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Can the impacts of connected and automated vehicles be predicted?

Rune Elvik, Transportøkonomisk institute, email: re@toi.no

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Abstract

A huge research effort is going on in order to develop connected and automated vehicles. Small-scale trials of automated vehicles in real traffic are already taking place. Can the societal impacts of a transition to fully connected and automated vehicles be predicted? This question has been studied in the Horizon2020 project Levitate. To predict the impacts of connected and automated vehicles, one must first identify and describe potential impacts. A list of 33 potential impacts, classified as direct, systemic and wider was developed. A survey was made of methods that can be applied in order to quantify and predict these impacts. Not all potential impacts can be predicted with any confidence. There is, first of all, large uncertainty about when and how long the transition to connected and automated vehicles will be. It is also impossible to predict some potentially quite important impacts, e.g. whether the transition to automation will be associated with a transition to various forms of shared mobility or whether individual ownership and use of vehicles will continue at present levels. Another important aspect which is difficult to predict is whether automated vehicles will continue to have internal combustion engines or be electric or based on fuel cells. Several methods must be applied to predict the impacts of connected and automated vehicles. As far as impacts on traffic operations are concerned, various forms of traffic simulation have been widely applied. Broadly speaking, connected and automated vehicles are expected to lead to increased road capacity, fewer accidents and less emissions. Increased road capacity may in turn generate induced travel demand, which to some extent will fill up the new capacity. Road safety is likely to be improved, but there is large uncertainty about how non-automated road users and automated vehicles can interact in ways that maintain current safety levels or, preferably, improve safety. It is, for example, not known how non-automated road users will adapt behaviour to automated vehicles.

Sammenfatning

Det pågår omfattende forskning med sikte på å utvikle selvkjørende biler. Forsøk i virkelig trafikk i mindre skal finner allerede sted. Kan man forutsi de samfunnsmessige virkninger av selvkjørende biler? Dette spørsmålet står sentralt i det pågående Horizon2020 prosjekt Levitate, som denne artikkelen bygger på. Det er utarbeidet en liste over mulige virkninger av selvkjørende biler. Til sammen 33 mulige virkninger ble identifisert. Mulighetene for å kvantifisere og predikere virkningene ble undersøkt. Det er ikke mulig å predikere alle virkninger. For det første vet man ikke når de selvkjørende biler kommer på markedet og hvor lang tid det vil ta før de erstatter biler med fører. For det andre vet man ikkde om selvkjørende biler stort sett vil bli benyttet

individuelt, eller om det vil skje en overgang til ulike former for delemobilitet. For det tredje vet man ikke om de selvkjørende biler vil ha forbrenningsmotor eller bli elektriske. For de virkninger der tallfesting og prediksjon er mulig, har en rekke metoder vært benyttet. Ulike former for trafikksimulering er en vanlig metode foir å studere de trafikale virkninger av selvkjørende biler. Det hersker enighet om at selvkjørende biler vil kunne utnytte vegkapasiteten bedre og redusere antall trafikkulykker og forurensende utslipp. Det er fortsatt stor usikkerhet knyttet til hvordan selvkjørende biler kan samhandle med fotgjengere og syklister.

Background and research problem

There are great expectations about the potential societal benefits of connected and automated vehicles (Fagnant and Kockelman 2015, Herrmann, Brenner and Stadler 2018). Vehicle automation and connectivity is expected to reduce congestion, thereby reducing the need for road investments, reduce energy consumption and vehicle emissions and substantially reduce the number of accidents. Fagnant and Kockelman (2015) find that benefits exceed costs by a wide margin.

Other analyses are more skeptical. Thus, Hoadley (2018) note that several of the potential impacts of automated vehicles are not obviously favourable. In particular, an increase in vehicle kilometres and a reduction of walking and cycling goes against current political objectives in many cities.

With respect to safety benefits, the report notes that: "Achieving road safety benefits presumes that systems are always on, always fully operational and will "fail safe". This is a big ask: In 2017, connected cars can be hacked; transport booking systems overbooked; fleet management systems can fail; power and communications systems have outages; components fail; and navigation guidance is not infallible."

These observations are correct. Automated systems need to have a very high reliability in order to perform better than human drivers. However, it should not be forgotten that human operators sometimes voluntarily choose to degrade their performance and erode their safety margins by drinking and driving, speeding, tailgating, or otherwise adopting a behaviour that involves an avoidable risk. Speeding, drinking and driving, and non-use of seat belts contribute to about 30-40 % of all traffic fatalities, and automated vehicles may eliminate this contribution.

What are the potential impacts of connected and automated vehicles? How well known are these impacts? Can they be quantified? Can uncertainty be indicated? Are some impacts more uncertain than other impacts? Can the impacts be converted to monetary terms as a basis for cost-benefit analysis?

This paper will discuss these questions based on research conducted in the H2020 project Levitate (Societal impacts of connected and automated vehicles). The paper is to a large extent based on three deliverables of the Levitate project (Elvik et al. 2019, Elvik et al. 2020, Elvik 2020).

A taxonomy of potential impacts

A taxonomy of potential impacts of connected and automated vehicles was developed by synthesising previously published taxonomies of potential impacts of connected and automated vehicles. Impacts were classified along two dimensions:

1. Their spatial and temporal extent of occurrence.
2. Whether they are intended (primary) or unintended (secondary).

Table 1 lists the impacts that were included in the taxonomy. With respect to the first dimension, a distinction was made between direct impacts, systemic impacts and wider impacts. Direct impacts are noticed by each road user on each trip. An example is changes in travel time or in monetary outlays associated with making a trip. Vehicle ownership cost was classified as a direct impact since it is noticed by each vehicle owner when buying and keeping a vehicle. Seven direct impacts were identified.

Table 1: Potential impacts of connected and automated vehicles

Impact	Description of impact
Direct impacts (micro)	
Travel time	Duration of a trip between a given origin and a given destination
Travel comfort	Subjective rating of the level of comfort on a given trip
Valuation of time	Willingness-to-pay for reduced travel time
Vehicle operating cost	Direct outlays for operating a vehicle per kilometre of travel
Vehicle ownership cost	The cost of buying and keeping a vehicle
Access to travel	The opportunity of taking a trip whenever and wherever wanted
Individual route choice	Technology to support route choice on a given trip
Systemic impacts (macro)	
Amount of travel	Vehicle kilometres or person kilometres of travel per year in an area
Road capacity	The maximum number of vehicles that can pass a section of road per unit of time
Congestion	Delays to traffic as a result of high traffic volume
Infrastructure wear	The rate per unit of time at which is road is worn down
Infrastructure design	Equipping roads with technology for vehicle-to-infrastructure communication
Modal split of travel	The distribution of trips between modes of transport
Optimising route choice	Directing traffic to routes that minimise overall generalised costs of travel
Vehicle ownership rate	Percent of household owning 0, 1, 2, etc. vehicles
Shared mobility	Car sharing or ride sharing; shared use of a vehicle by many users
Vehicle utilisation rate	Share of time a vehicle is used; share of seats in use
Parking space	Areas designated to parking
Traffic data generation	Data produced by connected and automated vehicles
Wider impacts	
Trust in technology	Share of population willing to use connected and automated vehicles
Road safety	Number and severity of accidents
Propulsion energy	Source of energy used to move vehicles
Energy efficiency	Rate at which propulsion energy is converted to movement
Vehicle emissions	Emissions (by chemical) in micrograms or grams per kilometre driven
Air pollution	Concentration of pollutants per cubic meter of air
Noise pollution	Number of individuals exposed to noise above a certain threshold
Public health	Population incidence of morbidity and mortality; subjectively rated health state
Employment	Number of people employed in different occupations
Geographic accessibility	Time used to reach given destinations from different origins
Inequality in transport	Skewness in the distribution of travel behaviour according to social status
Commuting distances	Length of daily trips to and from work
Land use	Density of land use for different purposes
Public finances	Income and expenses of the public sector

Systemic impacts are system-wide impacts occurring within the transport system. These impacts include, for example, changes in road capacity and congestion and changes in the modal split of travel. A total of twelve systemic impacts were identified.

Wider impacts may originate in the transport system but occur mainly outside the transport system in society at large. Examples of wider impacts are changes in employment and land use. A total of fourteen wider impacts were identified. In total, Table 1 lists 33 potential impacts.

It should be noted that there is an element of arbitrariness in any taxonomy. As an example, consider the potential impacts of connected and automated vehicles on road safety. An accident can be classified both as a direct impact (it happens to a road user on a given trip), as a systemic impact (it will normally delay other traffic), and as a wider impact (some impacts of accidents occur outside the transport system, like medical treatment and rehabilitation).

Some impacts form clusters. Thus, propulsion energy, energy efficiency, vehicle emissions, air pollution and public health, are closely related to each other and can be regarded as a causal chain. In a case like this, it is the end of the causal chain, changes in public health, that is of greatest interest.

The potential impacts of connected and automated vehicles can be both intended and unintended. Intended impacts are referred to as primary. The intended impacts include: increased road capacity, less travel delay, fewer accidents and less pollution. Connected and automated vehicles are widely believed to bring about all these impacts. However, new technology often leads to behavioural adaptation that partly offsets its intended impacts. Vehicle automation may, by reducing the generalised costs of travel, induce increased travel demand and a shift from walking, cycling and public transport towards individual use of cars. Many city governments are aiming for exactly the opposite: less individual use of cars and more walking, cycling and travel by public transport.

Litman (2020) states that: “It could go either way. By increasing non-drivers’ vehicle travel, increasing travel convenience and comfort, reducing vehicle operating costs, generating empty travel, and encouraging longer-distance commutes and more sprawled development, they (automated vehicles) can increase vehicle travel. … Alternatively, autonomous operation may facilitate vehicle sharing, allowing households to reduce vehicle ownership and vehicle travel.”

It is likewise uncertain whether automated vehicles will be electric or run on fossil fuels. Electric cars are becoming more competitive and cheaper to operate. It would therefore seem more likely than not that automated cars will be electric.

Quantifying and assigning monetary values to impacts

One of the research objectives of Levitate is to conduct cost-benefit analyses of policies intended to ensure that connected and automated vehicles are introduced in a way that maximises their societal benefits. In order to perform such analyses, the potential impacts of connected and automated vehicles must be quantified and converted to monetary terms. Furthermore, there must be a method for developing policy options that enables identification of the policy option that maximises the societal benefits of connected and automated vehicles.

Table 2 classifies the potential impacts of connected and automated vehicles identified in Table 1 with respect to whether they can be quantified and converted to monetary terms (Elvik et al. 2019, Elvik et al. 2020, Elvik 2020). It is seen that most impacts can be quantified, and a majority of impacts converted to monetary terms. However, a universally accepted scale for quantification does not always exist. Thus, travel comfort is to a large extent a subjective experience; what one traveller finds quite comfortable another will find uncomfortable. Factors that have been found to influence the feeling of comfort, like temperature, humidity, noise level and bumpiness can be quantified, but people react differently to these factors and will therefore have different opinions about the importance of changing them.

The modal split of travel is another case in point. It is often quantified in terms of the percentage distribution of trips between different modes of travel. The percentage of trips on foot or by bike may then be quite high. If, however, modal split is quantified in terms of kilometres travelled, the percentage done on foot or by bike will usually be very low.

Other impacts are multidimensional, like individual route choice. On a holiday trip, a route may be taken for its scenic beauty, not because it is the shortest route. Thus, travel time, vehicle operating cost, scenic beauty and availability of roadside rest areas are just some of the characteristics of a route. While most of these characteristics may be quantified, a meaningful conversion of them to monetary terms is difficult.

The amount of travel can be quantified as person kilometres. The monetary impacts associated with travel are the generalised costs of travel, which is the sum of all sacrifices made when travelling, converted to monetary terms, and the benefits of travel. The latter are usually stated in terms of the consumer surplus. In most cases, the consumer surplus associated with a certain amount of travel will be unknown. This is because the demand function for travel is unknown. It is usually only possible to estimate the change in consumer surplus associated with a change in the generalised costs of travel which leads to a change in the amount of travel.

No monetary valuation has been assigned to road capacity. It is assumed that changes in road capacity, or a more effective utilisation of it, are manifested in terms of changes in the amount of travel or travel time and thus captured by the monetary valuation of these impacts.

Monetary valuations are missing for some important wider impacts of connected and automated vehicles. This includes trust in automation technology, changes in employment, changes in inequality in transport and changes in land use. If trust in the technology breaks down, in particular when connected and automated vehicles are already in widespread use, the whole transport system may cease to function. This would obviously have very extensive societal impacts. One cannot image that society will keep a ”backup” transport system relying on manual vehicles. Thus, relying on a technology that is exposed to the risk of cyber attacks makes the transport system more vulnerable.

Vehicle automation may have extensive impacts on employment. When full automation is attained, drivers will no longer be needed. A lower number of accidents means less business for car repairs and vehicle insurers. If automated vehicles comply with all rules of the road, traffic police will no longer be needed. Worries about technology taking away jobs are not new; yet in the long run they have been found to be groundless. Not more than hundred years ago, more than half the work force was employed in agriculture. Today, the percentage is less than 2 % in many countries. Nobody deplores the enormous productivity growth in agriculture; it has benefitted everybody. It is the nature of economic development that the structure of employment changes. In 1930, there will still quite a few blacksmiths serving horses used in agriculture, but no computer engineers or software programmers. Today there are no blacksmiths, but lots of computer engineers and programmers.

One of the potential benefits of automated vehicles is that they make independent mobility possible for people who cannot drive a car. This will reduce inequality in the access to mobility. On the other hand, automated cars are expected to be more expensive than current cars and, at least initially, only affordable for the wealthiest. This may increase inequality in transport. No matter whether inequality is reduced or increased, it is impossible to assign a monetary value to it. One may perhaps assume that there is a widespread preference for less inequality. However, whether such a preference exists and whether it can be meaningfully expressed in monetary terms is not clear.

Table 2: Potential impacts of connected and automated vehicles that can be quantified and converted to monetary terms

Direct impacts	Quantification (yes/no)	Monetary valuation (yes/no)
Travel time	Yes	Yes
Travel comfort	No standard scale	Perhaps
Valuation of time	Yes	Yes
Vehicle operating cost	Yes	Yes
Vehicle ownership cost	Yes	Yes
Access to travel	Yes	Perhaps
Individual route choice	Aspects of it	No
Systemic impacts		
Amount of travel	Yes	Yes
Road capacity	Yes	No
Congestion	Yes	Yes
Infrastructure wear	Yes	Yes
Infrastructure design	Yes	Yes
Modal split of travel	Yes	No
Optimising route choice	Yes	Yes
Vehicle ownership rate	Yes	No
Shared mobility	Yes	Yes
Vehicle utilisation rate	Yes	Yes
Parking space	Yes	Yes
Traffic data generation	Yes	No
Wider impacts		
Trust in technology	Yes	No
Road safety	Yes	Yes
Propulsion energy	Yes	Yes
Energy efficiency	Yes	Yes
Vehicle emissions	Yes	Yes
Air pollution	Yes	Yes
Noise pollution	Yes	Yes
Public health	Yes	Yes
Employment	Yes	No
Geographic accessibility	Yes	Yes
Inequality in transport	Yes	No
Commuting distances	Yes	Yes
Land use	Yes	No
Public finances	Yes	Yes

Finally, changes in land use are difficult to predict and convert to monetary terms. Litman (2020), for example, states that with current policies vehicle travel and urban sprawl are likely to increase. As noted above, many city governments want to curb urban sprawl, discourage individual use of cars and encourage walking, cycling and public transport. More compact cities, i.e. cities with shorter mean travel distances, may promote public health (Stevenson et al. 2016). Improved public health may in turn be converted to monetary terms. Yet, it is not a priori clear whether building more compact cities maximises the benefits of connected and automated cars. Land, and house building, is more expensive in cities than in the countryside. Making cities more compact is therefore a matter of weighing costs and benefits.

How have impacts been quantified?

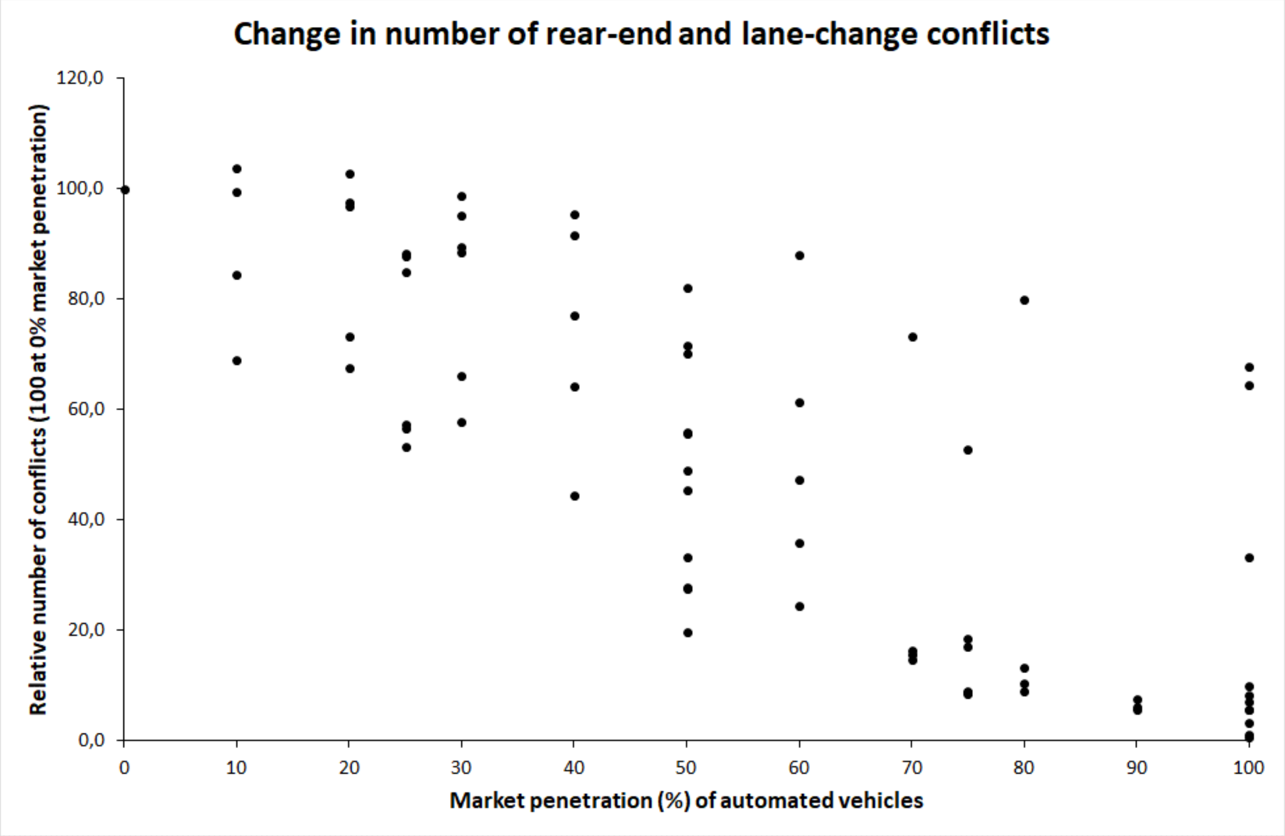
One widely applied method for studying potential impacts of new vehicle technologies, in particular with the aim of quantifying impacts, is traffic simulation. The results of traffic simulation studies and mathematical models of traffic are strongly influenced by the assumptions made. Given the sensitivity of the results of simulations to the assumptions made; and given the fact that these assumptions vary between studies, one might wonder whether trying to formally synthesise the results of simulation studies makes sense at all. This paper argues that it makes sense if the results are consistent and if functions fitted to the results are a fair summary of them.

An example: Safety on motorways

In traffic simulation studies, traffic conflicts are usually used as indicator of safety. Various studies have tried to find formulas for converting the number of conflicts to an expected number of accidents. No such conversion was attempted in LEVITATE. It was judged that the analyses were more replicable in future research by stating results in the metric used by original studies. The definition of a conflict most commonly used is time-to-collision below a certain threshold, often 1.5 seconds. The time to collision is the time remaining before two road users collide if they do not change speed or direction.

A number of studies made by Kockelman et al. (2016), Olia et al. (2016), Li et al. (2017), Rahman et al. (2018), Yang et al. (2018), Papadoulis et al. (2019) and Rahman et al. (2019) have simulated changes in the number of rear-end and lane-change conflicts on motorways as a result of the introduction of connected and automated vehicles. Figure 1 presents data points extracted from these studies.

Figure 1: Change in rear-end and lane-change conflicts associated with vehicle automation

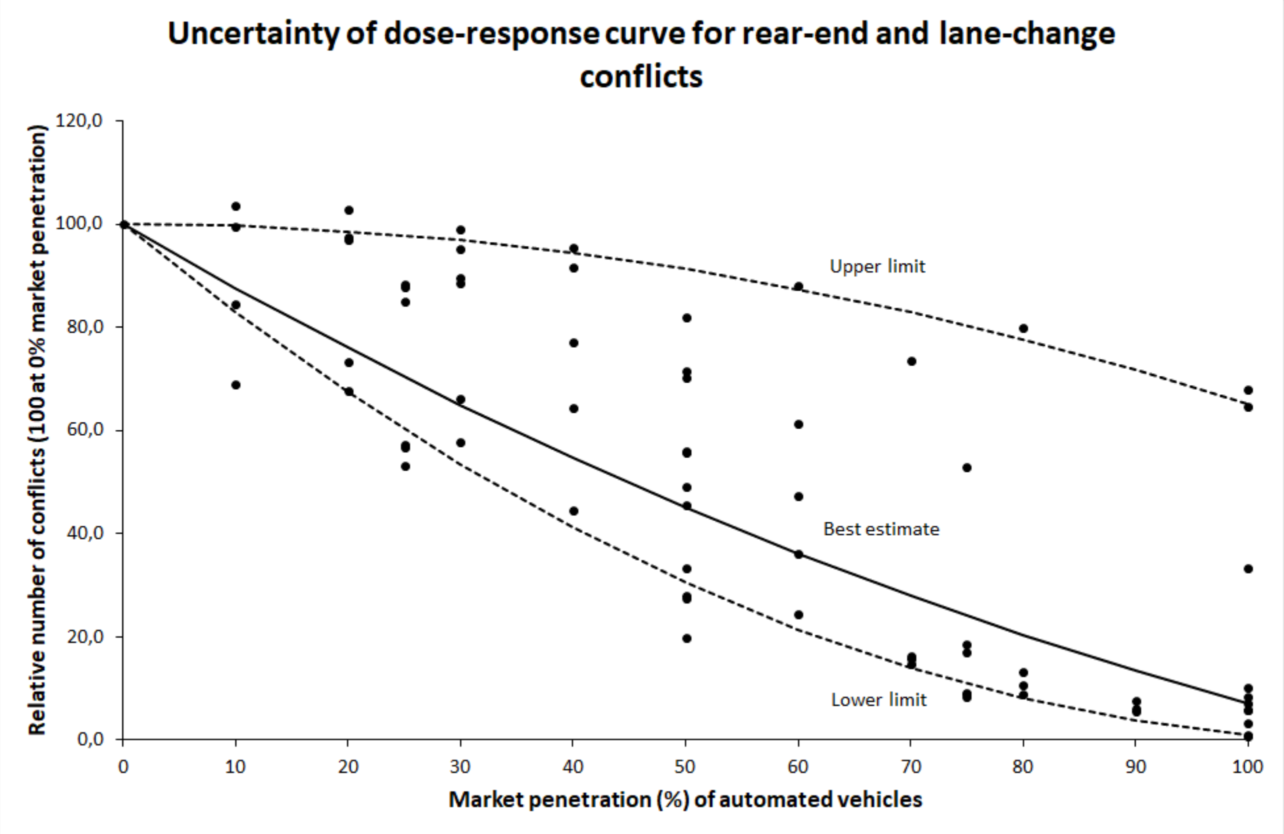


The data points are widely dispersed, but consistently indicate that the number of conflicts will be reduced at high levels of market penetration of automated vehicles. There is a cluster of data points indicating that conflicts will almost be eliminated at 100% market penetration, and three data points indicating smaller reductions of the number of conflicts. To summarise the main tendency of the studies and indicate uncertainty, curves were fitted to the data points applying the following rules:

1. The form of the function best fitting the data points was identified. The following functional forms were compared: linear, exponential, power and polynomial. Goodness-of-fit was assessed in terms of R-squared.
2. The parameters of the best-fitting function were adjusted so that it had an initial value of 100 at 0% market penetration and a predicted value equal to the median value of the data points at 100% market penetration.
3. Functions representing the lower limit for the change in the number of conflicts and the upper limit were fitted, using the same functional form as for the best fitting function.

A second-degree polynomial was found to best fit the data points. A third- degree polynomial fitted marginally better. It was rejected because it indicated an increase in the number of conflicts at high market penetration rates for connected and automated vehicles, which is implausible. The second-degree polynomial was adjusted to start at the value of 100 at 0% market penetration and end at the median value of the eleven data points for 100% market penetration, which was 7.1. Upper and lower curves were fitted so as to include most data points. Figure 2 shows the curves that were fitted.

Figure 2: Uncertainty in dose-response curve for rear-end and lane-change conflicts



While some data points are located outside the upper and lower limit curves, these curves pass close to the data points and are therefore a representative summary of the dispersion of the data points. Thus, even when data points are as widely dispersed as this case, it is possible to summarise their main tendency and the uncertainty surrounding this by means of dose-response curves.

It is nevertheless striking that the results of the studies are so widely dispersed. One might think that motorways are the easiest type of traffic environment for introducing connected and automated cars. There are no at-grade junctions, no sharp curves and no steep hills. There are no pedestrians or cyclists or slow-moving motor vehicles. In normal traffic operations, cars move in the same direction at roughly the same speed. Except for running off the road, the only conflicts that may occur are those involving rear-end collisions and lane changes. These conflicts involve only changes in relative speed and changes in direction. Yet, the estimates of the reduction in conflicts, applying the curves in Figure 2, range from 35% reduction to 99% reduction, with 93% reduction as the best estimate. This range should not be interpreted as a confidence interval in the statistical sense. It is rather a manifestation of the huge differences in results that may arise as a result of the choice of parameters in traffic simulation.

There is currently no business standard for parameters like acceleration, deceleration, headway or space required for a lane change. At some point such standards will have to be developed. Otherwise cars from different manufacturers may behave very differently and not interact efficiently or safely.

How can impacts be valued in monetary terms?

Monetary valuations should ideally speaking include all potential impacts of connected and automated vehicles in order to support cost-benefit analyses. As noted above, monetary valuations are lacking for a number of important impacts. Currently available monetary impacts can be placed in three main groups:

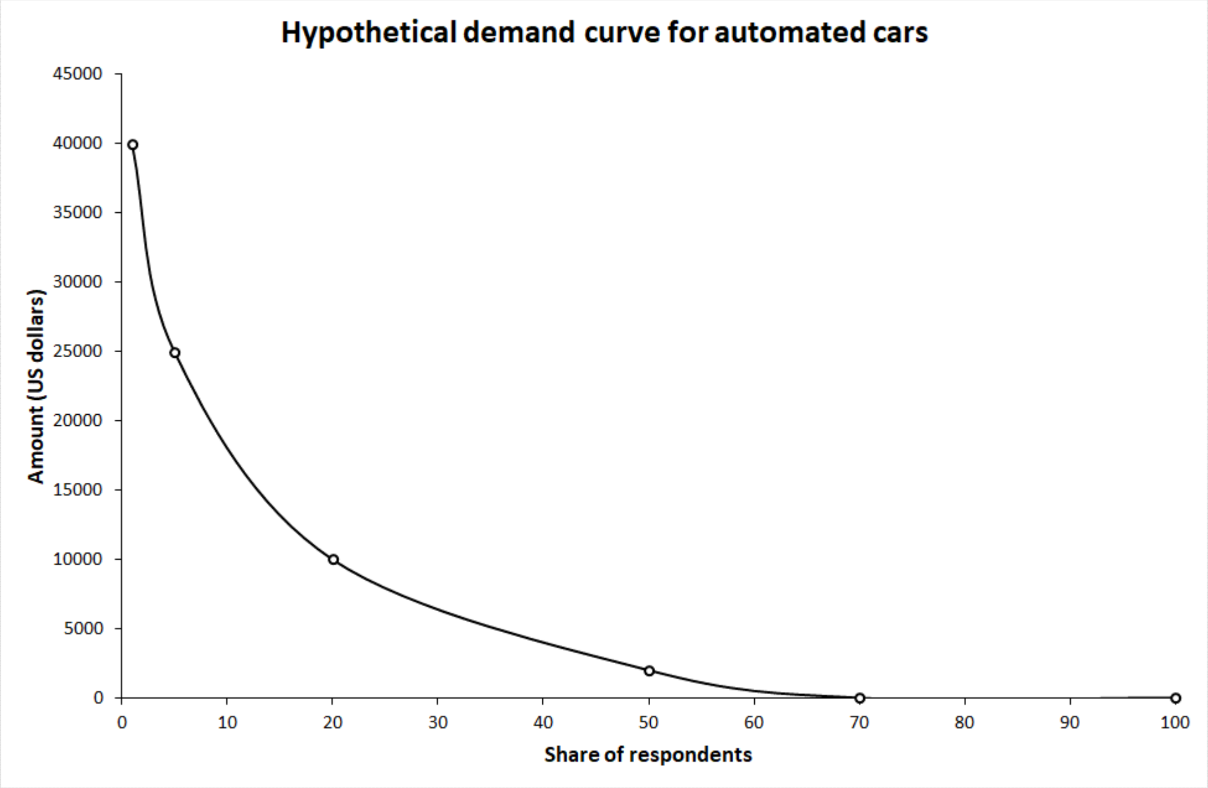
1. Valuations of the societal impacts of connected and automated vehicles, such as changes in travel time, in the number of accidents and vehicle emissions.
2. Estimates of the costs of connected and automated vehicles.
3. Estimates of willingness-to-pay for connected and automated vehicles.

Valuations of potential impacts on travel time, accidents and emissions are available at the European level, and, for accidents and travel time, for each European country (Wardman et al. 2016, Wijnen et al. 2017, Essen et al. 2019). For these impacts, recommended valuations have been developed. It is nevertheless necessary to make a choice about whether to apply country-specific valuations or average values for Europe. This choice can make a big difference for the results of cost-benefit analyses. If country-specific values are used, benefits will have a lower value in countries with a relatively low income (e.g. Greece or Portugal) than in countries with a comparatively high level of income (e.g. Luxembourg, Norway).

Estimates of the costs of automated vehicles vary considerably, but most studies estimate that an automated car will be between 10,000 and 40,000 US dollars more expensive than a manual car. This is a considerable increase in the price of a car. In 2014, the average price of a new car sold in the United States was about 34,000 US dollars. The price of a new car would more than double if the high cost estimate of 40,000 US dollars turns out to be correct.

Would there be demand for automated vehicles if they are priced 10,000 to 40,000 US dollars above current cars? Several studies have tried to estimate willingness-to-pay for automated cars. Elvik (2020) summarises these studies. Results vary, but the range of estimates is narrower than most studies of hypothetical willingness-to-pay find. A demand function which indicates the typical results of the studies is shown in Figure 3.

Figure 3: Hypothetical demand curve for automated cars



Even at an additional price of 40,000 US dollars, a few people would be willing to buy an automated car. If the increase in price is 10,000 US dollars, 20% of respondents in willingness-to-pay surveys indicate that would buy the car. About 30% of respondents indicate zero willingness-to-pay. This group probably includes passionate drivers who are not willing to give up driving manually. An issue which has been discussed, is whether manual driving should be banned once automated cars can be shown to be safer than manual cars (Sparrow og Howard 2017, Müller og Gogoll 2020). The main argument for banning manual driving is that it is an avoidable, and therefore unacceptable, risk once automated cars are safer. However, avoidable risks are tolerated today. Riding a motorcycle is an avoidable risk, but it is permitted. It seems unlikely both that motorcycles will be automated and that there will be a market for them if they were to be automated. If avoidable risks are to be banned, motorcycles should have been so long ago.

However, the fact that moral philosophers are discussing a ban on manual driving shows that the introduction of automated vehicles may raise several difficult policy choices. At the current state of knowledge, all these choices are made under uncertainty, i.e. while many of the potential impacts of connected and automated cars can be identified, both the direction and magnitude of many impacts remains uncertain, and probability distributions of likely impacts cannot be developed, as the probability of most potential outcomes – for example a growth in traffic volume – depends on policy choices. Hence, policy guiding the introduction of connected and automated vehicles is made under uncertainty. It is well-known that normative criteria of rationality, i.e. rules for identifying the ”best” choice in a set of alternative choices, break down under uncertainty (Dorfman 1962). Policy guiding and regulating the introduction of connected and automated cars will resemble a process of trial-and-error, or learning-by-doing, rather than a well-controlled and fully planned process.

It seems more likely that non-automated driving, of both motorcycles and cars, will continue to be permitted. A principle of not allowing avoidable risks is difficult, if not to say impossible, to implement consistently. It implies, for example, that all vehicles must be of equal mass, as differences in mass generate external risks that can be avoided by eliminating differences in vehicle size and weight.

Discussion and conclusions

The paper started by asking if the impacts of connected and automated vehicles can be predicted. The answers to the question is that many of these impacts depend on the policies implemented to regulate the introduction of connected and automated vehicles. This applies particularly to two of the impacts that are difficult to predict: whether vehicle automation will be associated with a transition to electric vehicles, and whether it will be associated with a transition to shared mobility.

It is more likely that automated cars will be electric than that they will have combustion engines. However, to make a transition to electric cars more likely and speed it up, policies favouring electric cars may be necessary. Norwegian experience shows that a transition to electric cars can be stimulated by public policy.

Studies (e.g. Clayton et al. 2020) consistently show that individual use of automated cars is preferred to shared use. If the introduction of connected and automated cars is left to the market, it is likely that individual car ownership will continue at current rates. In that case, traffic is likely to increase, as the generalised cost of travel will be lower in automated cars than in manual cars, chiefly because the value of travel time savings is likely to become lower. Travel time is less burdensome and less wasted if it can be used to work or relax. An increase in traffic will reduce the benefits of connected and automated cars in terms of less congestion, fewer accidents and less emissions.

If this prediction is accepted, policies aimed at maximising the societal benefits of connected and automated cars may, perhaps paradoxically, need to counteract some of the private benefits of these cars. Experience shows that whenever transport becomes cheaper and more convenient, the demand for it increases. In economic terms, the societal benefit of an increase in travel demand is the increase in consumer surplus associated with it. However, as noted, an increase in travel demand increases the external impacts of travel in terms of congestion, accidents and pollution.

Estimates of impacts made in Levitate suggest that even if there is an increase in traffic volume, there will still be a net gain in travel time, a reduction of accidents and a reduction of pollution. While the reductions are smaller than they would have been without increased traffic volume, they are not eliminated. Thus, all potential impacts remain favourable. In view of this, it is unlikely that policy makers will introduce controversial and often unpopular measures like road pricing or parking restrictions to curb the growth of traffic.

It is concluded that, at the current state of knowledge, it is predicted that connected and automated vehicles will lead to increased travel demand, but nevertheless reduce travel time, make travel time less wasteful, reduce accidents and reduce pollution, including global warming.

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