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Framework for assessing the impacts of automated driving

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Abstract

Members of the Trilateral Working Group on Automation in Road Transportation (ART WG) have been working to address the complexity of impacts caused by automated driving. They are setting up a high-level impact assessment framework to coordinate the impact assessments performed in the field of automated driving. The paper presents this framework. It gives recommendations for classifying automation implementations and determining impact areas to be assessed. It also presents the impact mechanisms through which automated driving is expected to impact our life, covering both direct and indirect impacts. In addition, recommendations are provided for experimental procedure, simulation approach and data sharing.

Keywords: automated driving, impact assessment, framework, methodology

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Nomenclature

AD	Automated driving
ADAS	Advanced Driver Assistance System
AV	Automated vehicle
FOT	Field operational test
V2I	Vehicle to infrastructure communication
V2X	Vehicle to vehicle/infrastructure/etc. communication

1. Introduction

Connected and automated driving and transport technologies can potentially transform the world's road transportation system. These impacts may be far-reaching and complex. There are high expectations on what connected and automated vehicles shall be able to contribute to several societal goals. Some impacts will be direct and others indirect, some intended and others unintended, and some will take place in short-term while others will take longer time to form.

Members of the Trilateral Working Group on Automation in Road Transportation (ART WG) have been working to address the complexity of impacts caused by automated driving. They have been setting up a high-level impact assessment framework (Innamaa et al. 2017) to coordinate the impact assessments performed in the field of automated driving. The motivation was the realisation that, as field tests are expensive and mostly done on a small scale, international harmonization would be in everyone's interest. With a harmonised approach, tests and studies can be designed to maximise the insight obtained and to arrange complementary evaluation across the world. Harmonisation would also facilitate meta-analysis.

The framework aims for high-level harmonisation of impact assessment studies globally. It is the first attempt to do harmonisation by the three regions (EC, US and Japan). 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) 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 the user of the results understands what was evaluated and under which conditions. For the recommendations on evaluation methods, the impact analysts can refer to e.g., the P.E.A.R.S. project (Page et al. 2015), the U.S. ITS Systems Engineering Guide (National ITS Architecture Team, 2007), or the FESTA Handbook (Barnard et al., 2017). The next update of the framework (January 2018) will include also recommendations on key performance indicators based on extensive global expert survey.

There are two major audiences for this report: designers of field operational tests (FOTs) and policy-makers. FOT designers may use it early in the systems engineering process (concept exploration, concept-of-operations development, as well as defining the aims objectives, research questions and hypotheses). The framework facilitates starting with the end in mind. For FOT designers, the framework provides a structure for addressing the "Where", "What" and "Why" of the project. 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 maximizes the value of the test. Those performing impact assessment for the automation of road transportation can use it as a starting point in design of their evaluation work.

Policy-makers may use the framework to support policy analysis, long-range scenario-based planning, and major infrastructure investment decisions, where various 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 inputs or outcomes in the future and trace them back through the framework to other things 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.

The paper presents this framework. It gives recommendations for classifying automation implementations and determining impact areas to be assessed. It also presents the impact mechanisms through which automated driving is expected to impact our life, covering both direct and indirect impacts. In addition, recommendations are provided for experimental procedure, simulation approach and data sharing.

2. Classification of automation implementation

As a first step in analysing a given implementation of vehicle automation, it is important to specify the description of the system and the service for which impact assessment is made. Otherwise, researchers risk comparing very different services even though they have a similar design domain. The description of the automation system or service should include (at least):

- Purpose of the system. Is it for person travel, or freight? Within person-travel, is it aimed at area residents, visitors, persons with disabilities, etc.? For freight, consider the type and size of shipments.
- Service type. Is it for short (a few km) or long haul? Does the system serve individuals or groups? Is it on a fixed route, or may the route vary? Is it a specialized system with a limited operational design domain (e.g., valet parking)?
- Vehicle ownership, management and maintenance. Does the system envision single privately-owned vehicles (similar to most automobiles today) or vehicles that are part of a larger fleet?
- Vehicle type(s) (e.g., passenger vehicle, mini bus, large bus, truck, etc.)
- SAE level of automation
- Available automated driving functions. What vehicle control is automated? How is the driving environment being monitored? Is there dynamic routing? Is there communications (V2X) with other road users or infrastructure?
- Operational Design Domain, as described below.

According to SAE J3016 (SAE 2016), the operational design domain may include geographic, roadway, environmental, traffic, speed, and/or temporal limitations. It may also include one or more driving modes. Examples of driving modes include expressway merging, high-speed cruising, and low-speed traffic jam.

Infrastructure requirements are part of the operational design domain, to indicate where the automation application is designed to function, and where it has been tested. Elements of the operational design domain include:

- Specific location where the automation system may operate
- Level of mapping needed where the automated system operates
- Type of road: number of lanes and carriageways, required markings, pavement type
- Types of intersections: merge, diverge, traffic signal, stop/yield sign
- Usage of road: exclusive to AVs, shared with other motor vehicles, shared with bicyclists and pedestrians
- Design speed
- Daytime / night-time
- Types of road surface conditions: dry, wet, snowy, icy
- Visibility: clear, rain, snow, fog
- Temperature, atmospheric pressure

3. Direct and Indirect Impacts of Automation

The impacts presented here are based in initial work by (Smith et al. 2015), and later refined at several conferences and meetings. AV (automated vehicle) impacts may be divided into two large groups: direct and indirect. Direct impacts are those, which have a relatively clear cause-effect relationship with the primary activity or action. They can be measured in an FOT (field operational test). They then can be scaled up to a regional or national level, and can lead to indirect impacts. For example, an FOT can measure driving conflicts (Safety), driver/traveller behaviour, car following and intersection performance (Vehicle Operations), energy consumption and tailpipe emissions (Energy / Emissions), and the comfort of the user or the user's ability to multi-task while in the vehicle (Personal Mobility).

Examples of direct impacts include:

Response of drivers and other road users: How do the vehicle occupants or other road users respond to the automation application? For driver assistance systems, one question is whether the drivers use the system, on which kind of journeys or environments and in which kind of circumstances, and if relevant, what parameters they choose (for example, car following distance). The driver's degree of engagement with the driving task is also relevant (for example, is the driver treating a SAE Level 2 system as though it is a SAE Level 4 system?). For applications operating in mixed traffic environments, the behaviour of other road users (drivers, pedestrians, bicyclists) is also relevant.

Vehicle Operations: Vehicle operations include acceleration, deceleration, lane keeping, car following, lane changing, gap acceptance: all affect road (network) capacity.

Safety: Ultimately, safety is measured as fatalities, injuries and property damage for vehicle occupants and other road users. Other road users may include pedestrians, bicyclists, slow-moving vehicles, construction workers and first responders. Nearly all AV applications, ranging from SAE Level 1 collision avoidance systems to SAE Level 5 self-driving vehicles, have potential safety impacts. A challenge with safety assessment is that actual crashes are rare events; therefore, proxy measures are often used. These measures may include selected traffic violations, instances where a human driver must take control of the vehicle, exposure to near-crash situations, and responses to near-crash situations. False positives – instances where the vehicle takes unnecessary collision avoidance action – are also important.

Energy / Environment: The energy and emissions category includes both the energy consumption of the vehicle through a driving cycle, and tailpipe emissions of pollutants including greenhouse gases. The direct energy/ emissions impacts come from the change in the driving cycle. Changes in vehicle propulsion (e.g., electric vehicles) may also have a significant effect on tailpipe emissions.

Personal Mobility: Mobility from a user's standpoint includes journey quality (comfort, potential use of in-vehicle time), travel time, cost; and whether the travel option is available to someone (e.g., a non-motorist). It also includes equity and accessibility considerations. The higher levels of automation will have the most significant impacts, by providing mobility for non-motorists and enabling multi-tasking. These include first mile / last mile services and accessibility applications. Challenges in measuring personal mobility impacts include the variety of sub-populations who may be affected in different ways, and the difficulty in assessing the actual value of automation to a person based on survey data.

In assessing indirect impacts, note that service offerings and fleet composition might change. For example,

- With better crash avoidance, it may be possible to use lighter-weight vehicles (with an effect on material and energy use or emissions) and avoid crash-related congestion (with an effect on network efficiency)
- The advanced control systems used for automation may also contribute to electrification (with impact on energy use and emissions)
- If there is no human driver, the layout of the vehicle might change (with an effect, for example, on energy use)
- Without the labour cost of a human driver, it may become economical to use smaller vehicles for both trucking and transit (with effects on energy use and network efficiency).

We are also concerned with how different groups of people might be affected, such as non-motorists, persons with disabilities, children, the elderly, and professional drivers.

Examples of indirect impacts include:

Network Efficiency: Network efficiency refers to lane, link and intersection capacity and throughput in a regional transport network. It also refers to travel time and travel time reliability. Improved safety may improve network efficiency via reduced incident delay. Also, changes in vehicle operations (e.g., car following) will affect network efficiency. In addition, changes in transport modes or mileage driven by AVs affect it, too.

Travel Behaviour: A traveller may respond to AV options, including new service offerings, by changing travel behaviour. There may be more or fewer trips. Modes, routes and destinations may change. Higher-level automation applications that have a significant effect on personal mobility or labour could have a significant effect on travel behaviour.

Asset Management: Automation may affect infrastructure assets required in several ways, though significant uncertainty still remains. Lane widths and the use of the hard shoulder may change. Automation may also require V2I infrastructure. For freight and transit, the changed fleet composition may have size and weight implications. Finally, increased use of shared vehicles may reduce parking needs.

Public Health: Automation may impact the health (physical and mental) of individuals and entire communities, via safety, air pollution, amount of walking and bicycling, as well as access to medical care, food, employment, education and recreation

Land Use: Automation may affect the use of land for transport functions (e.g., parking, road geometry). Longer-term land use changes may include community planning, i.e. location and density of housing, road network design, employment and recreation. The number of factors that contribute to long-term land use changes makes distinguishing those changes contributed by automation a particular challenge.

Socio-Economic Impacts: Improved safety, use of time, freight movement, travel options (for motorists and non-motorists), public health, land use and effects of changed emissions (including climate change) will have longer-term economic impacts. Automation may also have substantial impact on labour markets and industries.

4. Impact mechanisms

As there are different levels and concepts of automation, no single approach can be recommended for all impact assessments. Yet, our Framework indicates potential impact paths starting from direct impacts on vehicle operations, driver or traveller, quality of travel and transport system and leading to safety, network efficiency, emissions and use of energy and materials, personal mobility, as well as quality of life, equity, and public health. As an example, see paths leading to ‘emissions and use of energy and materials’ in Fig. 1.

It is recommended to sketch the potential impact paths foreseen for the specific function and system under evaluation to understand the underlying dependencies and for the setting of the methodology. The impact path graphs in the Framework are not inclusive but they can be used as a starting point for systematically determining the impact paths. Naturally, there are strong links between impact areas. Thus, assessment of indirect impacts is also recommended. The impact paths presented above should be elaborated further for the system/service under evaluation adding also the direction of change. Fig. 2 provides an example for that.

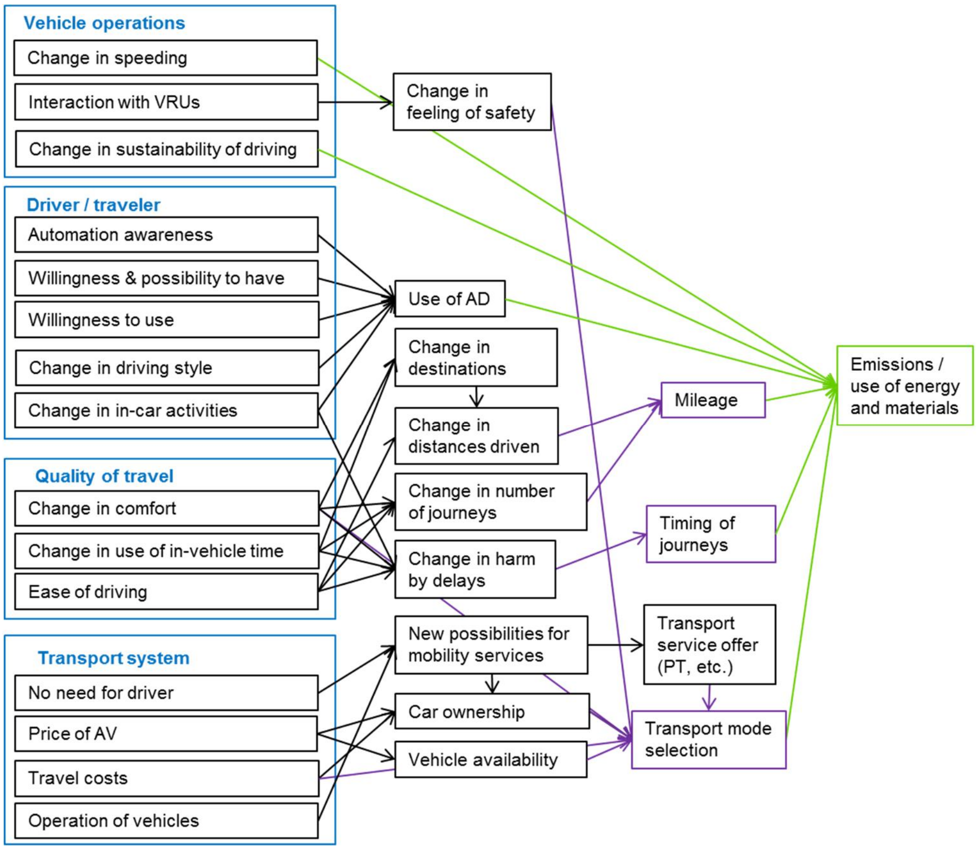

Fig. 1 Impact paths of automated driving for emissions and use of energy and materials

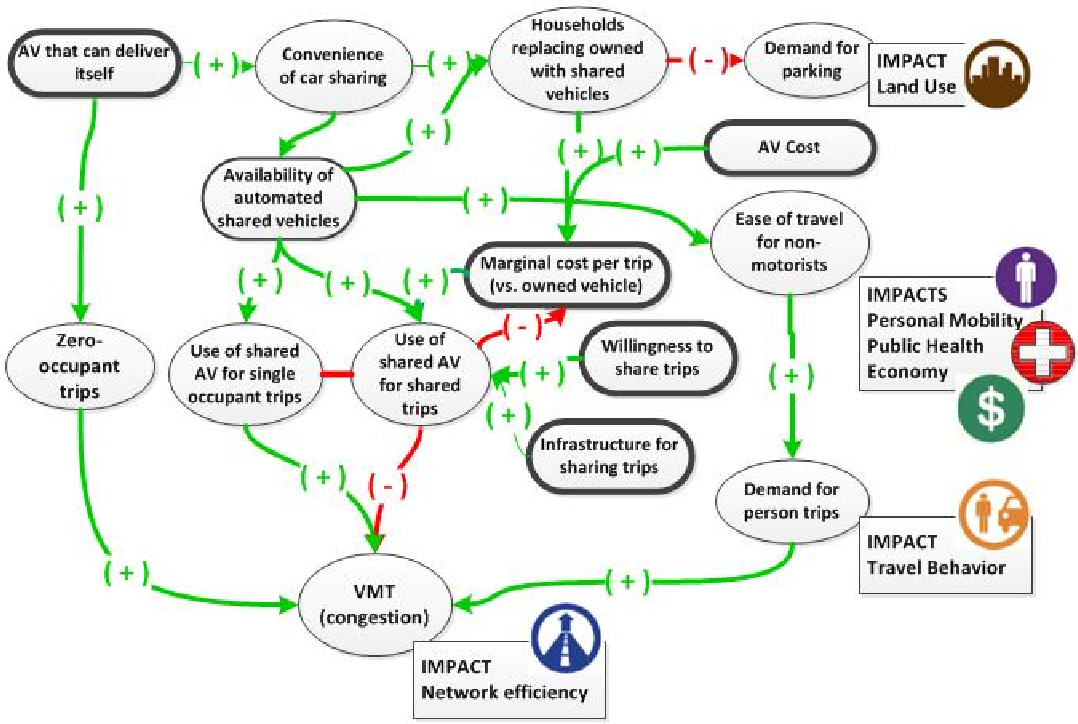

Fig. 2 Example of a detailed impact path of 'AV being able to deliver itself'. Note that the green plus signs and red minus signs indicate whether there is an increase or decrease, not whether the change is good or bad.

5. Recommendations for research methods and data sharing

5.1. Experimental procedure

FOTs are typically used to gather evidence to assess the impacts of new systems. The FESTA methodology (FESTA handbook version 6, 2016) provides an extensive set of recommendations for developing FOTs. It is currently being updated to address FOTs for automated driving.

The first step when planning an FOT is to identify and specify the concepts (AD functions, systems, or new services) where considerable knowledge about their impacts and effects in realistic (driving) situations is of major interest. For automated driving this step may be a major one, as automation may come in different forms; it could be a suite of automated functions but also completely new types of driverless vehicles or services utilizing these vehicles. Definition of use cases is needed to describe the boundary conditions under which the automated function is (intended to be) tested; in other words, how we should expect the vehicle to behave under what circumstances. Starting from the definition of use cases, specific research questions need to be identified. Research questions are directly related to the impact areas that are to be investigated. Typically, this leads to a list, which is too large to be covered by the FOT. Thus, a prioritization is needed to select the most relevant research questions, which the experimental design can provide the answer for. Selection, however, also means that not all potential impacts can be studied.

The next step is to define statistically testable hypotheses for the prioritized research questions and find measurable indicators to test the hypotheses, and a study design developed, defining participants, the environment, the sensors and measurements.

In order to determine impacts, it is generally recommended that driving with the system is compared with driving without it (the baseline). For fully automated vehicles we no longer have a system that can be viewed as independent from the vehicle itself, the whole vehicle is now the system. Some forms of automation, like autonomous vehicles, mean a radical change in transport, with no baseline available. Comparison with the “old” situation may not be very useful, and studying new emerging patterns may be of more interest. It might be ideal if we could compare automated driving with non-automated driving (SAE 0). However, there are several reasons why this is difficult. In the first place, some current vehicles already have some automated functionalities and may belong to SAE levels 1 or 2. If the baseline is chosen to be the prevailing vehicle population of the time when the automation FOT is conducted, we will always be comparing different kinds of baseline and a meta-analysis will be difficult to perform. If this option is selected, data and results from Naturalistic Driving Studies might serve as the baseline. In these studies, “normal” everyday driving is studied (Barnard et al, 2014, Antin, 2011). This behaviour could be compared with the participants’ behaviour when driving in automated vehicles. When selecting research questions and hypotheses and building a test design, we must bear in mind that things should not be compared when they are not comparable. For example, the percentage or duration of eyes-off-the-road may be much higher with automation than in conventional vehicles, but is this of any interest?

Although a naturalistic approach in the field tests may be most desirable for impact assessment, sometimes it may not be feasible for automated driving studies. If the test vehicle is still a prototype and a so-called safety driver must sit beside the test subject of the evaluation, a controlled test approach is practically the only option. The same applies if a large group of test subjects is targeted and the test vehicle fleet is small. If connectivity is evaluated with a small test vehicle fleet, controlled tests are needed to provide a sufficient number of encounters (e.g., with two connected vehicles interacting). The benefits of controlled tests include effectiveness in data acquisition (i.e. high number of events recorded in relation to the length of data collection period) and smaller variance due to differences in the driving conditions and environments. The drawback is clearly the short nature of tests per participant. The controlled tests seldom include frequent repetition of AV use for long periods. Therefore, the long-term impacts, such as the formation of new mobility patterns, cannot be seen.

5.2. Simulation approach

With the new impact areas that were not looked at in the Advanced Driver Assistance System (ADAS) evaluations and other previous FOTs, new methods need to be developed. With their indirect nature and long time to form, they are typically not anything that traditional FOTs can cover.

The use of traffic simulation models can provide the capability to assess the direct impacts of the new/planned ADAS (lower level of automation) onto traffic flows. Since traffic simulation is often criticized as the black-box, it is required to be modelled with sufficient transparency and rationality supported by the engineering validation process. The Energy-ITS Project (2013) recommends that the simulation models should be clarified with the "reference model" which figures out the causal relationships of the ADAS functions and the traffic phenomena leading to energy saving and CO2 reduction. They also recommend that the verification process should follow model clarification to ensure the quantitative relationship of each causal relationship appeared in the reference model. The validation process should verify that model outcomes are similar to fresh real data which might be collected through the small but precise field observations or coordinated tests.

Simulation models of market penetration and user response might be used to assess the social impacts on economics, quality of life, etc. The keys of those assessments are to predict how ADAS penetrate in the future market and how travel behaviour will change. The conventional macroscopic modelling using statistics will provide the solution if there is similar and well-studied market under the big assumption that the people will behave as before. Unless we can accept such an assumption, further investigation will be required.

A promising area for simulation is to assess safety impacts. For this purpose, we are actively investigating microscopic human-vehicle modelling. In general, this modelling tries to identify how human recognition and reaction will lead to the vehicle manoeuvrings and dynamics, and to explain that the ADAS covering the human errors will prevent collisions and accidents. Such direct modelling approaches will provide a comprehensive but qualitative answer to the question whether the ADAS will work correctly or not. However, continuous effort is still needed to identify the quantitative relationships in the human model. The use of the driving simulators is encouraged.

Another approach for the safety assessment is to use the microscopic traffic simulation models to estimate surrogate measures (FHWA, 2001) such as 'time-to-collision', 'post-encroachment-time', etc. By using well-calibrated traffic simulation models in respect of those surrogate measures collected through reliable observations, we may predict how the new/planned ADAS will change the driving behaviours to the safer direction. However, as there is a gap between the changes on those surrogate measures and accident reduction, the further investigations with the statistical analysis are still expected. Continuous video survey with effective image processing technology will be the key to collecting massive and precise vehicle motion data.

5.3. Data sharing

It is unlikely that any one study will be able to answer all questions on the impact of road automation nor collect data for that. This means that we will need data from different studies to analyse the wider impact. By sharing data between organisations and projects, new knowledge might be gained about what will happen when automated vehicles drive in real traffic. In Europe, the European Commission is stressing this need for data to be open and shared, as they are one of the main sponsors of data collection. A European coordination and support action FOT-Net Data built a Data Sharing Framework (Gellerman et al. 2017, Gellerman, Svanberg & Barnard 2016) to support data sharing and re-use. In the US, the Research Data Exchange (RDE) has been set up to allow for datasets to be re-used by third parties for new analyses. A wealth of information is hidden in the datasets that have been and will be collected.

There are several reasons why sharing and re-using data is a good idea, such as making efficient use of the large efforts needed to collect the data, allowing researchers who do not have the means to collect new data to answer research questions or providing others with better quality or larger datasets than they could collect. Data from previous FOT and Naturalistic Driving Studies may also be re-used, as this may provide information about the current situation, to be used as a baseline. In addition, knowledge about how human drivers tackle problems in traffic may provide ideas for informing and improving automated functions.

Data sharing between different countries may provide new knowledge about different conditions under which the automated vehicles drive and is of value for an internationally oriented automotive and service industry.

Re-using research datasets is seen to have several benefits on a societal level: it will yield further research results at minor additional cost, support education, improve collaboration and thereby create trust in providing more data, and e.g. contribute to market introduction of new systems by enabling several organisations to assess benefits. For such reasons, across different fields of science, publicly funded research projects will be required to share more of their collected data in the future.

Data sharing and re-use is easier said than done. There are five main obstacles that need to be addressed:

- Data are valuable and may contain competitive information. Therefore it cannot always be shared in the format it is collected or at all. Data may contain proprietary information regarding the performance of the technology used. This area needs more attention in automation compared to previous studies due to the responsibility issues within automation.
- Datasets may also contain privacy-sensitive data, such as personal data or video of the driver or random traffic participants happening to be around the vehicles. Participants may not have given permission to share data with other organisations and for other purposes.
- Looking at international data sharing, the different legal and ethical conditions in the involved countries might impose constraints and difficulties in sharing data.
- Data are not always easy accessible. Only if the dataset and related tools are well-documented and contains a rich set of metadata is it possible to create a larger re-use of data collected by others.
- Storing, maintaining and opening data after a project has a cost; it may be difficult to find a good financial model for covering or sharing these costs. It is important to find win-win situations between the data provider and data user in further re-use of the data.

In the European FOT-Net Data project, a data sharing framework has been developed to address these issues. The Data Sharing Framework consists of seven areas, all essential for a smooth data sharing process:

- Project agreements set the pre-requisites and the borders for data sharing together with legal and ethical constraints (Gellerman & Svanberg 2016).
- Documented, valid data and metadata, including a recommendation for a “standard” description of the data.
- Data protection requirements both on the data provider and re-users´ analysis site, including security procedures (Gellerman, Svanberg & Kotiranta 2016, Barnard et al. 2016).
- Security and personal integrity training content for all personnel involved.
- Support and research functions, to facilitate the start-up of projects, offer research assistance and analysis tools.
- Financial models to provide funding for the data to be maintained and available, and access services.
- Last, but not least application procedures including content of application form and data sharing agreement.

The sharing of data from road automation studies and the related analysis would benefit substantially, if a common, minimum dataset could be defined, that studies all over the world collect and share. This does not have to be a large set or include sensitive data. The data probably need to be pre-processed and anonymised to ensure that no confidential or personal information is shared, to facilitate a larger re-use. Examples of data that could be useful to allow cross-study comparison are variables describing vehicle behaviour such as speed, distance to other traffic participants, events and incidents, as well as user questionnaires shedding light on road user acceptance.

It is important to build a common view among the stakeholders of the benefits of such a minimum dataset of automation data. The key is to create a win-win situation, with a picture of the future use of the data resolving questions regarding the impact of automation and removing roadblocks for the implementation of automation. The advantages for each of the stakeholders providing and using the data must be clear. The common dataset need to be agreed within the coming 1-2 years, to be able to be collected and provided by the projects, currently planned and decided.

6. Discussion

This paper was designed to present the high-level impact assessment framework that the members of the Trilateral Working Group on Automation in Road Transportation have made. It must be noted that the paper is based on the summer 2017 version of it. As the work on the framework is on-going, at the time this paper is published a new version is foreseen to be available. It will be available in the Library of CARTRE website (connectedautomateddriving.eu).

This framework was made so that governments may use it to support policy analysis and long-range scenario-based planning, where various automation futures are envisioned. Automakers and after-market equipment manufacturers may use it to better understand the potential benefits of their offerings. Designers of FOTs and pilots may use it to ensure that the information gathered maximises the value of the test, and those making the impact assessment for the automation of road transportation can use it as a starting point in design of their evaluation work.

The framework was made by practitioners of impact assessment studies in Europe, US and Japan. As field-test-based socio-economic and other impact assessment of automated driving studies are still mostly to begin in large scale, the authors of the framework had to base the work on their expertise. All feedback of how the implementation of the framework into practice succeeded and how the framework could be improved is very welcome.

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