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Impacts of automated transport on cities: How to discuss and study impact mechanisms

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Abstract

This paper focuses on three main topics: the impacts that automated transport may have on cities in different scenarios, the impact mechanisms, and the methods to develop and discuss impact paths. We describe methods to break down the complex question of the impact of automated driving on society. By decomposing the impact into smaller impact areas and then further into factors determining or influencing the impacts, and into performance indicators that address specific issues, we aim to be able to go more in-depth in focussed discussions. By discussing, and investigating, for example, how automated driving can influence mobility behaviour we can focus on changes in mobility patterns that will influence the amount of traffic on the roads. The impact pathways are often depicted as a linear trajectory, even though they are not necessarily such. In the discussions, experts had different ideas about the directions of the outcomes of performance indicators, because they followed more complex impact paths, having in mind more variables and feedbacks affecting the outcome. Currently, we're developing a model of the impact paths in the form of causal loop diagrams, and a next step could be the development of quantified system dynamics models to be used for scenario and policy understanding.

1. Introduction

Large-scale introduction of automated transport has the potential to transform the cities of the future. Next to increased safety, it is widely thought that it could improve transport network efficiency, reducing congestion, and, in combination with electrification, reduce air pollution. It could improve personal mobility, especially for groups currently experiencing transport poverty. However, it may also have negative consequences (Crayton and Meier, 2017) such as a reduction in the use of active transport modes (walking and cycling) because of the improved access to motorised transport. In addition, public transport could be put under pressure, and reduction in the quality of public transport service may even lead to more vehicles on the road. Different scenarios are possible for the future of the mobility system, and scenarios are proposed and studied in several European projects and roadmaps (some of which we will discuss in Section 2). Alongside automation, shared mobility is an important concept that holds promises for (partly) solving the transport problems of our cities.

As the problems and solutions related to automated transport are complex, it is important to discuss and study the potential impacts at all levels of our society. This complexity makes it very difficult to have meaningful discussions on the directions that the developments in road automation will take, and even more important, which directions policymakers and citizens see as desirable to improve the quality of life in our cities. Different perspectives and estimations about the feasibility of large-scale automation, it's place within shared mobility, and the time it will require to get there, make these discussions very interesting and exciting on the one hand, but chaotic and unfocussed on the other. Although projects and trials on automation are conducted world-wide, it is difficult to bring results together in order to get a clearer picture on the impacts of automation.

In this paper, we discuss the ways in which several working groups, on both a global and a European level, try to take a systematic approach to discuss potential impacts, and the mechanisms that lie behind them. The paper focuses on three main topics: the impacts that automated transport may have on cities in different scenarios, the impact mechanisms, and the methods to develop and discuss impact paths.

Although for cities freight transport is important (especially for the 'last mile'), and the number of delivery vehicles is growing with the increase of online shopping, in this paper we focus on transport of people, and on the higher levels of automation, where vehicles can drive automated in certain areas and under certain conditions, or even be fully automated.

First, we will describe work being done on establishing a European roadmap for the development and deployment of connected and automated driving (ERTRAC 2019). Work on roadmaps helps us to establish an idea of what may be feasible in terms of technology becoming available, and on what time scale. This provides a perspective and a sense of urgency for cities to make plans for developing policies to deal with the developments in the market. As roadmaps are not predictions, we will also discuss the uncertainties and parallel developments such as shared vs private mobility that are taking place.

Next, we will discuss the work that is ongoing in the Trilateral (EU, Japan and US) Working Group on Automation in Road Transportation subgroup on socio-economic impact assessment. The trilateral group has developed a framework (Innamaa et al. 2018a; 2018b) for describing the impact areas, relating them to key performance indicators on a wide range of direct and indirect impacts such as, for example, safety, mobility, land use and public health. This high-level evaluation framework is used for assessing the impact of automation, and to harmonise these evaluations on an international level. In this paper, we focus on the impacts and impact paths that are most relevant for cities providing an example of potential impact pathways.

In the European CARTRE coordination and support project, the key performance indicators of the trilateral framework were used to gather expert opinions on the directions (positive or negative) developments could take in different future scenarios (Rämä et al. 2018). Scenarios related to shared and private mobility, with and without a leading role of public authorities were discussed, and estimations were made on where major changes in a variety of impact areas could be expected.

Finally, this paper discusses the lessons learned from these initiatives. Both ongoing and future work is described. Currently work is under way to enable insight into the complex impact paths, and to facilitate working with them, using graphical representations and system dynamics modelling techniques.

2. Perspectives on development of road transport: roadmaps, uncertainties and parallel developments

In Europe, the European Technology Platform, ERTRAC, involved experts from industry, research providers and public authorities to prepare a roadmap for Automated Driving (ERTRAC 2019). The main objective of the ERTRAC Roadmap was to provide a joint stakeholders view on the development of Connected Automated Driving in Europe. In the 2019 version of the roadmap the focus is on higher levels of automation, and addresses passenger cars, freight-vehicles, and urban mobility vehicles and buses. In **Figure 1**, the roadmaps for passenger cars and urban mobility vehicles are given.

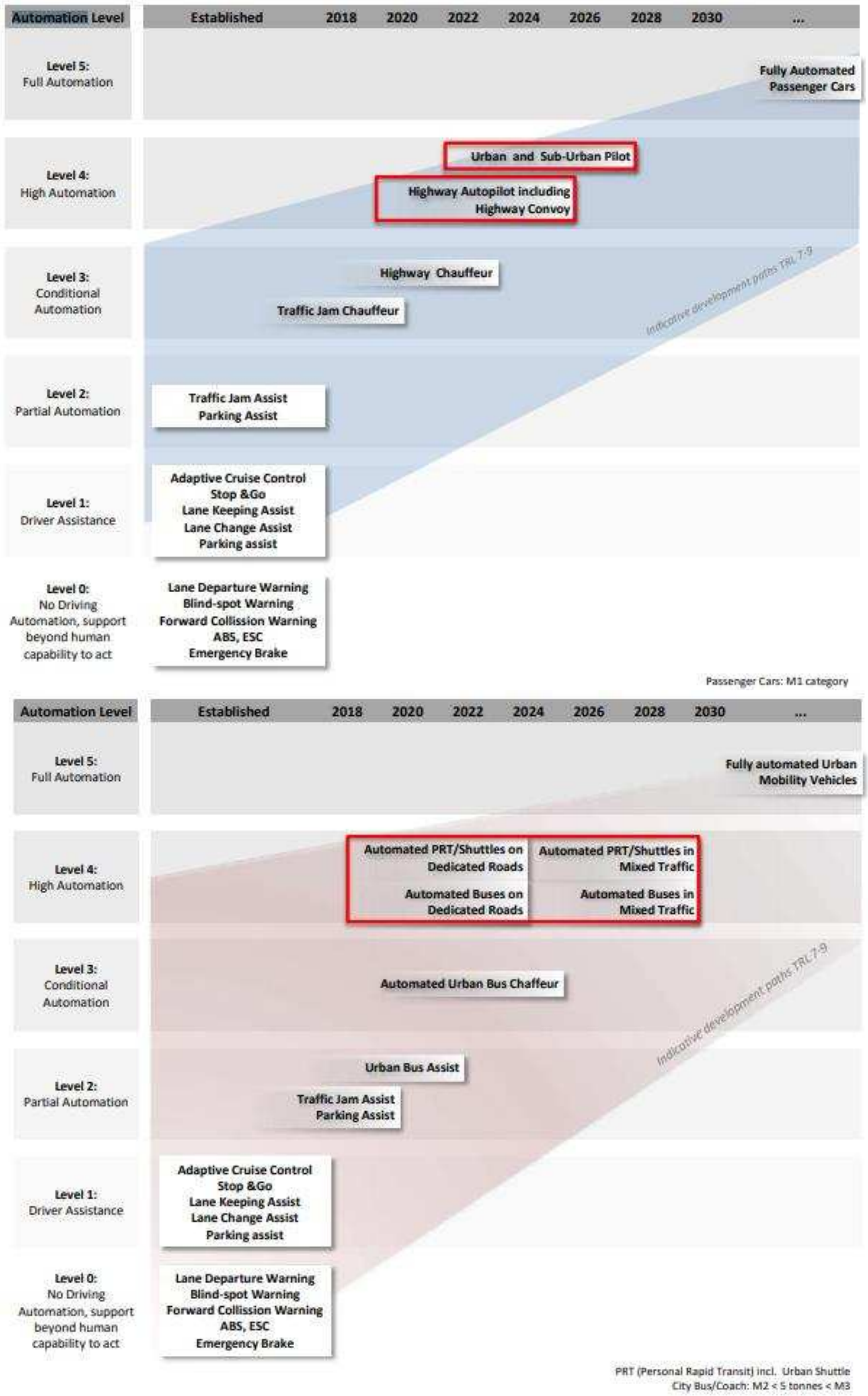

Figure 1. *ERTRAC Roadmaps for passenger cars (above) and for urban mobility (below) (ERTRAC 2019)*

In the ERTRAC roadmap from 2021 onwards, we may see the Urban and Suburban Pilot appear in urban and suburban areas. These functions enable highly automated driving up to limitation speed in urban and suburban areas. The system can be activated by the driver, but the driver can also override the system. Fully automated cars, however, are not foreseen in the near future.

Earlier, and in actual fact already in several cities, we will see Personal Rapid Transit (PRT) including Urban Shuttles and automated busses. At first, they will operate on dedicated lanes, but from 2024 onwards also in mixed traffic. PRT could mean both individual transport and ride sharing with other people, and they could be part of the public transport system or be run as a separate service.

As roadmaps are based on trends and experts' judgements, they are not predictors of the future. Many uncertainties, of course, exist when we look at the future of our cities. Automation will not only take place at a vehicle level; infrastructure and traffic management will also change due to automation. For example, the Internet of Things will be able to connect vehicles to a huge variety of other "things" within the system. In addition, we may be overoptimistic about the technological challenges that the development of fully autonomous vehicles pose. Other uncertainties concern city and transport policy and planning. For example, a city aiming for a transport system that is mainly based on active transport modes such as walking and cycling, alongside public transport, may close the centre or certain areas for motorised (private) traffic. Also, changing lifestyles make a big difference; for example, citizens may renounce private car ownership in favour of using shared mobility services (as is being witnessed in many larger European cities, especially amongst the younger generation (Kampen et al., 2019, Le Vine and Polak, 2019)).

Although it is not foreseen that the roads in our cities will soon be full of automated vehicles, partly automated vehicles will soon become available, and vehicles with automated functions (such as adaptive cruise control) are already on the roads. Alongside this, there exists increasing numbers of services offering more individualised forms of transport, such as car sharing services. The trends allow describing present and emerging societal factors that have impacts on mobility, both for freight and passengers' mobility.

The European project Mobility4EU identified nine major trends shaping mobility: distribution of wealth and labour market developments, urbanisation and smart cities, environmental protection, digital society and internet of things, novel business models and innovation in transport, safety, security, and legislative framework.

Cities need to set out policies to deal with these developments, reflecting on the impacts different scenarios will have on their cities and the daily life of their citizens. Mobility4EU recommends actions in five areas (Mobility4EU action plan, 2019):

- Low / zero emission mobility
- Automation and connected transport
- Safety and (cyber-) security in transport
- Mobility planning
- Cross-modal/ cross-border transport and integration of novel mobility
- Services in public transport, and inclusion: putting the user in the centre

POLIS (the network of European cities and regions working together to develop innovative technologies and policies for local transport) lists in a discussion paper the following impact areas that need to be addressed by cities (POLIS 2018):

- Travel behaviour
- Spatial aspects, such as reduction of (on and off-street) parking space, urban sprawl and longer commuting trips

- Socio-economic aspects, such as enhancing accessibility to persons with limited transport access, increasing social division and inequality, employment, value of time, and public finances
- Road safety, such as using technology to tackle driver distraction and to enforce road safety rules, and interaction with non-automated road users
- Traffic Efficiency, such as road space management, richer data for traffic and asset management, and infrastructure

In summary, although roadmaps indicate that automated vehicles will appear on the road network in the not so distant future, the impacts that they may have on our cities cover a wide range of areas, from a direct influence on traffic to the way in which cities are functioning and are planned. In the next section, we introduce a framework aiming to support the assessment of these impacts.

3. Trilateral impact assessment framework

3.1 Introduction to the Framework

At the moment, pilots and Field Operational Tests (FOTs) of automated driving are being conducted. Although methodologies exist for designing and performing tests of advanced driver assistance systems, assessing the impacts of wide-scale deployment is a difficult and complex endeavour (FESTA 2018; Page et al. 2015). For automated driving this is even more problematic (Barnard et al., 2018).

The Trilateral (EU-US-Japan) Impact Assessment Subgroup of Automation in Road Transportation Working Group (ART WG) published the Trilateral Impact Assessment Framework (Innamaa et al. 2018a). The framework aims for high-level harmonisation of impact assessment studies globally. It is the first attempt at harmonisation by the three regions.

As there are so many concepts of automated driving, the framework does not give detailed methodological recommendations (i.e., methods to apply for calculating the impact or designing evaluation studies) but it aims to facilitate meta-analysis across different studies. Therefore, the focus is on providing recommendations on how to describe the impact assessment study in a way that enables the user of the results to understand what was evaluated and under which conditions.

For designers of pilots and FOTs of automated driving, the trilateral framework provides a structure for addressing the "where", "what" and "why" of the project. It describes the elements of automated vehicle system classification including, but not limited to, the operational design domain (the where and what). The elements of the framework help describe "why" the project is necessary. The associated key performance indicators (KPIs) provide initial thoughts on measures for validation to define the data that should be collected, and to ensure that the information gathered maximises the value of the test. Those assessing the impacts of the automation of road transportation can use it as a starting point in the design of their evaluation work. The KPI recommendations in the framework were based on results of the International KPI survey (Innamaa & Kuisma 2018) that was conducted in 2017 to find common understanding on indicators, which can be recommended for use in measuring and expressing the impacts. Use of the commonly agreed KPIs supports comparison of the results from different studies and meta-analyses. It is acknowledged that additional KPIs may be needed when more experience with connected and automated vehicles is gained in the field.

Policy-makers may use the framework to support policy analysis, long-range scenario-based planning, and major infrastructure investment decisions, where various possible automation futures are envisioned. For policy-makers the direct and indirect impact areas, as well as their associated linkages, provide a path from the results of a field test towards potential larger societal impacts. As automation is deployed, the framework may be applied to evaluate the new data that becomes available, and can provide insight as to what related data should be collected.

Finally, for both FOT designers and policy-makers, the framework can support exploratory analysis. For example, users can take broad assumptions about either future inputs or outcomes and trace them back through the framework to other factors that should be considered or measured. A specific example of the latter might be to consider different roles of shared mobility in relation to transit (ranging from effective last-mile service to full replacement) and mapping that back out to total trips, new types of bottlenecks (e.g. at pickup/drop-off points), and other aspects of demand formation.

3.2 Impact pathways for cities

As there are different levels and concepts of automation, no single approach can be recommended for all impact assessments. Impact paths are introduced in the framework to describe a stepwise relation from the operation of the automated driving system (direct impacts and related KPIs) towards the impacts on a societal level such as on safety, infrastructure or quality of life. **Figure 2** gives an example of the impacts of automated driving in cities. It was put together taking the impact paths of the trilateral framework (Innamaa et. al 2018a) as a starting point.

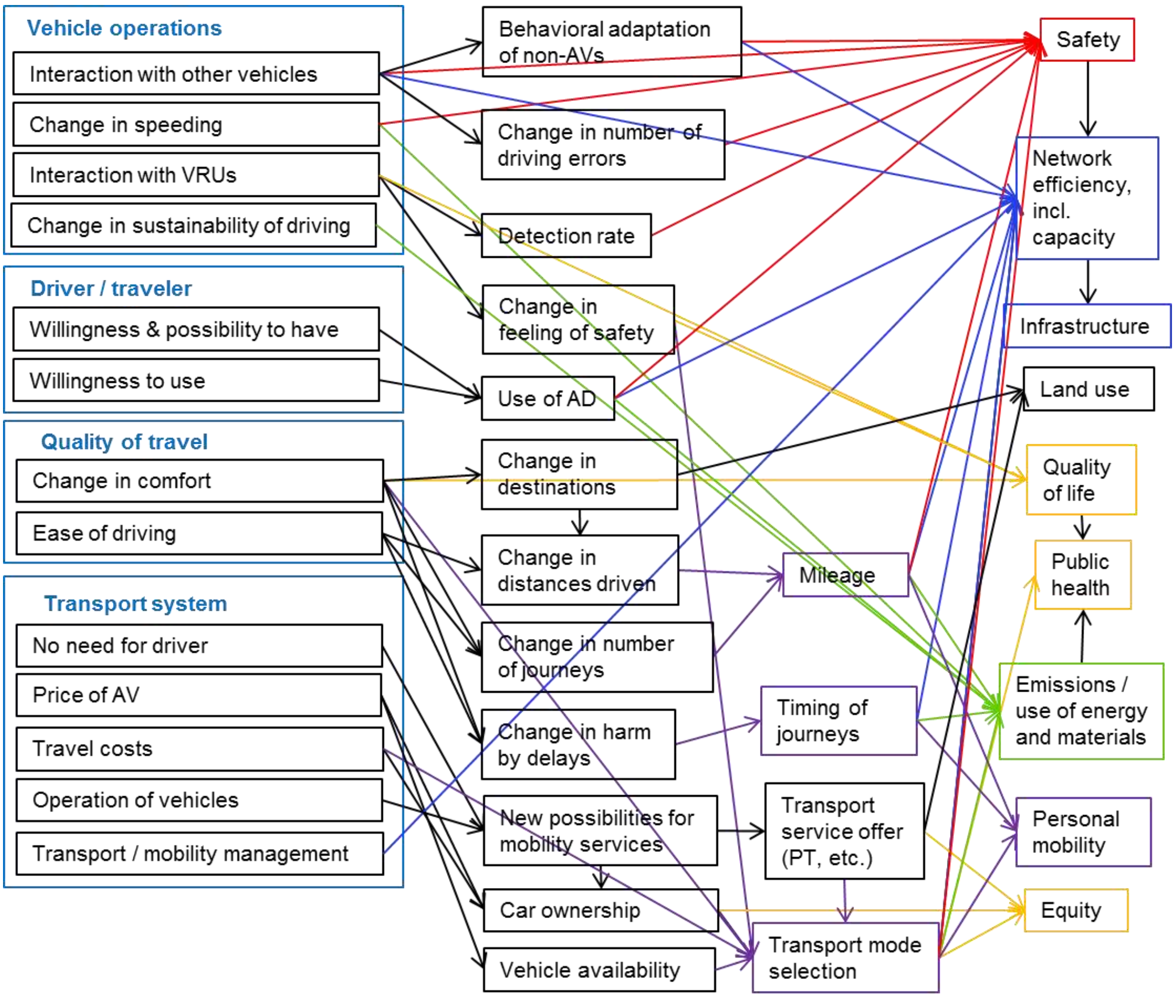

Figure 2. Impact paths for impacts of automated driving in cities

In cities, there will be interaction between automated vehicles and all other road users including drivers of non-automated vehicles of all kind, cyclists and pedestrians. The potential change in numbers of driver errors (speeding, red light violation, etc.) will influence this interaction. The interaction with vulnerable road users (VRUs) is affected also by the change in the detection rate of them (human driver vs. automated vehicle). All this influences the feeling of safety of all traffic participants.

The willingness and possibility to have and to use automated vehicles, or mobility services utilising them, leads to the use of automated driving. Automated driving will influence the quality of travel in terms of comfort and ease of driving/travelling. With these changes, and a change in the value of time spent driving, it is likely that there is a change in destinations and, thus, distances travelled, or in the number of journeys made, and consequently in the overall mileage. If there is an impact on harm caused by delays due to congestion, also the timing of journeys may be influenced - smaller harm leading to less people avoiding peak hours and, thus, leading to worse congestion during them.

The price of an automated vehicle is likely different from a conventional vehicle. From the point of view of the transport system: if there is no need for drivers there may be a change in the operation cost of a fleet or mobility management. These changes will lead to new possibilities for mobility services and for the transport service offered. The comparative price of a (personally owned) automated vehicle and the travel costs of different mobility services will have an impact on car ownership and vehicle availability, which lead to potential changes in transport mode selection and the demand of services, i.e. changes in mobility patterns on a personal level.

Traffic safety is impacted via changes in (the success of) interaction amongst automated vehicles, other vehicles and other traffic participants, as well as with other connected 'things' within the system. In addition, the change in frequency and magnitude of speeding, and the changes in the driving style of the non-automated cars will affect safety.

Transport network efficiency is impacted by the overall difference between the driving style of automated and non-automated vehicles, including the behavioural adaptation of the drivers of non-automated cars (imitation of driving style). In addition, the transport or mobility management and policies chosen for them have an impact on the overall efficiency of the system. The changes in the capacity of the road network and in demand may lead to (a need or possibility for) changes in the infrastructure. Changes in chosen destinations and transport service offer may lead to changes in land use. Emissions are impacted by the sustainability of driving and the selection of transport modes (as well as by fleet electrification).

The changes in mileage driven and transport mode selection have an overall impact on safety, transport network efficiency and emissions. Potential positive changes in those impact areas per kilometre driven can be compromised if the mileage increases.

Changes in available transport services and the quality of travel affect the personal mobility of single citizens, social equity and quality of life. Emissions, stress and safety of travel, and the use of active modes of transport affect public health. Thus, the small direct changes in the way that single vehicles operate will lead to long-term impacts on the whole population and city landscape.

4. Impacts of automated driving in cities

4.1 Scenarios

In order to see how the performance indicators of the Trilateral Framework (Innamaa et al. 2018a; Innamaa & Kuisma 2018) could be used to discuss impacts in difference scenarios, the European coordination and support action CARTRE organised an expert discussion around the indicators (Rämä et al. 2018). The group comprised 17 experts from 13 organizations including industry, research and road authorities.

The approach was a scenario-based assessment, aimed at comparing the impacts of four potential future scenarios. The following scenarios were used, with variations in terms, shared versus private mobility, and involvement of public authorities:

1. A short-term scenario (around 2025) in which the focus was on **gradual extrapolation** of automated services
2. A long-term scenario (around 2035) with a transport system in which **automation emerges parallel with shared mobility**, and the fleets of automated vehicles are **market-operated**
3. A long-term scenario (around 2035) in which **automation is authority-driven** and the focus is on **collective (public) transport** supported by shared mobility
4. A long-term scenario (around 2035) in which automated vehicles are mostly **privately owned** and **shared mobility has not succeeded**

The scenarios are summarized in **Figure 3**.

	SHORT-TERM SCENARIO (~2025)	LONG-TERM SCENARIOS (~2035)		
	Scenario 1 *Gradual extrapolation of automated services*	**Scenario 2** *Market-operated fleets of shared automated vehicles*	**Scenario 3** *Authority-driven shared automated transportation*	**Scenario 4** *Proliferation of private automated vehicles*
Automated vehicle technology	Gradual introduction of automated functions	Mature SAE L4 automated vehicles, penetration >50% in mixed traffic		
Use of shared mobility services	High interest, early adaptors use	High	High	Low
Locus of control	Cautious but enthusiastic public support for AVs & mobility services	Private	Authority-driven, public-private collaboration	Private

***Figure 3**. Scenarios (Rämä et al. 2018)*

4.2 Expert assessment of performance indicators

The expert group assessed the direction and magnitude of impacts in addition to the uncertainty related to the estimates. This was firstly done individually, and then a consensus was sought in group discussions. **Figure 4** gives an example of a summary of the outcomes of the rating of the experts, based on consensus after several rounds of discussion for impact areas of interest from a city perspective, namely mobility and travel behaviour, public health and safety as well as land use. The assessed impacts are elaborated in the sections below.

4.2.1 Mobility and travel behaviour

For the mobility and travel behaviour KPIs, it was estimated that the use of different transport modes would change in all different scenarios. In all long-term scenarios (2-4), it was supposed that the amount of travel would increase because travelling will become more comfortable. At the same time, it was estimated that total travel time would increase along with increased travel in scenarios 2 and 4. Although travelling reliability was assumed to increase in scenarios 1-3, for the scenario 4 there was no consensus concerning the travelling reliability estimate: on one hand new automated services could increase reliability, but on the other hand congestion due to increased private car use would diminish reliability. A transport system based on private automated vehicles was seen as more comfortable than shared mobility systems.

Concerning long-term impacts, it seemed clear that the most positive impacts were assumed in the scenario 3 (automated public transport). The most negative impacts were estimated for the scenario 4 (automated private cars), although some positive impacts were assumed in all of the scenarios. It appeared that impacts in the scenario 2 (market operated shared mobility) were the most difficult for the experts to assess.

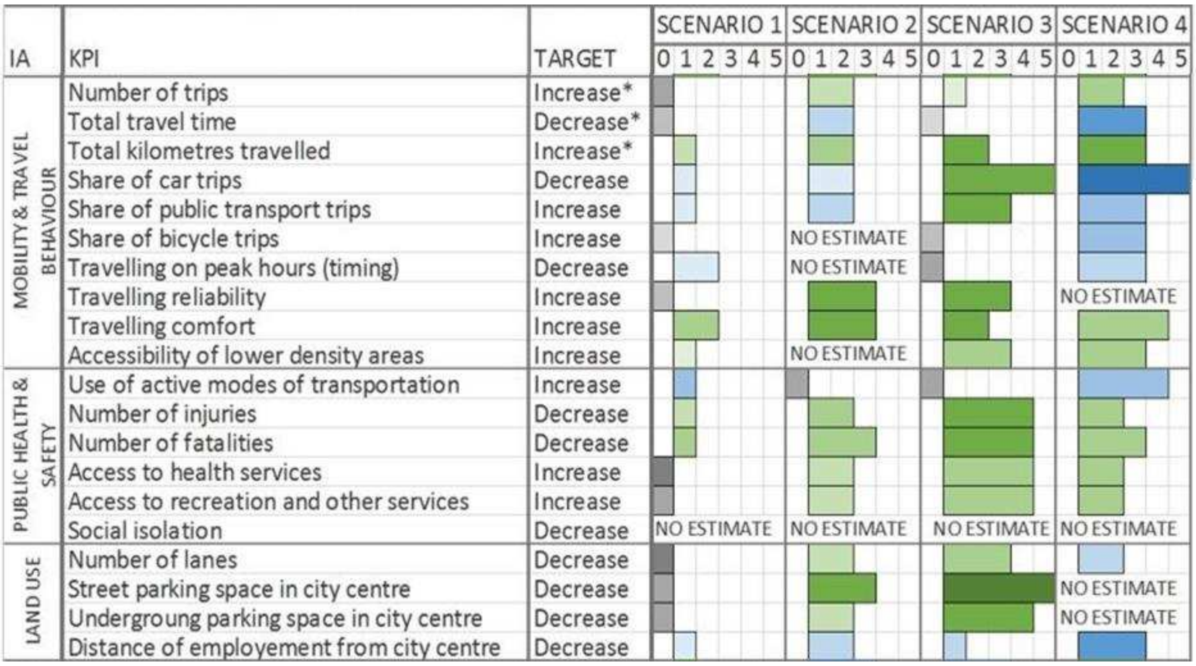

Figure 4. Magnitude (scale 0-5 where 0 = no change and 5 = large change) and direction of impacts. The targeted impacts are marked in green and undesired changes in blue. Grey indicates no impact (magnitude = 0). The lower the certainty of the estimate is, the paler the colour, the higher the darker the colour shading.

**Targeted direction of change can be both increase and decrease; decrease in travelling would decrease disadvantages of travelling (crashes, environmental impacts, costs …), but the aim of a transport system is to enable mobility. (Rämä et al. 2018)*

4.2.2 Public health and safety

For the public health and safety impact area, the total mileage travelled by active modes of transportation, walking and cycling, was not estimated to increase in any of the given scenarios. It was assumed that the increase in comfort of automation will be balanced by more shared mobility. In the scenario 4, it was assumed that the comfort of automation and private ownership of automated vehicles would lead to a considerable decrease in the use of active modes.

Access to health and well-being services could be improved by automated mobility services. There was no common understanding of the impact of automation on social isolation of people. For safety, most benefits were estimated in the scenario 3, where also the largest decrease in the number of injuries and fatalities due to automation was estimated. In the scenario 4, automation in private cars makes a difference in decreasing injuries and fatalities, but still many private cars are being used which might cause a higher accident rate than in the scenario 3.

4.2.3 Land use

For the land use impact area, car sharing and public transport would decrease the demand for parking space. Although automated parking functions have the potential to reduce the space needed for parking, the impact is not considerable as long as there is also a substantial amount of cars without automation in parking areas.

Automated transport may make it possible and more attractive to commute over longer distances, and therefore location of employment (distance from the city centre) is assumed to increase. Even though assuming that automated driving does not require dedicated lanes, more cars (scenario 4) would lead to the need for more lanes, and shared mobility to less.

Overall, more positive effects were assumed for the shared mobility scenarios (2 and 3) than for the private ownership one (4), mainly because of the increase of car use in that case. Scenario 3 has the most positive predictions, the experts assuming that active public authorities can have a major, positive influence on developments.

Other impact areas where also discussed, such as economy, environment and user acceptance. For the results we refer to the report (Rämä et al. 2018).

The work done in CARTRE, described above, was continued in a breakout session of the EUCAD2018 Symposium where 40 participants were asked to vote on the same kinds of topic (Iglesias et al., 2018). They also saw most benefits in scenario 3.

4.3 Discussions on impact pathways

In an interactive session at the ITS World Congress in 2018, we discussed with the audience in an interactive session some of the impact mechanisms presented as causal loop diagrams. In **Figure 5**, such a diagram is given.

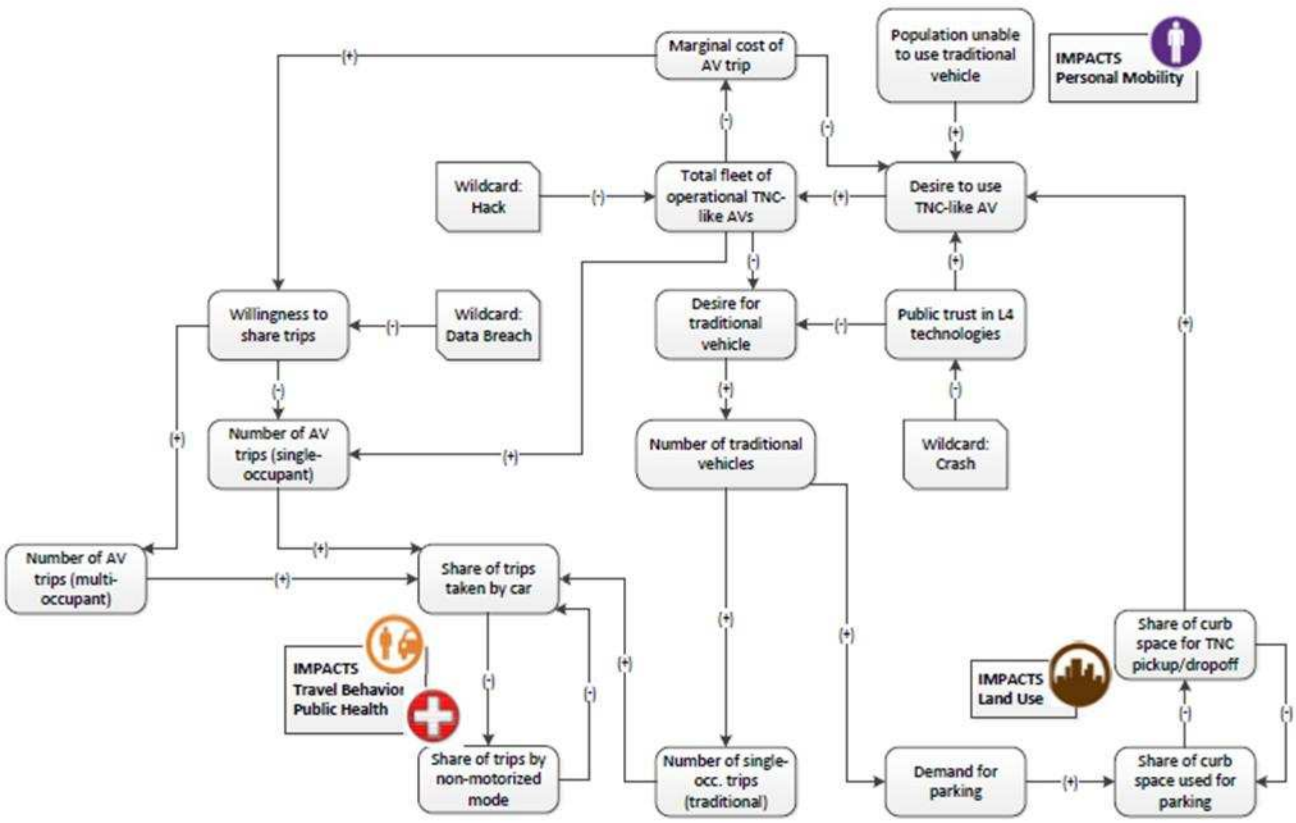

Figure 5: Loops diagram of impact mechanisms

The diagrams were also implemented in an interactive tool in which the user could focus on just a few elements of the bigger picture, allowing for a focussed discussion, taking the conversations from one impact link to the next. The notion of wildcards was introduced, for example, one wildcard says: "What are the effects if there is a major data breach – personal information released, including payment details, origins and destinations with names and associative information (e.g., with whom you were riding)." By following the impact paths, the consequences could be discussed.

4.4 Conclusions from the expert assessment of the impacts

What we learned most from these experiences may not so much be an accurate prediction of the future, but methods to engage in a meaningful discussion. By breaking down the impact areas in performance indicators, it becomes possible to discuss developments in much more detail. However, one of the findings in these discussions was that there are important feedback loops in the impact mechanisms. For example, automated vehicles may bring more comfort and safety, but this may mean that more people use automated vehicles more and on longer trips, leading to more traffic and less safety, annihilating the positive effects. For this reason, we are looking for methods to include these kinds of mechanisms, adding to some deeper insight into the impact paths.

5. Discussion

In this paper, we have described methods to break down the complex question of the impact of automated driving on society. By decomposing the impact into smaller impact areas and then further into factors determining or influencing the impacts, and into performance indicators that address specific issues, we aim to be able to go more in-depth in focussed discussions. By discussing, and investigating, for example, how automated driving can influence mobility behaviour we can focus on changes in mobility patterns that will influence the amount of traffic on the roads.

The impact pathways as described in the sections above are following a linear trajectory, for example, more comfort will lead to more trips, leading to more traffic. However, these paths are not necessarily linear. In the expert discussions described above, experts had different ideas about the directions of the outcomes in the performance indicators exercise, because they followed more complex impact paths, having in mind more variables and feedbacks affecting the outcome. We can take, for example, the scenario of shared mobility, where less people own a private car, and instead use an automated vehicle from a car sharing service. They call for one, use it to go to their destination, and abandon it, then someone else can use it. This may lead to more people using such a service for small trips, because it is more convenient than mass public transport and more comfortable than cycling when it is raining, making more trips than before because it is so easy. However, if more and more people are going to use this service, it may lead to more and more vehicles on the roads, and then it becomes less comfortable, because if you need a car it might not be available, and the ride may take longer. This may lead to less people using the service, the service becoming more attractive again, and the loop closes. So, some participants in the discussion would say car sharing services will lead to positive effects for cities, and others would say it will lead to negative effects, although they may agree on the same impact mechanisms.

Due to this recognition of these complex feedbacks, stock accumulations within the system and time lags affecting the dynamics, we're currently modelling the impact paths described above in the form of causal loop diagrams, and a next step could be the development of quantified system dynamics models (Sterman, 2000) that could be used for scenario analysis.

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