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Brace for impacts: Perceived impacts and responses relating to the state of connected and autonomous vehicles in Gothenburg

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ABSTRACT

It is anticipated that Connected and Autonomous Vehicles (CAVs) will be introduced for public use in the coming decade. Thus, it is important to consider how ready cities are to integrate them into the urban environment. To address this question, this article frames the introduction of CAVs within the context of a socio-technical transition. We use the Drivers, Pressures, State, Impact and Response (DPSIR) framework to identify the impacts and responses of the introduction of CAVs in cities, with a specific emphasis on Gothenburg, Sweden. The results of the DPSIR analysis are then analyzed through the lens of transition management, in which the responses are related to strategical, tactical, operational and reflexive governance strategies. It was found that the reflexive component is likely to be critical for a successful introduction of CAVs in cities, so that policies can be adjusted as the uptake of the technology changes. Many issues that could arise from CAVs, such as increased car traffic and physical barriers to mobility, are already addressed in the City of Gothenburg's official transportation strategy, but there is room for clearer policy with regard to CAV technology.

1. Introduction

Connected and Autonomous Vehicles (CAVs) are at the forefront of emerging transportation technologies. The introduction of this technology has seen challenges in recent years, but many vehicles already have functions that makes it possible for the driver to enter some form of automated driving mode. On a system-wide scale, one can consider the introduction of CAVs to be a socio-technical transition (Geels, 2004), implying multiple transitions to CAV technology use that take place at different levels – e.g. cultural, structural and practical levels – that have different time frames and scales (Loorbach, 2010).

Business models for CAV technology are being explored by many companies around the world, but governments have been slower to devise ways to incorporate CAVs into everyday life, particularly at the city and regional levels (Grindsted et al., 2022). The City of Gothenburg in western Sweden is an especially interesting example of this lack of CAV planning, since the city has historically been closely connected with the car manufacturing industry, and has a strong engagement with CAV pilot projects (Rebalski et al., 2022; Urban Transport Administration (Trafikkontoret), 2020). CAV technology has already been tested in and around Gothenburg for many years, but the focus so far has been largely on the technical aspects of CAVs, as opposed to the broader society-wide consequences. This has created gaps in the research concerning the consequences of the implementation of this technology, and ensuing policies or strategies that address those consequences.

This study seeks to fill these research gaps by using the Drivers, Pressures, State, Impact and Response (DPSIR) framework to analyse interview data. In a previous article, we focused on the drivers and pressures components, and analysed factors stated by the interviewees that could affect the introduction of CAVs in cities (Rebalski et al., 2022). This article aims to make an empirical contribution to the emerging literature on CAV governance by identifying impacts (ways in which CAVs can be implemented, or the consequences of their implementation), and responses (strategies that respond to both positive and negative drivers, pressures, or impacts). Since the interviewees are discussing a technology that is not yet widely used, we consider the plausibility of the impacts and responses by comparing them to the findings in academic literature. We also identify stakeholders who are affected by the impacts and are associated with the responses. Finally, we make a methodological contribution to the literature by testing the combination of DPSIR and Transition Management (TM) as a way to analyse future scenarios.

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We focus on the city of Gothenburg as a case study, but the context and the results of this research are applicable in many mid-sized European cities. Much research has been done on the need for more urban planning and governance related to CAVs (Hopkins and Schwanen, 2018; Milakis and Müller, 2021; Miloš N Mladenović et al., 2020; Mukhtar-Landgren and Paulsson, 2021). This study can hopefully be useful for future research on sociotechnical transitions, especially in cases where the analysis could be improved by combining frameworks such as DPSIR and TM.

The following research questions were used to direct this study:

RQ1: How are potential future Impacts of CAVs in cities perceived by local stakeholders in Gothenburg?

RQ2: How can the complexity of the responses identified in the interviews be captured and interpreted for policy interventions using the transition management framework?

The first question paves the way for a better understanding of the stakeholders' attitudes towards and concerns about the possible impacts of CAVs, which is a prerequisite for successful implementation in cities. The second relates to aspects of governance and management of the transition towards the implementation of CAVs.

The remainder of this article is structured as follows: Section 2 is a literature review of relevant societal effects and potential governance implications with CAVs. Section 3 explains the theoretical and analytical frameworks behind the methodology, and the methods used in this study. Section 4 reports the findings from the application of the DPSIR model to interview data. Section 5 discusses the results, and Section 6 presents our conclusions.

2. Literature review

This literature review details recent research regarding the effects that CAVs may have on different aspects of society, especially within cities, and the ways in which CAV governance is envisioned. Based on themes that emerged during the literature review process, the information presented here is divided into subsections entitled: *Travel Behaviour and the Value of Travel Time, Shared CAVs, Land Use, Energy Savings, Sociopolitical Effects,* and *Governance*. This information also helped to inform the impacts and responses identified in Section 4.

2.1. Travel behaviour and the value of travel time

Wadud et al. (2016) examined the potential energy demand of different levels of CAV adoption based on various mechanisms that were identified through research and organised using the Activity, modal Share, energy Intensity, Fuel carbon content (ASIF) formula. They found that CAVs could reduce or increase the CO2 emissions related to transportation, depending very much on the use case in question and the level of automation. Wadud et al. (2016) opened the door for a broad range of studies on the effects of CAV adoption. Wadud (2017) examined the effects of changes in the value of travel time (VoTT) on energy use from CAVs in the UK for private vehicles, taxis, and trucks, finding that there were significant economic advantages for CAV adoption in the trucking sector. Taiebat et al. (2018) did a study modelling CAV adoption and use based on certain changes in VoTT, using the US National Household Travel Survey as a baseline, and found that a net rise in energy use could be possible among higher income groups.

It is important to point out that the study of VoTT is an entire branch of transport research, and the methods for estimating how CAV could impact VoTT is outside the scope of this article. But VoTT tends to have an outsized effect on travel demand and energy use in CAV models (Soteropolous et al., 2018), and thus it is also important to acknowledge that our understanding of how VoTT will change in CAVs is still very limited, largely due to a lack of empirical evidence. Put simply, since we do not use CAVs yet, we do not know how convenient they are. Singleton (2019) has argued that the use of time in CAVs might not be as productive as many models suggest, although utility may be gained from subjectively valued activities like relaxing, as opposed to doing paid work while travelling in a CAV (which is one common reason for a higher VoTT).

2.2. Shared CAVs

Using shared rides to limit transportation growth, and thereby limit greenhouse gas emissions from transportation, has been examined in the Swedish context for some time (Åkerman and Höjer, 2006). In terms of CAVs, there have been studies done in other countries of users' potential willingness to share; for example, Lavieri and Bhat (2019) found that users might be more willing to share commuting than leisure trips, and Rahimi et al. (2020) found that attitudes can be influential on the choice to share, sometimes more so than demographic variables.

In England, Wadud and Chintakayala (2021) used discrete choice modelling to find that women put a higher value on owning a CAV than men do, and more than 75 % of respondents, regardless of gender, attribute a negative value (or monetary cost) to using a shared automated ride service. Wadud and Mattioli (2021) published a article that used a combination of Total Cost of Ownership use analysis and multinomial probit modelling to look at adoption rates of various shared and private CAVs. They found that ownership is more affordable for up to 30 % of the UK population, even in a test case that emphasized mobility services, and that individual rides were cost-effective for more cases compared to pooled, on-demand automated ride services.

2.3. Land use

CAV scenarios are also relevant in relation to potential increases in urban sprawl or other land use changes that could result from widespread CAV adoption. Soteropoulos et al. (2019) reviewed modelling studies on CAV travel behaviour and resulting land use effects and found that while private CAVs could lead to scattered urban sprawl, much of that growth could be mitigated through sharing measures. More importantly, the authors caution that many studies do not have high spatial detail, and oversimplifications could be hiding more complex travel patterns, especially in rural areas and in specific contexts (i.e., a limited area within a city, as opposed to widespread adoption throughout a city). Gelauff et al. (2019) found in their study of car and public transportation automation scenarios in the Netherlands that depending on how much public transportation was automated, larger cities might become more popular, and smaller cities and rural areas could see a reduction in population. Zhang and Guhathakurta (2021), used an agent-based model to examine how shared CAVs could affect land use in Atlanta, a city in the USA. They found that when there was a reduction in the cost of commuting due to shared CAV use, residents chose to move to areas that were further from their place of work, but closer to better schools or cheaper housing.

2.4. Energy savings

The component of CAVs that removes humans from the equation has also been studied to look at how energy could be saved per unit of distance driven. Vahidi and Sciarretta (2018) examined the energy-saving potential of various driving patterns, and found that, due to the ability to share information and related eco-driving, CAVs could save anywhere from 3 to 20 % of energy use per unit distance, depending on the level of CAV market penetration and the driving situation (highway driving, arterial roads, intersections, etc.).

2.5. Sociopolitical effects

While many studies have been devoted to examining the quantitative aspects of CAV use, such as VoTT, willingness to pay for the technology, energy use, travel demand, land use, and the interactions between these aspects, research has emerged in recent years that takes a qualitative view of CAV use. An example of this is Fraedrich et al. (2021), who used group discussions to gather data about participants' perceptions of CAVs, and to study the "collective frames of knowledge" of the group, otherwise known as implicit knowledge. Group participants were connected with a university, research institution or were personal contacts of the researchers in the study. In this case, the collective frame of knowledge supported conventional car ownership, even though most participants stated at the beginning of the discussions that they were skeptical towards car use, car ownership. and autonomous driving. Fraedrich et al. found that because of this underlying support for car ownership, alternative mobility options "could be only of short relevance within [the participants] lives" (2021, p. 264).

Issues related to equity, or freedom from bias, are inherently connected to the introduction of CAVs in cities due to the inequalities that exist in transportation systems today. VoTT and models based on VoTT are a one good example of this; those with a higher VoTT, usually based on a higher income, often see a larger reduction in overall travel costs associated with CAVs (Chen and Kockelman, 2016). Cohn et al. (2019) model different scenarios of CAV use in the Washington DC area to better understand potential job accessibility, trip duration, trip distance, mode share, and emissions in different neighbourhoods, which have been previously identified as "Equity-Emphasis Areas" (concentrations of people with lower income and minority populations) and "Non-Equity Emphasis Areas". They found that high-occupancy CAVs and CAV public transportation could reduce inequalities in terms of job accessibility, trip duration, travel costs. Vehicle miles traveled did not decrease in any scenario, but Cohn et al. point out that with electrified vehicles and increased safety due to CAVs this might be acceptable. Wu et al. (2021) also did a study on the impacts of CAVs on marginalized social groups, and make a series of policy recommendations relating to public transportation, infrastructure, car and ride-sharing, and inclusion at various stages of introduction and with various specific groups in mind.

In terms of more specific segments of the population who might stand out in terms of public health, Curl and Fitt (2019) describe CAVs as a tempting panacea "drug", that could cure issues like loneliness by bringing mobility to a larger segment of the population. But they warn that urban planners should also think about alternatives like creating walkable communities and take an approach that prioritizes communication with health professionals. Dianin et al.(2021) have reviewed CAV literature and analysis based on what they describe as the four main areas where CAVs could influence accessibility: accessibility polarization, accessibility sprawl, exacerbation of social accessibility inequities, and alleviation of social accessibility inequities. They also point out that the assumptions used in studies, and the way that impacts are analysed, are both very important to consider in relation to accessibility.

2.6. Governance

Mladenović et al. (2020) set the tone for describing CAV-related governance approaches by stating that governing CAV technology is a classic example of the Collingridge dilemma on guiding technology regulation, where there is currently a lack of useful information about the technology in question, but in the future when we have that information the technology may already be firmly embedded in society, and all attempts to steer its regulation and use will be more expensive and difficult (Collingridge, 1980). Mladenović et al. (2020) compare policy documents in Germany, Finland, and the UK to examine country-specific approaches to CAV governance, and the cultural and social context of each. They found that all three countries were working with more traditional, liability-related methods of governance, while also actively developing strategies to incorporate data management and public experimentation (for example, pilot projects) into ongoing governance efforts.

Mukhtar-Landgren and Paulsson (2021) examined administrative practices of governing in relation to CAVs, focusing specifically on the categories of pilots, standards, scenarios and collaboration. They argued that the creation of scenarios, use of pilot projects and collaboration between government and stakeholders generates new information (which in turn can inform standards), but also that all these processes serve to further "create and delimit" smart mobility. Thus, there is a form of iteration occurring between the governance processes, and the use and understanding of smart mobility technology.

Hopkins and Schwanen (2018) used Transition Management (TM) as a basis for examining the CAV transition in the UK within the context of a global race towards automation. They find that while there is much learning happening within the industry in the UK, the lessons are not being spread to the public. Milakis and Müller (2021) use the multilevel perspective to identify three research areas within a CAV transition that are important to consider from a societal perspective: societal acceptance, societal implications and governance of AVs. They make more specific recommendations within each of these areas, including moving from "forward-looking exploratory scenario-based analysis to participative anticipatory analysis of desirable urban and transport futures exploring the role and societal implications of AVs within those futures" (Milakis and Müller, 2021, p. 8).

Some academic research has been carried out using analysis that focusses on citizen (as opposed to expert-only) participation. González-González et al.(2023) use a combination of Q-methodology and backcasting to involve 30 people in a participatory visioning exercise focussed on urban planning for a driverless city. They found that their approach resulted in defined areas of divergence and consensus on urban planning and CAVs that could be useful when considering public acceptance of CAV policy. Lyons (2022) classifies the introduction of CAVs as a wicked problem, and uses a novel participative foresight technique entitled "Emulsion Methodology" to bring together people with opposing views, and have them confront unconscious biases through dialogue and shared learning about different aspects of CAVs. This research involved over 100 participants and found that mechanisms such as constructive conflict resulted in more individual learning and even a collective ability to better understand and address wicked problems. Acheampong (2023) used similar methodology to that of Lyons in that participants discussed with one another, but they recruited mainly policymakers, practitioners, and academic experts for their multi-criteria analysis visioning exercise. They found that their method was useful for envisioning and deliberating on the issues with a future transportation system that included CAVs, and they suggest that their methodology could be used in the future by academics and practitioners who wish to encourage public participation.

3. Methodology

Methodologically, this article applies a combination of the Drivers, Pressures, States, Impact and Responses (DPSIR) and Transition Management (TM) frameworks to a concrete case study, which is the City of Gothenburg in Sweden. The following sub-sections accordingly describe frameworks and local context, which is intended methodologically as a case study of application. Finally, the focus returns to the interviews as the main operational method used in the research process to engage with local stakeholders.

3.1. Theoretical and analytical framework

This section explains the analytical tools and theoretical underpinnings used to process the interview data. The DPSIR framework, explained in the next sub-section, is a methodology used to analyse the raw interview data by identifying impacts and responses. Transition Management has both a theoretical and analytical value: theoretical in the sense that it acknowledges the stages of a socio-technical transition; and analytical since these stages (or spheres) can be used to further explain the impacts and responses in the context of a sociotechnical transition to CAVs.

3.1.1. DPSIR

This article focuses on the State, Impact and Response (SIR) components of DPSIR (Rebalski et al., 2022). The entire DPSIR chain is explained in detail below, so that the reader can situate the S, I, and R components within the broader context. This understanding may be helpful when reading the Discussion section, which links together different parts of different potential DPSIR chains.

Drivers: These are positive or negative, and are represented by broad driving or restraining forces, e.g., environmental concerns.

Pressures: They are related to each driver and emerge in the interviews as expressions of interests from different stakeholders, entailing a higher level of specificness compared to drivers. For instance, some pressures related to the driver of environmental concerns could be the need for less fuel use, shared cars easing CAV acceptance, and CAVs marketed as reducing the number of cars.

State: Projected into the future, is intended as the introduction of CAVs in cities.

Impacts: These refer to the potential effects, as expressed in the interviews, of future scenarios that might arise due to CAVs, e.g., increased suburban sprawl or facilitated transport of societal groups that are not able to drive.

Responses: These can be related to the drivers, pressures, and impacts. Responses can strengthen the positive drivers and pressures, tackle the negative restraining drivers and pressures, or be expressed as strategies that respond to the impacts. We relate the responses to the TM spheres to better explain the time scale and stakeholders involved in the response.

DPSIR was first developed by the European Environment Agency as a method to give "structure within which to present the indicators needed to enable feedback to policy makers on environmental quality" (Kristensen, 2004, p. 1). Two key differences between that definition and the use of the DPSIR terms in this study are that the feedback is aimed at academics and policymakers, as this article and its companion article (Rebalski et al., 2022) will hopefully further the research in this field; and that, of course, we focus on the introduction of CAVs, rather than environmental quality. Selected DPSIR chains are detailed in the Discussion section, using a format adapted from Ness et al. (2010a), shown in Fig. 1.

There are some criticisms of DPSIR; the most common being that it does not address the complexity of the processes that it attempts to analyze (Niemeijer and De Groot, 2008). In this study the simplification is helpful for the initial stages of DSPIR component categorization. We then attempt to include a degree of complexity by considering the cyclical nature of DPSIR (Ness et al., 2010b; Niemeijer and De Groot, 2008), and by combining DPSIR with TM. In Fig. 1 it is possible to see theoretically how the different components can form a cycle or many iterative cycles. The solid black arrows in Fig. 1 represent the "forward" moving, causal relationship between components, and the dotted arrows represent reactive relationships, where a result has caused changes in the system.

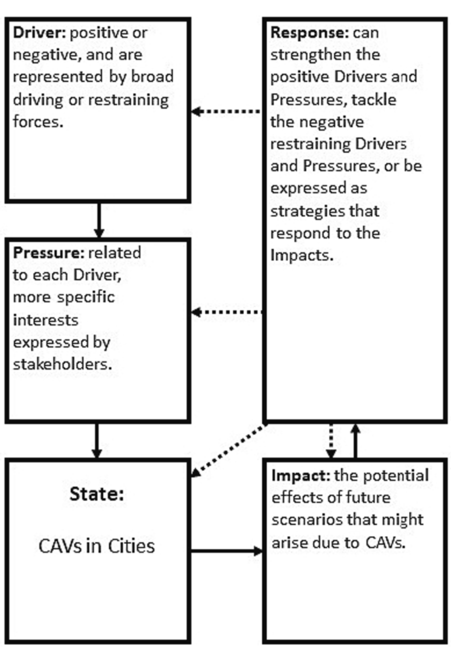

Fig. 1. DPSIR framework diagram, adapted from Ness et al., 2010.

3.1.2. Transition management

This study is based on the idea that the introduction of CAVs will imply a socio-technical transition that "not only entail[s] new technologies, but also changes in markets, user practices, policy and cultural meanings" (Geels, 2010, p. 508). Taking this starting point into account, Transition Management (TM) (Loorbach, 2010) was chosen as a theoretical tool for categorising and contextualising impacts and responses relating to the introduction of CAVs into cities.

TM is a governance framework that attempts to include complex systems theory as well as practical experience by involving practitioners in the iteration of a policy goal. In this research, we use the four strategical, tactical, operational and reflexive governance spheres from TM (see Fig. 2) to categorise the responses. The strategic sphere involves long-term cultural aspects including the development of a long-term vision and what is known as the transition arena, comprised of stakeholders who have relevant competencies, interests and backgrounds. The tactical sphere focusses on governance structures, regimes and institutions, and barriers to an established vision. Scenario creation can be a key part of the tactical sphere. The operational sphere contains practices such as transition experiments, which we suggest could be pilot projects in the context of a CAV introduction. Finally, the reflexive sphere includes monitoring, evaluating, and learning about the progress of the other spheres, specifically regarding established goals, strategies, and actions.

The circular arrow in Fig. 2 demonstrates that these spheres are connected and related but does not dictate that they must take place in a certain order. It is important to realise that the spheres can take place in any order that is relevant to the given context (Loorbach, 2010).

3.1.3. Combining TM and DPSIR

We combine TM and DPSIR by categorising responses and their associated DPSIR chains into TM spheres. By applying the TM spheres to the responses that were identified in interviews, we are not aiming for a measure of the strength of the RESPONSE (as in for example (Berg et al., 2015)), but rather a characterisation that can help suggest where the

Fig. 2. The Transition Management (TM) framework. Re-drawn from Loorbach (2010).

response fits into the larger transition process. Further, by identifying types of responses that are underrepresented or missing in the research literature, we can contribute to the literature on CAV transitions (such as Hopkins and Schwanen, 2018) in the Gothenburg or similar contexts. We elaborate on stakeholder involvement in the transition process in the Discussion section since this analysis was a step beyond the identification of the DPSIR components in the Findings section.

3.2. Gothenburg as a case study: rationale

Gothenburg is the second-largest city in Sweden, with a population of approximately 600,000 (City of Gothenburg, 2023a). The city has ambitious climate-related goals where transportation is concerned, many of which are laid out in the City of Gothenburg's transportation planning strategy document *Gothenburg 2035: Transport Planning for a Close-Knit City* (Hellberg et al., 2014). These include reducing the emissions of carbon dioxide equivalents from transportation in Gothenburg by at least 90 percent compared to 2010 levels, and reducing the volume of motorized traffic by at least 25 percent compared to 2020 levels, both by 2030 (City of Gothenburg, 2021).

The city has strong connections to the automobile industry. In 2017, Volvo Cars and AB Volvo were the largest employers in the Gothenburg Region, and those companies reported the largest turnover in 2016 (Business Region Göteborg, 2018). Volvo's impact on the city goes beyond the production of vehicles, as Volvo Cars sponsors the Gothenburg Symphony Orchestra, numerous sporting events, and supports academic research at both of the city's major universities, including a professorship (Berk, 2018). Interviewees from Gothenburg have the potential to be relatively more knowledgeable regarding CAVs, since it is difficult to be involved in any civil, industrial, academic or government activity and not have a basic understanding of the automobile industry.

3.3. Use of interviews to engage with local stakeholders: method and process

Qualitative, semi-structured interviews were used as the main source of data for this article. Seven of the eleven interviewees were based in the Gothenburg area, three in Stockholm and one interviewee was from outside of Sweden (this person was chosen because they had relevant experience in transportation planning and CAVs). Due to the restrictions caused by COVID-19, all interviews took place via video chat.

We used contingent purposive sampling of quadruple helix categories to select interviewees (Bryman and Bell, 2015; Hasche et al., 2020), and looked for people who had a position within industry, civil society, academia or government, and had some professional knowledge of or connection to CAVs. The interviewees answered questions from an interview guide, but the interviewers also followed up on topics that were uniquely salient in specific interviews. In order to reduce bias as much as possible (Cohen et al., 2011), we were sure to seek clarification if we were every unsure of a point that an interviewee was making, and we also gave interviewees ample opportunity to ask clarifying questions so that they could fully understand what was being asked.

The strength of this sample of interviewees lies in its diversity; as can be seen in Table 1, interviewees came from all parts of the quadruple helix. One person came from civil society, six from industry, two from government, one from academia, and one person was an academic involved with City government and civil society, so that person covered parts of three categories. There was also a degree of diversity within the quadruple helix categories, for example the government-related interviewees came from different City departments, and the industry interviewees were from the automobile industry and the real estate and architecture industry. There is a limitation to the sample in that only one interviewee came from a civil society organisation. We felt that this was acceptable, however, since at the time of the interviews there was not a widespread understanding of CAVs within the public at large. Finally, practically speaking, the interview recruitment was slightly curtailed due to the start of the COVID-19 pandemic, which coincided with interview invitations being sent out.

Table 1
Interviewees and Quadruple Helix categories.

Number of Interviews	Quadruple Helix category
6	Industry
2*	Academia
2*	Civil Society
3*	Government

*One interviewee is an academic who is also active on a regional government committee and with civil society, so they accounted for three quadruple helix categories.

Directed content analysis (Hsieh and Shannon 2005) was used to analyse the interview transcripts and extract impacts and responses. Information from the literature review was useful for providing a basic level of understanding of impacts or responses that were mentioned in the interviews, but not explained in detail. Additionally, the background information helped to place the interview data in a wider research context.

The final step of the process was to use TM to categorize and place certain responses in a relevant theoretical context.

4. Findings from the application of the DPSIR model

In this section, we present the Impacts and Responses that were explicitly or implicitly referred to in the interviews.

4.1. Impacts

The impacts represent the consequences perceived by the interviewees of introducing CAVs in cities that are. The impacts are explained in more detail with quotations from the interviews. Here is the full list of impacts:

- *Better public transportation especially in low density areas*
- *Increased transportation demand*
- *New infrastructure and use of limited urban space*
- *Parking companies losing revenue*
- *More individual decision-making power related to transportation*
- *Replacing people with technology*
- *Changes in vehicle to cyclist/pedestrian communication*

4.1.1. Better public transportation especially in low density areas

The economic benefit of not needing to pay wages to a public transportation driver came up quickly in the interviews. It was pointed out that "Once you don't need to pay the driver, instead, you might be able to buy several shuttles that come every ten minutes and that's a real game-changer. That's also in terms of [improved service] frequency and people wanting to use it, but it's also a real game-changer for… I think, it's actually the areas that do not, currently, have public transport because they're low density." (Interviewee 3, Academia).

This impact is closely related to the state of CAVs in cities but is considered an impact in this category here since it implies changes to the existing system. Removing drivers from buses would lower operating costs for public transportation providers, and this could help facilitate more frequent and widespread transportation options.

Others were very optimistic about the possibilities for increased public transport services in currently underserved areas, for example "… you can start your own [public transport system] with your neighbours, if you live in a small village, but it doesn't have to be location-based, it could be like Google run services for their employees, you can have all the people who live there and work there, you can have this communal service set up." (Interviewee 9, Government).

4.1.2. Increased transportation demand

One interviewee directly stated how single-person transport could increase simply due to convenience, saying "I also see a big risk that autonomous self-driving vehicles could lead to extensive use of single-person transport because it becomes very convenient, and you don't lose any more working time or leisure time while being in transit." (Interviewee 5, Academia, Government, and Civil Society).

This type of impact was echoed in another interview, where the interviewee also highlighted the potential zero-sum situation where CAV users see increased convenience, and non-users see increased congestion that could affect their mobility.

> "… if we see massive adoption of private AVs; if, as several studies show, that might double congestion, and they're just going to be driving through existing communities and adding to the problems of congestion without providing benefits to those existing communities' (Interviewee 3, Academia)

4.1.3. New infrastructure and use of limited urban space

The creation of new infrastructure for CAVs was expressed as a responsibility for everyone developing the technology: "We do know that the cars can certainly bring safety for anyone in the car or outside of the car, but so can infrastructure. Roads need to be built or developed in a way, that, if there is an accident, there is a smaller risk of fatalities. It's a shared responsibility that needs to be taken very seriously, and we do." (Interviewee 11, Industry).

Changes to the built environment were brought up as an impact in terms of the way that CAVs will be used as compared to conventional vehicles, since CAVs will not need to be parked close to users workplaces when they are not in use during the day: "Urban planners will also have to deal with the fact that, okay, maybe we will be in need of fewer parking spaces in the city, but where should we store cars when they're not in use?".

(Interviewee 6, Industry).

Another interviewee built on this, suggesting that it is crucial to start planning the construction of parking facilities that only hold CAVs and are too small for conventional vehicles.

> "We're working quite a bit with urban planners and property developers and people that plan parking, where I'm quite clear, if you develop, let's say, a parking facility, you should already, now, prepare for floors that can accommodate cars that park themselves" (Interviewee 4, Civil Society).

4.1.4. Parking companies losing revenue

The impact of the revenue stream from parking fees disappearing relates to the changes in urban space: "…the City owns, also, our own parking company, I think that's where my mind thought about affected, that they will perhaps not have any parking anymore and then they are more affected…" (Interviewee 7, Government). While this may seem contradictory in relation to the above impact, it is important to consider that there may be a different payment scheme resulting in less revenue for parking if humans are no longer involved in the parking activity.

4.1.5. More individual decision-making power related to transportation

This impact is based around the idea that new forms of 'personalised democracy' will be created because people will have the ability to use transportation-related technology in a more decentralised manner, as compared to the way that taxi companies, public transport companies and car companies hold the balance of power in transportation today.

> "I think the new, technological developments – and you can compare this to social media, for instance – will very much impact, then it will open the way for a more… you could call it, 'personalised democracy.' At least, as an individual, you can have your say, so I think, unless the solutions are monopolised, then the power, it will be more shifted towards the consumer, to the individual, to the citizen, to the citizen of Gothenburg."

(Interviewee 9, Government).

4.1.6. Replacing people with technology

A clear impact arose when one interviewee responded to a question about who would be affected by CAVs by saying "First, of course, all the people you're replacing…" meaning those who currently work as drivers of taxis or public transport services. The interviewee added "… but to a certain extent, that's the normal way, we've been replacing people with technology throughout the development of technology" (Interviewee 4, Civil Society).

Another interviewee was blunter, simply stating that "…if the driver isn't vigilant, the car will be." (Interviewee 11, Industry).

4.1.7. Changes to vehicle to pedestrian/cyclist communication

If the driver is removed from the vehicle, other road users lose a part of their traditional communication method. For example, pedestrians will no longer have a driver to make eye contact with as they navigate pedestrian crossings.

> "Pedestrians and cyclists and kids, that group, they would be affected in many ways…today, you can interact in some way, at least with the driver in the car, there is really no one to interact with in the future."

(Interviewee 6, Industry).

4.2. Responses

The responses can be related to the drivers, the pressures (Rebalski et al., 2022) and the impacts. They can enhance or dampen the positive driving forces, tackle the negative restraining forces, or be expressed as strategies that respond to the impacts. The responses are further explained below in the context of quotations from interviews. Here is the full list of responses:

- *A step-by-step introduction of CAVs*
- *Flexibility during city planning*
- *Barriers in cities*
- *Encouraging non-car forms of transportation*
- *Ridesharing programs*
- *New jobs in a new transportation system*
- *Cooperation between industry, government, and academia to better understand how CAVs will be used*
- *Policy harmonisation between different levels of government*
- *Cities becoming more powerful*

4.2.1. A step-by-step introduction of CAVs

It was expressed in the interviews that there could be a negative reaction to the abrupt introduction of CAV technology. The interviewee stressed that "It has to come step by step … in that case, I don't think that they feel affected by it, but on the other hand, if this is not introduced in a good way, maybe if people do feel affected by the new technology".

(Interviewee 8, Industry).

This thought was echoed by another person from the industry category, who also related a gradual introduction to safety concerns:

> "I think we need to have systems in the car that really safeguard the safety. I think it's sort of mind-blowing, the whole concept of the car taking over. For us, it's really a matter of taking it step by step." (Interviewee 11, Industry)

4.2.2. Flexibility during city planning

It was brought up during interviews that transportation infrastructure can be based on current or even past transportation systems, and that infrastructure will be in place for a long period of time.

"You need to have that kind of basic, physical planning that comes with the change of behaviour, you have to take that into account when you plan infrastructure that will stay there for 20/30/50 years." (Interviewee 4, Civil Society)

In addition, infrastructure can be based on rigid requirements that give rise to large, expensive projects when there might be alternative possibilities that would still meet customers' needs or societal needs in general, in terms of parking spaces for example.

"One municipality could say you need 32 parking spaces here. But if our budget is going to be met, we can only fit 31. Then we must have [the parking lot with 32 spots] underground. So, we are pretty rigid, we have to start to think more flexibly." (Interviewee 10, Industry)

4.2.3. *Barriers in cities*

One interviewee suggested that to "simplify" the introduction of CAVs, that cities begin to be built around CAVs, which creates a response that we refer to here as *Barriers in cities.* This could take the form of large corridors that pedestrians and other forms of traffic cannot pass through, effectively blocking off parts of the city to those who are not CAV users.

In the interviews, barriers were expressed as follows:

"… one extreme is, basically, that they should dedicate transport corridors with fences which simplify all the actions for the autonomous vehicles to optimise their flow. This will create large barriers in the cities, at least for the main roads, I think that is a great risk. It will soon look like some parts of the tram lines, also for these vehicles, with fences." (Interviewee 5, Government, Academia, and Civil Society)

4.2.4. *Encouraging non-car forms of transportation*

One interviewee suggested that the priority should be more equitable mobility options, focusing on pedestrians and cyclists, and then introducing CAVs as the next level of mobility prioritization.

"I would say transition the cities into walkable and bikeable transit-oriented cities first, then we can introduce autonomous vehicles." (Interviewee 1, Industry)

A specific response that was outlined by more than one interviewee was to reduce speed limits so that CAV introduction could be easier. This measure is also generally associated with making non-car forms of transportation more attractive to use.

"I think that, already now, we can start preparing our cities by reducing speeds in general for vehicles. That's one way of already starting to adapt the cities for autonomous vehicles."

(Interviewee 5, Academia, Government and Civil Society).

4.2.5. *Ridesharing programs*

It was recognized that, for some users, adopting the idea of a car-sharing service and using that service to supplement or replace a private vehicle can be a big step. But once an individual or household has become familiar with the notion and practice of car-sharing, the technological jump to a shared CAV might seem less intimidating. The networks of car-sharing users could thus be potential early adopters of CAVs if the CAVs are introduced through the car-sharing services, as one interviewee suggested:

"The phase that we are in right now, we are trying to get people to relinquish their own cars and embrace car-sharing. That's a journey in itself. But if you have started that journey, maybe it's easier to share a self-driving vehicle. If you do not make that journey, then I think you will go from having your own car, to having your own car and now everyone in the family can use it because they don't need to have a driving license. I think we all need to think more sharing, sharing, sharing." (Interviewee 10, Industry)

Car-sharing and ridesharing were also brought up in the interviews as an important way to achieve energy efficiency goals.

"How many are in the car at the same time, how many cars are on the market, how many people use them, compared to how many people own them? So, I think the sharing issue and the mobility service issue, it's a much more important thing than the autonomous vehicle part." (Interviewee 6, Industry)

Note here that it was not clear from the interview if the interviewee meant shared cars, like self-driving taxis or shared rides, were different concepts. Shared cars, including self-driving taxis, might decrease car ownership, but would not necessarily decrease the number of cars on streets and related issues such as congestion (Eldsjäl, 2021). Ridesharing, on the other hand, means using more of the capacity of vehicles on the road, as more people share each ride and thereby increase the average occupancy rate. Therefore, ridesharing could contribute to fewer vehicle kilometers travelled and help lessen issues such as congestion.

4.2.6. *New jobs in a new transportation system*

It came up in more than one interview that it will be important to adapt to new opportunities and systems that will be created because of CAVs. One example of this is through new jobs that will be created in the form of both technology development and business model development.

"I think, on a European level, on a political level, you will see that it's a lot about jobs, new jobs and they realise we will lose some 'old jobs'. And when we need to be in a good position in order to compete for the new jobs that will arise… " (Interviewee 9, Government)

These new jobs could also be as simple as attendants on CAV public transportation vehicles who ensure that passengers feel safe and receive relevant information about, for example, trip planning. In this case the job itself is not new, but the context for it is.

4.2.7. *Cooperation between industry, government, and academia to better understand how CAVs will be used*

The importance of cooperation was brought up in multiple interviews when the respondents were asked what is needed to prepare for CAVs. Some interviewees suggested that they could contribute experience and expertise to this cooperation:

"The industry can contribute [to the CAV transition] by bringing technology out there. If we cooperate with academia and governments, then we will get there. And anyone, including myself, representing the OEM, can be the ambassador, both for the company and for new technologies, new trends … trying to explain benefits and why this will happen, also pointing out the challenges, trying to be realistic, and being open about the things we need to do better or improve or do more of. One of the things we need to do more of is maybe projects where we cooperate." (Interviewee 11, Industry)

Others felt that their industry needed to be part of this cooperation so that they could learn more:

"I would welcome more discussion about how [CAVs] will affect us in the future, with the municipalities, and with us, who are building apartment buildings. I would say we do not talk so much about that today." (Interviewee 10, Industry).

4.2.8. *Policy harmonisation between different levels of government*

Policy harmonisation in relation to CAVs has been reflected in literature discussing both national (Legacy et al., 2019) and international (Lee and Hess, 2020) harmonisation. Transportation is particularly interesting since one vehicle can be in different jurisdictions (municipal, regional, national, global) and cross between jurisdictions quickly.

> "One of the problems or challenges is that there's no harmonised regulation or policy. We have the Vienna convention,[1] but not all countries have signed. There are European initiatives … And then we have the national level of course, where Member States in the EU, or outside of the EU for that matter, they need to find a common way of speaking to each other." (Interviewee 11, Industry)

One interviewee had a more cynical view of the idea of harmonised CAV policy at the local level when they stated that: "I think less strategic planning will happen at municipal level; it will be more like putting out fires and giving permits for different communities outside of cities." (Interviewee 1, Industry).

4.2.9. *Cities becoming more powerful*

Cities tend to have jurisdiction over CAV-related issues, such as parking and local traffic regulations (Freemark et al., 2019). Thus cities are gaining more bargaining power when it comes to policies that could be related to or affected by CAVs. One interviewee, when discussing the role of industry, remarked that "It might be that we don't need to build up parking spaces anymore. It's not up to us really, it's up to the municipalities. More and more we are having a dialogue about what can we offer, and how they can reduce the [minimum number of parking spaces]." (Interviewee 10, Industry).

Another interviewee had very proactive suggestions when it came to the role of the city in a CAV introduction:

> "Maybe, on the political level, we should step up a little bit with these questions and not just leave it to the civil servants and to research projects, but also maybe demand a plan, a strategy and a policy for introducing autonomous vehicles in Gothenburg, for instance." (Interviewee 5 Academia, Government and Civil Society)

4.3. *Analysis of selected impacts and responses through the lens of transition management*

In the next step, we used the four governance spheres from TM to better understand how certain impacts and responses reflect issues that emerged in the literature review, and to suggest where those impacts and responses fit into the larger transition to CAVs in cities as part of a complete DPSIR chain.

Not all impacts and responses are examined here. We used the DPSIR chain shown in Fig. 3, which starts with the driver *Politics and Policy,* then the more specific pressure *Economic Interests of Car Manufacturers,* leading to the state *CAVs in Cities.* The main impact that is examined is *Increased Travel Demand*. This was chosen because it is one of the main consequences of CAV introduction that arises in the literature. Many studies examine the idea that CAVs could lead to increases in travel demand due to decreased VoTT, (see for example (Soteropoulos et al., 2019; Taiebat et al., 2019; Wadud, 2017). The interviewees echoed these ideas, suggesting that convenience might make it easier for passengers to spend more time in a CAV as compared to a regular car, and thus contribute to negative effects such as congestion.

Increased Travel Demand can be addressed in a variety of different ways, making it the ideal impact to use when examining different responses. We used the TM spheres, starting with the strategic sphere, to categorise and further analyse the responses and the DSPIR chains of which they could be a part.

[1] The Vienna Convention on Road Traffic of 1968 is an international treaty that attempts to organize international traffic. The EU does not have its own traffic legislation, and thus the Vienna Convention is most often referred to as a means of bridging traffic policy between EU countries.

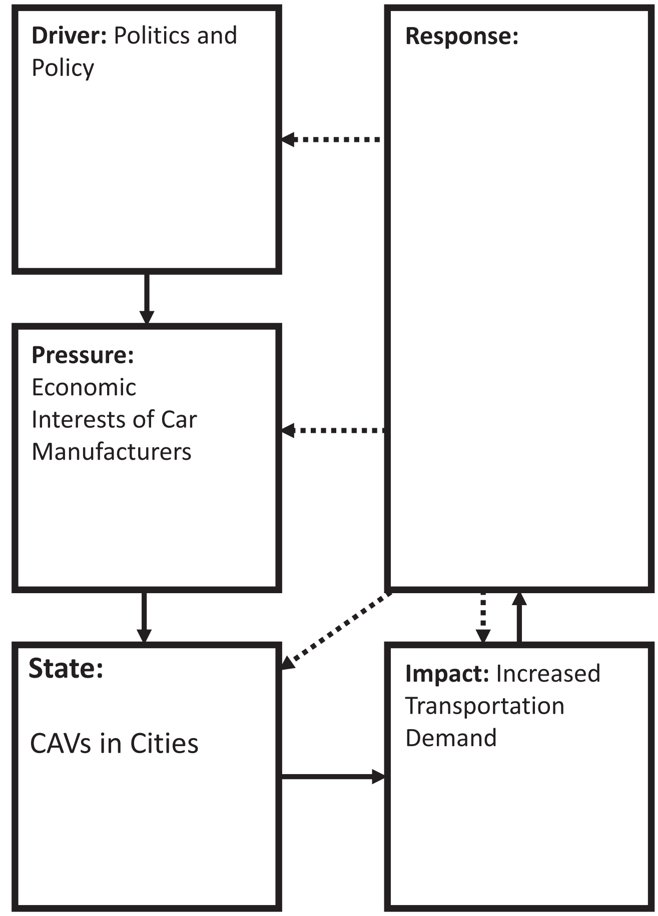

Fig. 3. A DPSIR Chain example.

4.3.1. *The strategic sphere*

The strategic sphere of TM requires a long-term vision. In much of the CAV governance-related literature (Acheampong et al., 2023; Hopkins and Schwanen, 2018; Lyons, 2022; Milakis and Müller, 2021; Miloš N. Mladenović et al., 2020; Mukhtar-Landgren and Paulsson, 2021), authors stressed the importance of collaboration between government, industry and users, and the use of participatory pilot projects. This is captured by the response *Cooperation between industry, government and academia to better understand how CAVs will be used*. In addition, a sustainable socio-technical transition to CAVs will require policies that deal with congestion, emissions, and increases in transportation demand (Milakis et al., 2017; Taiebat et al., 2019). Such issues span various regional, national, and international government jurisdictions, thus matching the response *Policy harmonisation between different levels of government*.

In both cases, these responses are overarching and could target all the different parts of the DPSIR chain directly through policy or regulation (see Fig. 4). This influence is characteristic of the strategic sphere, which focusses on the culture that underpins a transition.

The most likely target would, however, be the driver level, in this case *Politics and Policy*, since political and bureaucratic processes tend to be slow, and create incremental changes. Loorbach emphasizes the importance of implicit knowledge and information that is created through discussions within the transition arena at the beginning of a transition. The actors in who could be involved in these responses would likely be more institutional than what is suggested for a transition arena, but the processes of cooperation and harmonisation match the transition arena task of creating shared, long-term basic principles for sustainable development (Loorbach, 2010).

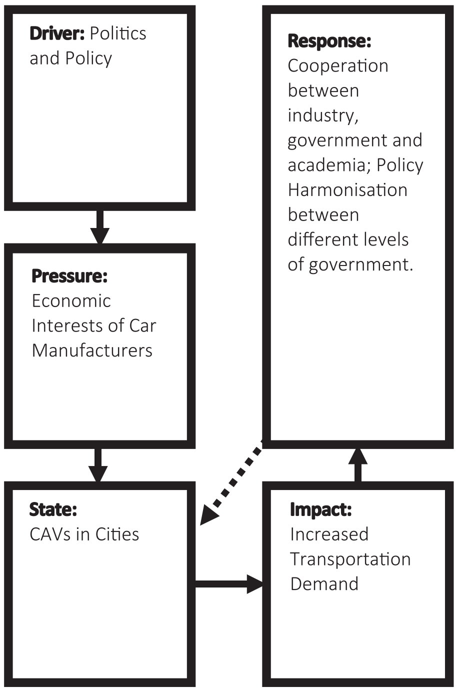

Fig. 4. DPSIR chain as part of the strategic sphere.

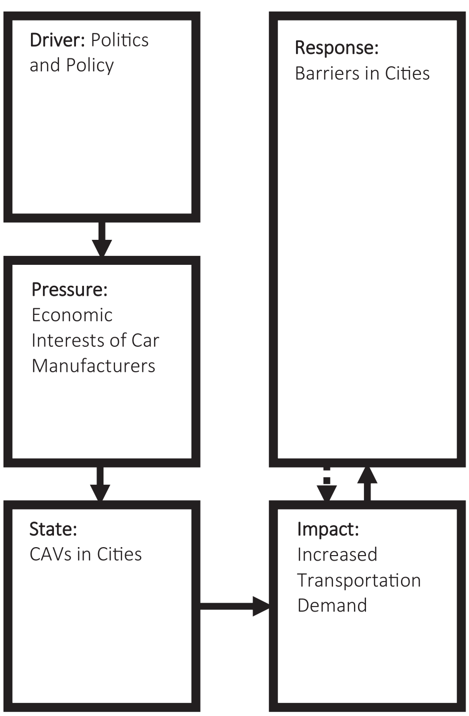

Fig. 5. DPSIR chains with examples of different responses to the impact of *Increased Transportation Demand.*

4.3.2. The tactical sphere

The tactical sphere focusses on governance structures, regimes and institutions, and barriers towards an established vision. The *Creation of Barriers* response was taken from the interviews and explained as the idea that a new road system, where certain roads would be CAV-only, would exclude road users who do not have access to CAVs (Fig. 5).

This could lead to increased economic benefits for car manufacturers, who would sell more cars or car-related services, leading to the impact *Increased Transportation Demand*. Here we assume that barriers could exacerbate the transportation accessibility inequities discussed by Dianin et al. (2021) and Wu et al. (2021). This can be categorised as part of the tactical sphere of TM, because it describes the creation of physical infrastructure barriers that hinder a sustainable introduction of CAVs.

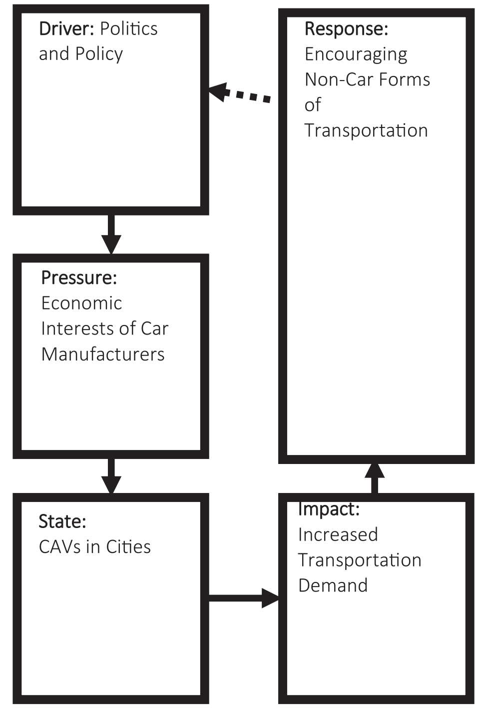

Fig. 6. DPSIR chains with examples of different responses to the impact of *Increased Transportation Demand.*

An example of a very different response to the impact *Increased Transportation Demand* could be *Policies that Encourage Non-Car Forms of Transportation* (see Fig. 6). This response would be at the level of the tactical sphere because it involves action on the part of a governing institution, which is already happening in Gothenburg. The City has the goal that 23 % of trips within the city should be made on foot, and 12 % by bicycle, by 2035 (as compared to 2011) (City of Gothenburg, 2023b). Currently pedestrian trips are at 22 % and cycling trips at 7 % of total trips. Since this response involves government action, it would likely target the driver stage of the DPSIR chain.

4.3.3. The operational sphere

The response *Ridesharing Programs* fits into the operational sphere as these programs can be considered transition experiments. Loorbach (2010) notes that transition experiments can take as long as 5–10 years which, depending on the intended scale and usage of a ride-sharing program, could be possible. Loorbach also points out that this level of TM should create many transition experiments that “complement and strengthen each other” (p. 176). This could be an example of other Mobility as a Service (MaaS) components, such as rental cars, e-bikes, and larger rental vehicles. Ridesharing with CAVs has been modelled using data from Gothenburg travel surveys. A research project called Eldsjäl recently used computer simulations to show that total vehicle kilometres driven could decrease by 17 % if ride-sharing was introduced in Gothenburg and its nearest suburbs (Lorig et al., 2023).

It was brought up in the interviews that ride-sharing programs could act as a less intimidating way to introduce people to CAVs. There are examples in the literature which show that when people envision future transportation systems, they carry forward a vision of how they use the transportation system today, even if they are aware of its drawbacks, such as those of an increase in privately owned vehicles (Fraedrich,

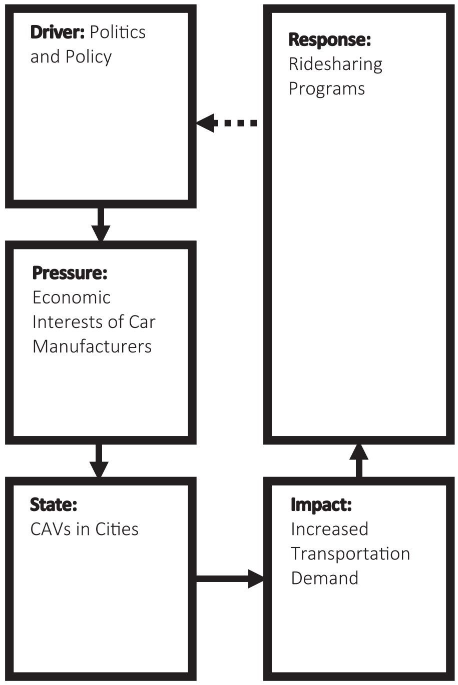

Fig. 7. An example of a DPSIR chain with the response *Ridesharing Programs.*

2021). While there are many factors that influence willingness-to-share (Rahimi et al., 2020), ride-sharing is perceived as being both more inconvenient, and in some cases more costly than a private vehicle (Wadud and Chintakayala, 2021; Wadud and Mattioli, 2021). Thus, a shift to ridesharing could represent a broader change in behavior that could be connected to societal drivers, hence being a response that could in fact target the entire DPSIR chain (see Fig. 7).

4.3.4. *The reflexive sphere*

In some cases, the timing or speed of the impact is crucial, for example the response *Step-by-Step Introduction of CAVs*, which focusses on the speed at which the technology is introduced (Fig. 8). The interviewees from industry stated the importance of viewing CAV technology as a system of many Operational Design Domains (ODDs). The EU defines ODDs as: "operating conditions under which a given automated driving system is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics" (European Union, 2022).

One example of a *Step-by-Step Introduction of CAVs* is introducing a type of ODD with each step, similar to how the UN and EU have recently adopted regulations for certain types of roads (European Commission, 2022; UNECE, 2022). This process could in fact be viewed as many new states each time a new ODD is introduced, each causing a new impact on user behaviour, with each one potentially requiring a response in the form of more technology testing to address safety or HMI issues, new traffic legislation, or other measures. Hence, this would be a reflexive technology adoption process, and part of the reflexive TM sphere. This response would primarily target the state of *CAVs in Cities*, since it relates directly to the CAVs.

The reflexive TM sphere could also be connected to the response *Flexibility in City Planning.* This could mean that the development and role of CAVs are regularly monitored and evaluated, potentially affecting policies so that the role of CAVs in the transportation system is aligned with the overall long-term goals for the city as an urban system. This is similar to how goals from the *Gothenburg 2035* strategy plan are revisited in yearly reports from the City's Traffic Committee (City of Gothenburg, 2023c; Hellberg et al., 2014). This response would target the driver stage of the DPSIR chain (Fig. 9).

5. Discussion

In this section, we address the research questions posed at the beginning of the article.

RQ1: How are potential future impacts of CAVs in cities perceived by local stakeholders in Gothenburg?

The stakeholders in question here are the interviewees and the people who the interviewees discussed in the context of Gothenburg. In

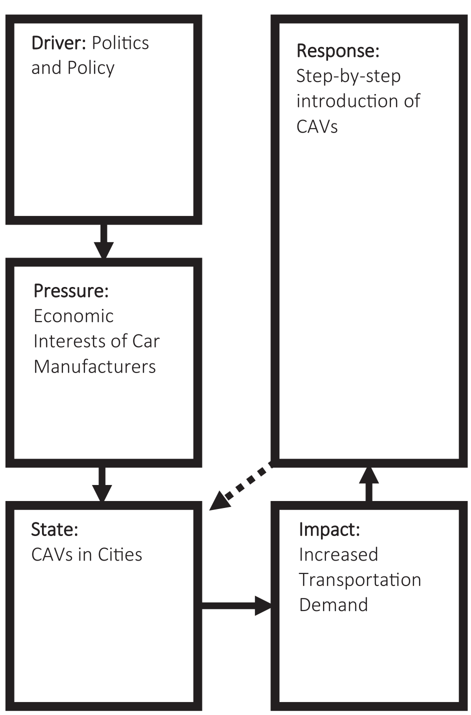

Fig. 8. DPSIR chains in the reflexive sphere.

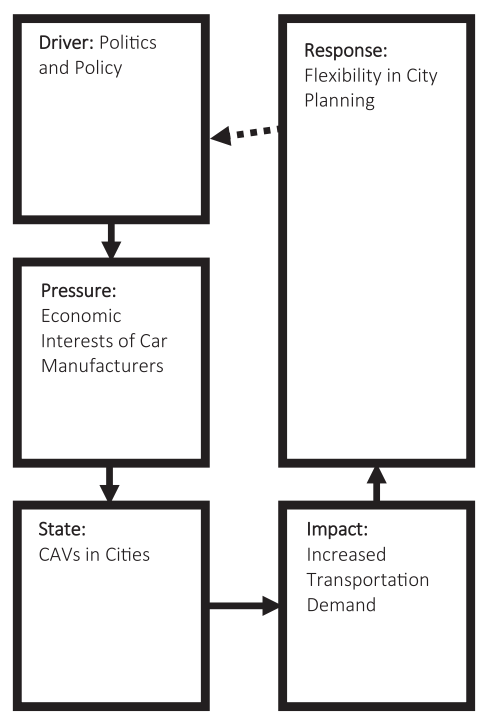

Fig. 9. DPSIR chains in the reflexive sphere.

answering this question, we also discuss the plausibility of the interviewees' perceptions and opinions by comparing them to the findings in the literature.

As was mentioned in Section 4.3, an impact that came up constantly in the interviews and that is also present in the literature is *Increased Travel Demand*. When we apply this to the context of Gothenburg, it should be noted that the City has a goal to reduce car traffic by 25 % by 2035 compared with 2011 levels. Car traffic is falling by about 0.5 % per year, thanks in part to congestion charges, but this is not a fast enough rate to meet the 2035 target (City of Gothenburg, 2023b). If measures like congestion charges that make car travel more expensive have contributed to a decrease in car travel, CAVs that make car travel cheaper and more convenient could cause more travel demand. In this regard, the interviewees' perceptions match the findings in much of the literature, and of the policies and statistics in the City of Gothenburg (Milakis et al., 2017; Taiebat et al., 2019; Wadud, 2017).

Not all impacts matched the literature in a straightforward way. The interviewees named changes in urban planning and building (classified as the impact *New infrastructure and use of limited urban space*) such as parking garages that allow cars to park more closely together. They also brought up the impact of *Parking companies losing revenue*. Parking solutions are a hot-button issue in Sweden, not least in Gothenburg. But there were some discrepancies in the way that interviewees perceived the loss or adaption of parking spaces, and how these changes are presented in the literature. The interviewees were mostly focussed on the idea that parking or space for cars will still be necessary, though the garages could be smaller. In the literature, there is more focus on the connection between parking spaces and car ownership, and a reduction in the latter (Johansson et al., 2022; McAslan and Sprei, 2023).

Another example where interviewee perceptions and literature didn't quite match was around the impact *Changes in vehicle to pedestrian/cyclist communication*. As Dey et al. (2020) point out, there are many different physical and communications aspects that can create confusion even before users are part of the system. In a more recent review of external Human Machine Interface (eHMI) literature, Brill et al. (2023) found that there are still many gaps in the scientific literature, including a taxonomy of the different types of shared spaces that CAVs and other users will be interacting within, because in such spaces it is often unclear who has priority. The discrepancy between the literature and interviewees' perceptions here is that there was an implication in the interviews that it might be more difficult for pedestrians and cyclists to communicate with CAVs than with regular cars. While this was not rejected by findings in the literature, Brill et al. (2023) point out that this communication is currently flawed even with conventional traffic.

One impact that has less uniform support in the academic literature is the suggestion that CAVs could be introduced through the existing public transportation system (UITP, 2017) i.e. *Better Public Transportation,* especially in low density areas. While this is a common suggestion in the literature, Legacy et al. (2019) argue that strategic planning needs to happen for CAVs to be integrated into public transportation, and highlight Docherty et al.'s (2018) warning that it could be advantageous for corporate actors to benefit from individual travel. Thus, it could be possible that the interviewees had a rather naïve view of the rollout of CAV technology that overlooked the interests of automobile industry incumbents.

In general, the interviewees identified impacts that were also present in the literature. But the nuances of certain impacts were lacking, such as the difficulties surrounding CAV integration into public transportation, and the current difficulties in communication between pedestrians, cyclists, and car drivers. This could suggest that while the interviewees' perceptions regarding the impacts of CAVs are plausible, these impacts require comparison with the literature and further analysis in order to produce results that are contextually grounded. The analysis in Section 4.3 is an example of such research.

RQ2: How can the complexity of the responses identified in the interviews be captured and interpreted for policy interventions using the Transition Management framework?

The strategic sphere of TM emphasizes the creation of a long-term vision. The responses that we have connected to this sphere are *Cooperation between industry, government and academia to better understand how CAVs will be used* and *Policy harmonisation between different levels of government*, both of which could benefit from a common vision for CAV introduction. The City of Gothenburg does not include CAVs in its current transportation strategy goals, although the technology is briefly mentioned, and the City is involved in multiple research projects on CAV use. If there was a clear CAV strategy to complement existing transport planning, these diverse testing and research projects could be working towards one long-term vision (albeit from different perspectives). Gothenburg is not unique in not having stated planning goals related to CAVs. Grindsted et al. (2022) show in their review of various European capitals that even cities that mention CAVs explicitly in planning documents lack more specific standards, visions, or planning goals.

Regarding the tactical sphere of TM, the first response that we focussed on in the discussion was the *Creation of Barriers.* This could create a more socially unsustainable transportation system where stakeholders without access to a CAV have less convenient transportation options. Barriers to accessibility are already acknowledged as an issue in conventional traffic planning in Gothenburg: "Creating a denser and more interconnected network of streets without barriers" is one of the sub-goals of the City of Gothenburg's transportation planning strategy document *Gothenburg 2035* (Hellberg et al., 2014). This relates in turn to the second response that fell within the tactical sphere, *Policies that Encourage Non-Car Forms of Transportation*. Gothenburg is also already working on this response in many ways, one of which is the recent creation of a guideline stating that vehicle speeds should be reduced to 30 km per hour based on the presence of pedestrians or cyclists (this is in addition to existing low speed limits for schools and other special zones) (City of Gothenburg, 2023b).

Both of these responses in the tactical sphere highlight the fact that the same policies can be useful for conventional and CAV traffic. Identification of such policies, in addition to monitoring and evaluation, could be very useful, because then CAV planning can be built into existing regulatory structures.

Another current phenomenon that could have implications for the introduction of CAVs is *Ride Sharing Programs.* This was placed within the operational sphere as a transition experiment. As was mentioned in the previous section, it could be necessary to address the fact that ridesharing might not be affordable and convenient enough to be adopted at a sufficient rate to offset the congestion, emissions, and other effects from *Increased Transportation Demand*. If we consider that *Ridesharing Programs* are part of the operational sphere, then perhaps a policy intervention is necessary at the tactical stage. This policy intervention could be part of a broader effort to acknowledge both a lack of interest in, or discomfort with, ridesharing and to make it a more viable option for potential users.

Finally, when considering the reflexive sphere, we examined the responses *A Step-by-Step Introduction of CAVs* and *Flexibility in City Planning.* This need for adaptive governance regarding the introduction of CAVs can also be placed in the national context of a sustainable socio-technical transition. Swedish policy documents on reaching long-term climate targets often stress that flexible regulatory approaches are required to meet long-term goals. If the system is moving faster towards carbon neutrality and transport efficiency, or if various possibilities or obstacles emerge, policies may be revised so that the long-term targets remain attainable. See for example Hunhammar et al., (2021) and Nohrén et al., (2022). At the European level, the EU now has Regulation 2022/1426, which regulates certain automated driving functions such as speed and braking, as well as the number of fully autonomous vehicles allowed on EU roads. The EU plans to introduce new measures in the Regulation in 2024 and 2029 (European Commission, 2022).

6. Conclusion

6.1. Limitations

The most blatant limitation of this study, and most studies that focus on CAVs, is that all the data (both interview data and the literature review) is based on a future vision of a technology that is not widely used today. Thus, there is likely a gap in terms of how both the scientific literature and the interviewees view CAVs, and what will happen in reality. There are also fewer interviewees representing civil society than other parts of the quadruple helix structure, which puts a limitation on the perspectives represented in the interview data. This limitation is, however, quite tempered by the broadness of perspectives in the literature review, and by the comparisons between literature and interviewee perceptions in the Discussion section.

6.2. Conclusions

By categorizing DPSIR chains into TM spheres, we can give an indication of the scale of potential impacts of and responses to CAV technology. This also suggests the scale on which policy interventions could be made in the future, and thus this research could act as a base condition for future policy research. Certainly, actual CAV use remains almost non-existent, but there are global regulations in place, and plans to continue monitoring and adapting to the technology. Additionally, many pilot projects that test user behaviour and address other urban planning issues are being carried out, and research into CAVs is being updated constantly.

This article builds on studies that call for more research into the social dimension of CAVs (Cohen et al., 2020; Hopkins and Schwanen, 2018; Milakis and Müller, 2021). There are a group of interrelated impacts including *Replacing people with technology, New infrastructure and use of limited urban space,* and *Changes in vehicle to cyclist/pedestrian communication* that can act as starting points for new research into the social effects of removing people from the driver's seat, where humans might still be needed and why; and the most equitable and efficient way to use limited urban space.

After examining the different spheres of the TM framework in relation to perceived impacts of and responses to CAVs, it is clear that there is already a great deal of research and practical experimentation happening in the strategic, tactical and operational spheres. In the reflexive sphere, the passage of EU Regulation 2022/1426 represents an exciting opportunity for monitoring, evaluation, and reflexive change when the Regulation is updated between 2024 and 2029.

In the short term, the next step will be to see how individual Member States choose to implement the Regulation. In the longer term, activities in each sphere of the TM framework should be examined, and new goals agreed upon. In Gothenburg, there are already examples of policies that could help address impacts such as *Increased Transportation Demand.* If, for example, the 2035 goals for reduced car traffic and increased pedestrian and cycling traffic are to be met, then ride-sharing programs and non-car forms of transportation will require continuous support.

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CRediT authorship contribution statement

Ella Rebalski: Conceptualization, Data curation, Writing – original draft, Writing – review & editing. **Marco Adelfio:** Conceptualization, Data curation, Writing – original draft, Writing – review & editing. **Frances Sprei:** Conceptualization, Writing – review & editing. **Daniel J. A. Johansson:** Conceptualization, Writing – review & editing.

Data availability

Data sharing of a quantitative nature is not applicable to this article as no quantitative datasets were generated or analysed during the current study. Interview data, including names of interviewees and interview transcripts, is confidential.

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Brace for Impacts

Perceived Impacts and Responses relating to the State of Connected and Autonomous Vehicles in the City of Gothenburg.

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