# Impact Assessment

**Satu Innamaa, Scott Smith, Isabel Wilmink and Nick Reed**

**Abstract** Automated vehicles can potentially transform the world's road transportation system. Direct impacts include traffic safety, transport network efficiency, energy/emissions and personal mobility. Second order indirect impacts, such as the possibility of increased travel leading to more congestion and emissions, are of significant concern. This chapter discusses the direct and indirect impacts by applying systems thinking to the impacts of automated vehicles, presenting two case studies related to different aspects of automation: low speed shared shuttle and truck platooning.

**Keywords** Impact assessment · Direct impact · Indirect impact · Automated driving · Automated shared shuttle · Truck platooning

## 1 Introduction

Automated vehicles can potentially transform the world's road transportation system. Benefits realized could include traffic safety (automobile crashes are a leading cause of accidental deaths), transport network efficiency (most cities experience

S. Innamaa (✉)
VTT Technical Research Centre of Finland Ltd.,
P.O. Box 1000, 02044 Espoo, Finland
e-mail: satu.innamaa@vtt.fi

S. Smith
U.S. Department of Transportation, Volpe Center,
55 Broadway, Cambridge, MA 02142, USA
e-mail: scott.smith@dot.gov

I. Wilmink
TNO Netherlands Organization for Applied Scientific Research,
P.O. Box 96800, 2509 JE Den Haag, The Netherlands
e-mail: isabel.wilmink@tno.nl

N. Reed
TRL, Crowthorne House, Nine Mile Ride, Wokingham, UK
e-mail: nreed@trl.co.uk



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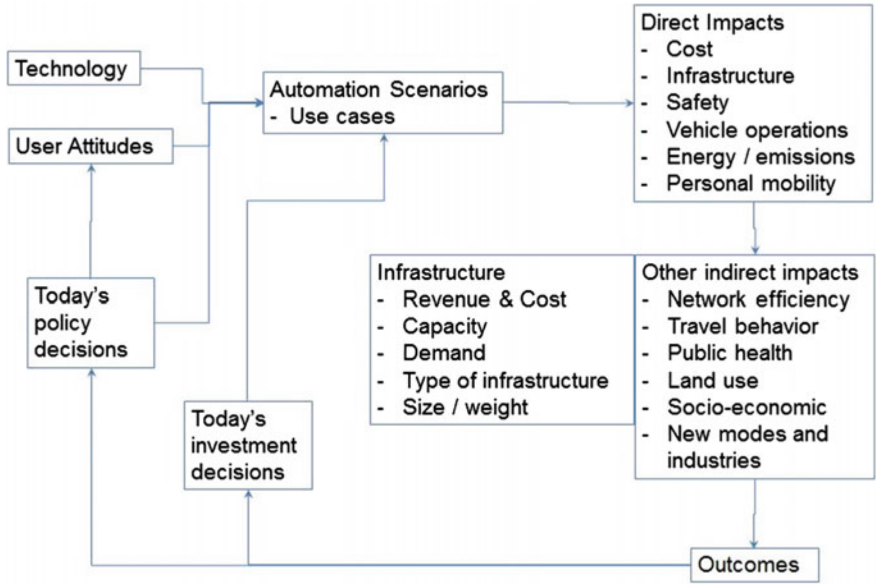


**Fig. 1** Applying systems thinking to automated vehicles' impacts

significant traffic congestion), energy/emissions (oil consumption, air pollution and greenhouse gas emissions are of worldwide concern) and personal mobility (new mobility options for non-drivers). Automated vehicles are being introduced into a complex transportation system. Second order impacts, such as the possibility of increased travel leading to more congestion and emissions, are of significant concern.

Direct and indirect impacts related to automated vehicles can be defined by applying systems thinking to the impacts of automated vehicles (see Fig. 1). It is essential to identify the most important direct and indirect impacts and the main linkages between them. Information on these impacts and their outcomes will enable decision makers and researchers to address the investment and policy decisions needed today to make desired outcomes more likely. The purpose of this chapter is to discuss the direct and indirect impacts of road traffic automation and present two case studies related to different automatization of road transportation and their impacts.

## 2 Direct and Indirect Impacts

Figure 2 (based on Smith et al. 2015) depicts the impact areas. Direct impacts are those which have a relatively clear cause-effect relationship with the primary activity or action. They are generally easier to capture, measure and assess in a field

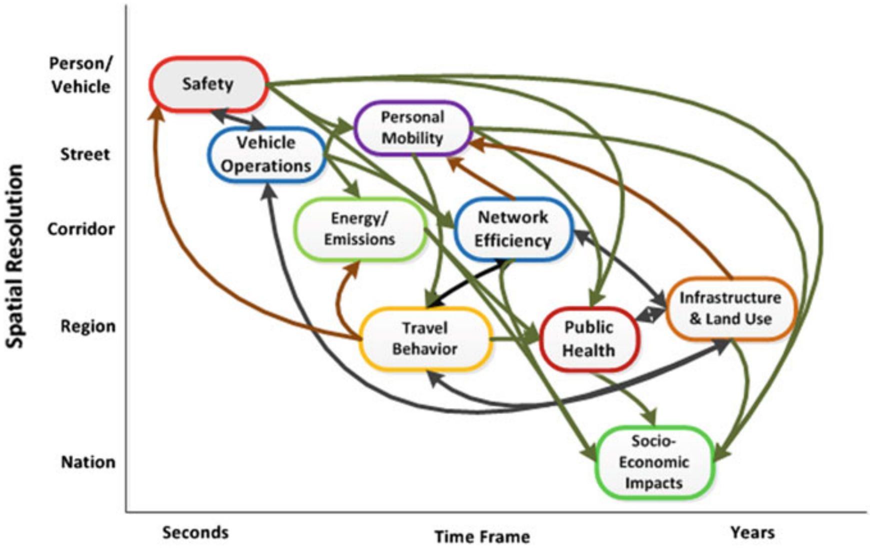


**Fig. 2** Direct and indirect impacts

operational test, and are often (though not always) immediate to short-term in nature. In Fig. 2, they are in the upper left, and include safety, vehicle operations, energy/emissions and personal mobility. The others are indirect impacts. Indirect impacts can be characterized as secondary, tertiary, or still further removed from the original direct impact. Indirect impacts summarize the broader effects of the individual direct impacts and are produced as the result of a path/chain of impacts, often with complex interactions and external factors. They are typically more difficult to measure and are longer than the time horizon of a field test.[1] Impacts are described below.

*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 Level 1 collision avoidance systems to 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 traffic violations, instances where a human driver must take control of the vehicle, exposure to near-crash situations, and responses to near-crash situations.

*Vehicle Operations*: Vehicle operations include acceleration, deceleration, lane keeping, car following, lane changing, gap acceptance: all affect highway capacity.

[1]This explanation is inspired by that of direct and indirect environmental impacts of road development in 'Roads and the Environment—a Handbook' (World Bank 1997).

Relevant automation applications include those, which provide longitudinal and/or lateral control with respect to the road and other vehicles.

*Energy/Emissions*: Energy and emissions 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.

*Personal Mobility*: Mobility from a user's standpoint includes journey quality (comfort), 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 the context of a fleet operation (trucking or transit), it is the direct impact on labor. Is the driver still needed? What are the implications of automation for driver productivity (ability to multi-task or reduced fatigue)?

*Network Efficiency*: Network efficiency refers to lane, link and intersection capacity 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.

*Travel Behavior*: A traveler may respond to AV options, including new service offerings, by changing travel behavior. There may be more trips. Modes and destinations may change. Higher-level automation applications that have a significant effect on personal mobility or labor could have a significant effect on travel behavior.

*Public Health*: Automation may impact the health of communities, via safety, air pollution, amount of walking and bicycling, as well as access to medical care, food, employment, education and recreation.

*Land Use and Infrastructure*: Automation may affect the use of land for transport functions (e.g., parking, road geometry). Longer-term land use changes may include location and density of housing, employment and recreation. Automation may also affect infrastructure assets required in several ways:

- Number of lanes and lane widths
- V2I infrastructure used by automation
- Size and weight implications of changed fleet composition
- Effect of travel behavior changes on trip making

*Socio-Economic Impacts*: Improved safety, use of time, freight movement, travel options for 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 labor markets and industries.

## 3 Use Case: Low Speed Shared Shuttle

Within level 4 of the Society of Automotive Engineers (SAE) J3016 standard (SAE 2016), one can classify two different broad varieties of automated vehicle. The first is a vehicle that is human driven some of the time but capable of operating without the need for driver input or attention on particular roads. The second variety is vehicles that are designed never to have a human driver in normal operation; these are capable of navigating a route and safely dealing with any hazards it may encounter. However, these vehicles are geo-fenced, restricted to specific areas of operation and cannot operate in an automated manner outside of those areas. An example is the Heathrow Ultra Personal Rapid Transit system, which began operation 2010 and transports passengers in fully driverless pod vehicles between Terminal 5 and one of two user selected car parks using dedicated infrastructure. As software and sensors improve, automated vehicles of this nature are starting to be operated in more complex, unsegregated environments. By constraining the task, the technical requirements to deliver a workable solution are simplified and creating a vehicle capable of meeting the specification is commensurately more achievable. As a result, low speed shared shuttle vehicles operating in unsegregated pedestrian or low speed traffic environments have begun to emerge.

A prominent project in the development of low speed automated shuttle vehicles was called CityMobil 2, which ran from 2012 to 2016. Automated shuttle vehicles were demonstrated operating on fixed routes in seven European cities (CityMobil2 2016). This project was led by University of Rome, La Sapienza with 45 partners and tested two different types of automated passenger shuttle to demonstrate their viability in supporting urban mobility. More than 60,000 passengers were transported over the course of the project. Following the example set by CityMobil 2 is the GATEway (Greenwich Automated Transport Environment) project in Greenwich, London (Reed 2015). This initiative is led by TRL and co-funded by UK government and industry. It will see seven automated shuttle vehicles, each capable of carrying six passengers, tested as a pseudo-service in the city to explore public trust and acceptance of automated vehicles.

The impact of this service will be assessed in a number of ways. Firstly, there have been workshops with a range of different stakeholder groups to explore their hopes and fears about the introduction of automated vehicles to the city; secondly, participants from these stakeholder groups will be invited to experience the use of the automated shuttle vehicles and their pre- and post-trial attitudes to the system will be explored. Finally, there will be a longer period of continuous daily operation of the shuttle service where longitudinal changes in attitude and use of the vehicles will be assessed.

In the workshop held at the Automated Vehicle Symposium 2016, the direct and indirect impacts of low speed shared automated shuttles were explored and the topics discussed are presented in the following sections.

## 3.1 Assumptions

The following assumptions were made about likely early deployments of low speed shared shuttles:

- They would be integrated with existing city transit networks where travel demand was high and options for new travel systems dependent on significant infrastructure (e.g. tram, light rail) are costly.
- Infrastructure requirements to deploy the vehicles would be minimal.
- They would be relatively low cost to the user (possibly subsidized)—similar or lower cost than a comparable bus fare.
- Although they may operate cautiously, the vehicles drive in a manner that is at least as safe as (and likely significantly safer than) a human operator.
- Vehicles would be electrically powered and accessible for wheelchair users and travelers with push-chairs, luggage etc.

## 3.2 Direct Impacts

Perhaps the fundamental impact of these vehicles operating as a service is that they would increase connectivity to transport hubs, increasing mobility options and potentially reducing the use of private cars to satisfy travel needs. Research is needed to confirm whether this would indeed be achieved in a commercially viable manner. Workshop attendees agreed that the use of these vehicles would increase options for those with additional travel needs, such as disabled and/or elderly people.

An anticipated direct impact was that the use of low speed shared automated vehicles would increase safety for road users. This assumption needs to be validated with such vehicles operating as an integrated part of the transport network. There was also a suggestion that because the automated vehicles behave consistently and predictably and are powered electrically, active travel modes (walking/cycling) would be more appealing. However, it is possible that fewer would choose active travel modes if low cost, flexible, on-demand automated vehicle options were available.

A further impact discussed was the potential for energy use and emissions to reduce through consolidation of travelers onto public transport services. However, discussions suggested the opposite effect could also occur if overall mobility increased. Operation of the vehicle services would also create employment opportunities in the maintenance and management of the vehicle services.

## 3.3 Indirect Impacts

The planning and use of land in city environments was seen as the most important indirect impact of these vehicles, with the opportunity to reclaim space allocated to car parking for alternative uses if low speed shared automated vehicles could be used to meet mobility needs. The potential for residents' health to improve through better air quality if automated electric vehicles displaced combustion engine vehicles for transportation was also discussed.

The ability to connect currently underserved areas with the wider transport network through the deployment of low speed automated vehicle services may have important socio-economic effects, enabling better access to education, employment and healthcare for residents. Consequently, the desirability of those areas may increase, leading to speculation that current residents may be priced out of the market—an unintentional adverse consequence of the vehicle services.

### *3.4 Future Research*

The workshop discussions highlighted that whilst some direct and indirect impacts can be foreseen, there is a need for further research to gain a better understanding of the implications of low speed automated shuttle vehicle deployment. Research projects like CityMobil 2 and GATEway have demonstrated the technical feasibility of operating these vehicles. Further work is required to show how they can genuinely work as an economically viable and fully integrated component of city transport services. This should cover topics such as reliable, secure collection of payments; ensuring occupant safety and comfort (including sharing in a confined space); what size of vehicle/number of passengers is optimal for a particular use case; and how to design route provision to achieve social equity.

## 4 Use Case: Truck Platooning

The second use case is about truck platooning. Several tests with truck platooning have already taken place (for instance, the recent European Truck Platooning Challenge, see Rijkswaterstaat 2016) and more are planned.

To discuss potential impacts, a use case was defined in which platooning trucks have SAE level 4 automation functions. Platoons can be formed on the fly, with trucks from different brands and different haulers. Legislation concerning driving and resting times has been revised. This means that part of the trip, the driver is not considered to be driving, and so the vehicle can be on the road longer before a stop is required. The physical and digital infrastructure have been adapted to enable safe and efficient driving in mixed traffic—there will still be manually operated trucks and cars on the same road. Adaptations can be, for instance, that platoons communicate their path to vehicles that are nearby or that are merging onto the highway.

## 4.1 Direct and Indirect Impacts of Truck Platooning

What kind of impacts can be expected? There have been several studies on the impacts of platooning on energy use and emissions, but other impacts are usually only described in very general terms ('improved safety is expected'). Even if not a lot of quantitative data are available from studies, insight into the possible impacts can be given using the categories of impact described in Sect. 2. The DRAGON project, commissioned by the Conference of European Directors of Roads (CEDR), is now underway and one of the use cases in this project explores the impacts of truck platooning in 2030 (Wilmink et al. to be published). The DRAGON truck platooning use case is slightly different than the one discussed here, as several different levels of automation are assumed to be present on the road (instead of the level 4 vehicles assumed here), but the impacts described are very similar. A summary:

Positive *safety* impacts are expected, due to the presence of full automation or at least advanced driver support systems, which help prevent accidents where, for instance, the driver was distracted. There is, however, a risk of dangerous maneuvers of merging vehicles encountering a platoon.

Substantial *energy use and emission* reductions per distance travelled have been measured on the road, primarily in controlled tests (see, e.g. Tsugawa 2014; Davila 2013). Whether the reductions can be as large in real-world driving depends on the ability of trucks to find other trucks to platoon with (which needs the fleet managers' and drivers' willingness to cooperate), traffic conditions and safety considerations (would platoons have to split up often, to ensure safe driving for all traffic?).

*Personal mobility* may be affected if the truck drivers are able to engage in non-driving activities.

Truck platooning can also have a positive effect on *network efficiency*, especially when trucks not only communicate with the other vehicles in their platoon, but also with other road users and the infrastructure. Also, the trucks drive closer together and so take up less space. However, in busy traffic, truck platoons can be in the way of other traffic, resulting in disturbances that affect road capacity negatively. But, improved safety means less accident-related congestion.

For overall *travel behavior*, there are a lot of uncertainties about the impacts. The number of drivers needed could decrease and asset utilization could be improved. This could lead to a reduction of the transport costs, leading potentially to more freight miles on the road network, and less freight miles by other modes of transport (e.g. rail, waterways, air).

If the emissions are reduced, pollutant concentrations along roads will be reduced and this has a positive effect on *public health*. However, the reduction of emissions per vehicle could be canceled out by the increase in mileage due to lower transport costs.

Impacts on *land use and infrastructure* are also unclear. Some expect dedicated infrastructure for platooning trucks at some time in the future, but in the short term platoons are expected to use the existing infrastructure, possibly with a few modifications such as ramp metering or warning signs on on-ramps, to ensure merging vehicles are not hindered by platoons. This means that upgraded communications infrastructure may be needed for V2V and V2I communication. Another infrastructure issue is the question whether truck platooning will have significant impacts on infrastructure elements such as the pavement (extra ruts because of precise lane keeping?) and bridges and viaducts with long spans (load effects of heavy vehicles driving closely together). Regarding land use, transport companies and/or distribution centers may relocate to locations more suited to truck platooning.

*Socio-economic impacts* also need to be explored more thoroughly. On the cost side, it has been remarked that the costs of the system (at least C-ACC) are small compared to the costs of a truck. There may be an impact on the labor market when fewer drivers are needed—but in many regions, driver shortages are expected within in the next decade and this could mean lower investment costs for driver training. On the other hand, drivers operating a truck platoon may need additional training to ensure safe and efficient operation.

## *4.2 Future Research*

During the breakout session, there seemed to be consensus on the direction of the direct impacts. There was more uncertainty about the indirect impacts. Members of the audience also discussed how field tests could be set up and the performance indicators that they would like to measure and derive for truck platooning. The following performance indicators were mentioned:

- Safety indicators, initially by determining surrogate or proxy measures such as the number of near-crash situations and changes in the behaviour of other vehicles around the platoons
- Fuel consumption
- Vehicle utilization (share of time that truck is in use)
- Driver productivity, including the share of time spent driving, working but not driving, resting
- Need for truck parking areas (which may be reduced if there is less need for trucks to stop)
- Type of trucks and what they're carrying

A baseline would be existing trucking operations. Participants thought that a two-stage field test may be appropriate. The first field test would be focused on vehicle operations (fuel consumption, safety), working with vehicle manufacturers for measurements. The second test would be focused on user issues, for which it would be useful to work with fleet owners.

In order to scale up results from field tests, especially to analyze network efficiency, traffic simulations could be used, especially to explore the impacts in mixed traffic of various compositions. There are some challenges that need to be addressed in order to achieve realistic simulations, for instance the need for real-life descriptions of the microscopic behavior of automated vehicles, realistic representations of manually driven conventional vehicles and the interactions between automated and manually driven vehicles. In particular, we need more information on their lateral behavior. See (Calvert et al. 2017) for more information.

## 5 Discussion

This chapter discusses the direct and indirect impacts of automated vehicles by presenting two case studies related to different aspects of automation: low speed shared shuttle and truck platooning. It is based primarily on discussion at the AVS2016 breakout session on Impact Assessment.

In addition to the specific impact areas and two case studies, discussed earlier, several themes emerged from the session:

- Firstly, impact mechanisms are complex and far-reaching. The impact mechanisms include interactions between direct impacts to indirect impacts, and they vary from short-term impacts to very long-term ones.
- It is necessary to keep in mind that most important impacts are different for different people—a positive impact for one can be negative for someone else.
- It is also essential is to clearly define the use cases and context. This means defining the environment, the time scale, perception, and other parameters. It is a challenge to consider future uncertainty in today's policy and infrastructure decisions.

For future research, it was understood that whilst some direct and indirect impacts can be foreseen, there is a need for further research to gain a better understanding of the implications. For example, for the low speed shuttles further work is required to show how they can genuinely work as an economically viable and fully integrated component of city transport services. In addition, more research is needed for the indirect impacts of truck platooning.

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