urbanisation.

PADDEU, D, SHERGOLD, I, & PARKHURST, G (2020). The social perspective on policy towards local shared autonomous vehicle services (LSAVS). *Transport Policy, 98*, 116–126. 10.1016/j.tranpol.2020.05.013.

PATTINSON, J-A, CHEN, H, & BASU, S (2020). Legal issues in automated vehicles: critically considering the potential role of consent and interactive digital interfaces. *Humanities and Social Sciences Communications, 7*, 153. 10.1057/s41599-020-00644-2.

PAUL, A, & SEN, J (2020). A critical review of liveability approaches and their dimensions. *Geoforum, 117*, 90–92. 10.1016/j.geoforum.2020.09.008.

PFAFFENBICHLER, P, EMBERGER, G, & SHEPHERD, S (2008). The integrated dynamic land use and transport model MARS. *Networks and Spatial Economics, 8*, 183–200. 10.1007/s11067-007-9050-7.

PUDĀNE, B, VAN-CRANENBURGH, S, & CHORUS, CG (2021). A day in the life with an automated vehicle: Empirical analysis of data from an interactive stated activity-travel survey. *Journal of Choice Modelling, 39*, Article 100286. 10.1016/j.jocm.2021.100286.

PUTNAM, RD (1995). Tuning in, tuning out: The strange disappearance of social capital in America. *PS: Political Science and Politics, 28*, 664–683. 10.2307/420517.

PUYLAERT, S, SNELDER, M, VAN NES, R, & VAN AREM, B (2018). Mobility impacts of early forms of automated driving – A system dynamic approach. *Transport Policy, 72*, 171–179. 10.1016/j.tranpol.2018.02.013.

RAKOFF, H, S SMITH, S INNAMAA, Y BARNARD, G HARRISON & SHAW, J. 2020. Building feedback into modelling impacts of automated vehicles: Developing a consensus model and quantitative tool. *8th Transport Research Arena.* Helsinki, Finland.

ROE, J & MCCAY , L 2021. *Restorative Cities: urban design for mental health and wellbeing*, Bloomsbury.

SAEI. 2021. Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles (J3016_202104) [Online]. https://www.sae.org/standards/content/j3016_202104. (accessed 28/10/21): Society of Automobile Engineers International. [Accessed].

SHATANAWI, M, GHADI, M, & MÉSZÁROS, F (2021). Road pricing adaptation to era of autonomous and shared autonomous vehicles: Perspective of Brazil, Jordan, and Azerbaijan. *Transportation Research Procedia, 55*, 291–298. 10.1016/j.trpro.2021.06.033.

SHEPHERD, SP (2014). A review of system dynamics models applied in transportation. *Transportmetrica B: Transport Dynamics, 2*, 83–105. 10.1080/21680566.2014.916236.

SHOCKLEY, KM, GABRIEL, AS, ROBERTSON, D, ROSEN, CC, CHAWLA, N, GANSTER, ML, & EZERINS, ME (2021). The fatiguing effects of camera use in virtual meetings: A within-person field experiment. *Journal of Applied Psychology, 106*, 1137–1155. 10.1037/apl0000948.

SOTEROPOULOS, A, BERGER, M, & CIARI, F (2019). Impacts of automated vehicles on travel behaviour and land use: An international review of modelling studies. *Transport Reviews, 39*, 29–49. 10.1080/01441647.2018.1523253.

STANFORD, J 2015. Possible Futures for Fully Automated Vehicles: Using Scenario Planning and System Dynamics to Grapple with Uncertainty. PhD Thesis.

STECK, F, KOLAROVA, V, BAHAMONDE-BIRKE, F, TROMMER, S, & LENZ, B (2018). How autonomous driving may affect the value of travel time savings for commuting. *Transportation Research Record, 2672*, 11–20. 10.1177/0361198118757980.

STEPHENS, TS, GONDER, J, CHEN, Y, LIN, Z & LIU, C 2016. Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles. Technical Report: NREL/TP-5400-67216. Available from: https://www.nrel.gov/docs/fy17osti/67216.pdf [Accessed 31st May 2022]: National Renewable Energy Laboratory.

STERMAN, JD 2000. Business Dynamics: Systems Thinking and Modelling for a Complex World, Boston, McGraw-Hill Higher Education.

STERMAN, JD (2006). Learning from evidence in a complex world. *American Journal of Public Health, 96*, 505–514. 10.2105/AJPH.2005.066043.

UN. 2021. The 17 Goals [Online]. https://sdgs.un.org/goals (accessed 28/10/21). [Accessed].

VITALE BROVARONE, E, SCUDELLARI, J, & STARICCO, L (2021). Planning the transition to autonomous driving: A policy pathway towards urban liveability. *Cities, 108*, Article 102996. 10.1016/j.cities.2020.102996.

WADUD, Z, MACKENZIE, D, & LEIBY, P (2016). Help or hindrance, the travel, energy and carbon impacts of highly automated vehicles. *Transportation Research Part A: Policy and Practice, 86*, 1–18. 10.1016/j.tra.2015.12.001.

WILKERSON, B, AGUIAR, A, GKINI, C, CZERMAINSKI-DE-OLIVEIRA, I, LUNDE TRELLEVIK, LK, & KOPAINSKY, B (2020). Reflections on adapting group model building scripts into online workshops. *System Dynamics Review, 36*, 358–372. 10.1002/sdr.1662.

ZIMMERMANN, N, PLUCHINOTTA, I, SALVIA, G, TOUCHIE, M, STOPPS, H, HAMILTON, I, KESIK, T, DIANATI, K, & CHEN, T (2021). Moving online: reflections from conducting system dynamics workshops in virtual settings. *System Dynamics Review, 37*, 59–71. 10.1002/sdr.1667.