The economic and social impacts of fully autonomous vehicles

While many people see autonomous vehicles as the solution to reduce congestion, traffic accidents and greenhouse gas emissions, others believe this technology will result in a loss of jobs in many sectors. Taking a holistic view on this technology, by taking both positive and negative impacts into account and converting them into societal costs and benefits, can result in new insights. This article provides a snapshot of these potential societal costs which can be used by governments, car manufacturers and other stakeholders as a starting point for discussing how to ensure this technology will optimally benefit all of us.

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INTRODUCTION

Autonomous vehicles (AVs) have the potential to significantly impact society by providing driverless mobility to a broad range of people, from door to door. Not only those who are currently able to drive a vehicle, but also those who don't due to physical, psychological or other conditions will be affected by this new technology. Furthermore, AVs can improve access to mobility to lower- and middle-income classes, as the costs of transportation will be reduced: some experts estimate that this form of transportation will become almost 50% cheaper compared to current costs ([KPMG15]), meaning that this form of transportation might be cheaper than public transport.

This new technology can bring many benefits to society, as experts estimate that AVs can drastically reduce travel time due to reduced traffic jams. On top of this, people within the AV who do not drive can be productive during their journey, while being in a much safer vehicle.

However, as with all technologies, there are plenty of downsides. While millions of jobs might be transformed, many will also be lost as demand for human drivers in the transportation sector may disappear. While some jobs such as taxi drivers might disappear completely in the long run, other jobs such as those of police officers might change as they will not be needed anymore for giving speeding and parking tickets.

Autonomous vehicles also have secondary effects. As AVs are expected to be safer than vehicles with human drivers, the chance of getting an accident will be reduced. This reduction in car accidents will impact transport-related sectors such as insurance industries and car repair centers, again impacting millions of jobs. For instance, Tesla is already offering insurance services to its customers as it expects it can offer this at a much cheaper rate than current insurance providers due to the constantly improving over-the-air updates, which make its vehicles safer due to autonomous functions. Furthermore, public transport might become redundant, as AVs will become cheaper than public transport, safer in terms of less accidents, and also could be more comfortable in terms of privacy and hygiene. In fact, during a global pandemic where public transport is hardly used anymore, autonomous vehicles might even be a solution to sustain economic activity while reducing the chance to spread a virus.

Along with the broader movement of the sharing economy, AVs have the potential to be a catalyst of seeing mobility not only as a product (owning a vehicle) but as a service or a combination of these two. The threshold for owners of AVs to rent their vehicle to others will be lowered significantly, as people know who is driving it. As a result, everyone who owns an AV can start their own taxi service or car rental organization: AirBnB for vehicles.

As vehicle production companies are developing this technology, and the public is slowly embracing the concept of autonomous driving, it is important for many stakeholders – including policymakers and mobility-related industries – to understand how AVs might impact society and their business. This article explores how autonomous vehicles have the potential to create and destroy value for society, the economy and the environment both in the United States and in the Netherlands.

THE SOCIETAL IMPACTS OF FULLY AUTONOMOUS VEHICLES

What are the societal (economic, social and environmental) impacts of fully autonomous vehicles? We analyzed a selection of what we believe are key societal costs and benefits for multiple stakeholders. We looked at the following three areas: economic, social and environmental value. Although this has resulted in many high-level calculations, and we realize that the outcomes are highly depending on assumptions about the future, its purpose is mainly to inform how the value shifts between several stakeholders in society are expected to take place to anticipate this change. The numbers are more illustrative than factual and deeper research is needed to also understand interdependencies between impacts. We also recognize that there may be other impacts for society, which we have not included, and invite the readers of this article to add these to the debate on the benefits and costs that AVs bring to better understand which actions to take, to enable optimum benefits for us all.

Fewer accidents

According to the World Health Organization ([WHO18]), 1.35 million people died worldwide in 2016 because of traffic incidents. In fact, more people die as a result of road traffic injuries today than for instance AIDS. The importance of this is underpinned by the United Nations (UN), who have incorporated ambitious goals to reduce road traffic deaths and injuries within the UN Sustainable Development Goals.

Not only do road safety incidents result in injuries and fatalities, vehicles will also be damaged, resulting in unwanted costs for users or insurance companies. There are, however, benefits for other stakeholders, such as car servicing and repair centers and car (parts) manufacturers. AVs will impact the way how these costs and benefits are divided between stakeholders.

In 2010, the cost of motor vehicle crashes in the United States alone was estimated at a staggering $836 billion. Of this, $242 billion was linked to economic damage, including $57.6 billion in lost workplace productivity. The cost due to loss of life and decreased quality of life due to injuries was estimated to be almost $600 billion ([NHTS15]).

In the Netherlands, the social costs of road crashes in the Netherlands in 2018 are estimated at 17 billion euros, more than 2% of the gross domestic product (GDP) ([SWOV20]). Half of these costs are attributed to human costs: costs related to deaths and injuries. Property damage is around 26%, linked to the damage of the vehicles.

There are many underlying reasons for such safety incidents, studies claim, however, that most of the underlying reasons are related to human errors. For instance, distraction during driving is a key factor in vehicle crashes and around 30% of all road deaths in the US are alcohol related ([CDC20]). Some of these human behavior related incidents have the potential to be reduced significantly by autonomous technologies. Making vehicles autonomous, could result in a reduction in road safety incidents, although studies are not always aligned in terms of how much. Some studies estimate that AVs can reduce the chance of a vehicle crash with 33% ([IIHS20]) while others indicate a 90% ([McKin15]) reduction.

Despite this lack of consensus, only a 1% reduction in road safety incidents would – in the US alone – result in a cost reduction of more than $8 billion annually, which implies significant value to be gained from AVs for several stakeholders including the users of the vehicles.

Table 1 provides an overview of the shifts taking place between stakeholders and the change in costs/benefits for those stakeholders.

Improved use of time during travel

The impact on congestion
According to the global traffic scorecard of INRIX, an organization measuring traffic data, which shows information on congestion and mobility trends, citizens in the US lost on average 97 hours a year due to congestion. The cost of this: nearly $87 billion in 2018, an average of $1,348 per driver. Furthermore, the total cost of congestion in the freight sector can be as high as $74 billon a year ([Forb20]) in the US.

In the Netherlands, costs of congestion were estimated at EUR 3.3 to 4.3 billion in 2018 ([KIM19]), which is 0.5% of the Dutch GDP. These are costs related to loss of travel time and loss of productivity due to arriving late at work. Costs related to delays of transport of goods are included in this number, and amount up to EUR 1.1 to 1.4 billion.

There have been many studies on the impact of AVs on congestion and one thing is certain: it is unclear what the impact of AVs will be on congestion.

On the one hand, the more vehicles become autonomous, the more they are able to interact. At a certain level, AVs may be capable of communicating with each other (called vehicle to vehicle technology (V2V)), enabling smoother traffic flow and a higher capacity (because vehicles can drive closer to each other), which will result in less congestion. This will depend on the level of penetration of AVs: the more AVs we will have on the road that are able to communicate, the greater this effect will be. Eventually, so called platoons can be formed, which will enable much closer driving.

On the other hand, AVs could also increase car use and therefore worsen congestion because of:

1. *Increased accessibility.* Those who are not able or qualified to drive may have access to using a fully autonomous vehicle. Some estimate that this will result in an increase of vehicle miles travelled with 14%, potentially worsening congestion ([TRPC16]). This is because AVs could provide new mobility options to millions more Americans: there are 49 million Americans over the age of 65, and 53 million people have some type of disability. In many places, employment or independent living rests on the ability to drive. Automated vehicles could extend this ability and freedom to millions more. One study suggests that automated vehicles could create new employment opportunities for approximately 2 million people with disabilities ([Rude17]). In the Netherlands, similar figures occur, with around 10% of total population being limited in its mobility ([VGZ18]).

Table 1. AVs have the potential to save major societal costs related to traffic related injuries.

Stakeholder	Type	Current cost per year		Potential benefit from AVs *33-90% reduction*	
		US (in bln USD, 2010)	NL (in bln EUR, 2018)	US (in bln USD, 2010)	NL (in bln EUR, 2018)
Vehicle users and their families	Injuries and loss of income	–600	–8.5	+198-540	+2.8-7.6

2. *Travel cost reduction.* autonomous vehicles could result in lower costs, leading to more usage of these AVs ([Metz18]), called rebound effects. A study by KPMG in 2015 revealed that the total cost per mile (including fixed and variable costs) of today's cars are $0,82. Future mobility cars could reduce that cost to $0.43 per mile, almost a 50% reduction ([KPMG15]).

The key question is: what is the driving factor behind congestion and how much of it can be solved by using autonomous vehicles, and how much by other factors such as road capacity and number of vehicles on the road?

The impact on economic use of travel time
The impact of AVs on travel time is not only affected by congestion, but also by the freedom of what people can do during travelling. To illustrate this: on average, people in the Netherlands only get stuck in traffic 1 minute per day ([KIM20]), while the minutes people spend on their commute every day is a lot more: 49 minutes ([CBS17]). It is therefore less relevant to calculate the actual congestion which will be solved by AVs; instead the improved (economic) usage of travel time should be calculated. A recent study stated that automated vehicles could free up as much as 50 minutes each day per passenger in the US that had previously been dedicated to driving ([NHTS20]). For our calculations, we have estimated that users will only spend a part of this time effectively, namely 75%.

As fully autonomous vehicles will enable users to use their time productively during travel, this can save society significant costs. A high-level estimation of the economic impact is provided in Table 2.

Impact on jobs

We will highlight three sectors in which we expect significant impact due to AV technology: workers employed in driving occupations, servicing and repair centers and the insurance industry.

Of all workers in the US, 2,9% are employed in driving occupations. These workers, more than 4 million in total, could potentially lose their jobs due to AVs. The occupations that suffer the most include delivery and heavy truck drivers, bus drivers, and taxi/chauffeur drivers ([CGPS17]). With an average income of around $45,000 per year, the total loss of income amounts to around $180 billion per year.

According to the national statistics agency, more than 600,000 people work in the transport and logistics sector in the Netherlands, which includes taxi drivers, truck drivers and other driving occupations. Taking an average income of EUR 23.2k a year (people with a lower level of education), the total loss of income could amount to EUR 14 billion a year if these jobs would be lost.

The US market size of the motor insurance industry is more than $300 billion ([IBIS20]) annually and EUR 4 billion in the Netherlands ([KPMG18]). A shift can and is already taking place in the integration of insurance services up the value chain, with car manufacturers like Tesla offering their own car insurance for users because they trust the safety of their vehicles. This is based on the current use of autonomous technologies and the expected increase of usage in the future as autonomous technologies are being developed further. A KPMG study in 2015 calculated that there is a potential for a 40% drop in total loss costs in 2040, compared to 2013 ([KPMG15]). This in return will potentially reduce the auto insurance premiums benefiting users of vehicles, eventually leading to a change in income for insurance companies.

There will also be a significant change in income for vehicle service and repair centers. In the US alone, vehicle crashes currently result in $71 billion a year in repair costs. In the Netherlands this figure is around EUR 4 billion. Reducing the number of vehicles crashes with 33-90% can reduce this income with billions of euros or dollars.[1]

1 Note that there will be further impact to this industry, as electric vehicles have fewer moving parts/or vulnerable parts and therefore require less maintenance. This will have an additional impact on the income of the service centers.

Table 2. AVs have the potential to reduce economic costs by making people more productive during their travel. Reduction in congestion is uncertain due to use increase.

Stakeholder	Type	Current cost per year		Potential benefit from AVs	
		US (in bln USD, 2018)	NL (in bln EUR, 2018)	US (in bln USD, 2018)	NL (in bln EUR, 2018)
Vehicle users and their families	Travel time lost due to congestion	–87	–3.3	*Congestion will not decline, but value of (lost) time will change for travelers (see below)*	
Economy	Travel time usage (driving versus other)	–324	–12	+243	+9
Freight	Economic delays	–74	–1.1-1.4	0	0

Table 3. The full implementation of AVs can result in severe societal costs due to loss of jobs.

Stakeholder	Type	Current benefit per year		Potential loss from AVs	
		US (in bln USD, 2017 or 2018)	NL (in bln EUR, 2017 or 2018)	US (in bln USD, 2017 or 2018)	US (in bln USD, 2017 or 2018)
Workers in driving occupations	Income	+180	+14	–180	–14
Insurance industry	Income	+300	+4	*A shrink of up to 40% of the current size. Note that a secondary effect can occur in a shift in value towards car manufacturers* –120	–1.6
Car repair centers	Income	+71	+4.4	–24-64	–1.5-4.0

Environmental impact: greenhouse gas emissions

More than a quarter of all greenhouse gas emissions in the US come from the transportation sector. AV technologies can have both positive and negative impacts on these emissions.

AV technology can improve the energy use of vehicles by improving the way vehicles brake and accelerate according to the department of energy ([Worl16]), eventually resulting in a reduction of emissions by 90%.

On the downside, automation would make car travel easy, which may encourage extra trips and commuters deciding to move farther away from work knowing they could be spending their time on something else other than driving. Although true for passenger vehicles, this effect seems less likely to occur for the transport of goods and bus-passengers. Both of these transportation vehicle types are also responsible for a significant portion of the greenhouse gas emissions in the US and the Netherlands. A summary of potential cost implications is shown in Table 4, in which the social costs of global warming have been calculated based on the social cost of carbon from the US Environmental Protection Agency ([EPA16]) and the potential benefits from AVs to reduce these ([EPA20], [CBS20]). We've assumed a potential reduction of 90% for truck emissions due to efficiencies.

Note: AVs will have an effect on the CO_2 emissions of vehicles, because most of these AVs are electric. This electrification will have an effect on CO_2 emissions, and will depend amongst others on the energy source from which the energy is produced: renewable versus non-renewable. Furthermore, the production of AVs will have a different environmental impact when compared to gasoline vehicles due to the use of different materials such as lithium batteries. Therefore, the full lifecycle of these vehicles should be taken into account to determine the actual environmental impact including greenhouse gas emissions. For further readings see for instance "The Underestimated Potential of Battery Electric Vehicles to Reduce Emissions" by Auke Hoekstra ([Hoek19]). Because this research has focused on AV technology only, not electric versus non-electric, we have not taken these wider effects into account.

Impact drivers

Trust in technology: algorithms & security

AVs can only be autonomous if they can make decisions. The technology behind autonomous vehicles is based on algorithms. An algorithm determines what to do when certain situations occur, for example: when a person crosses the street, the algorithm needs to first identify a moving object, then it needs to determine what it is, and thirdly it should determine if the vehicle should slow down (if possible), or steer the vehicle towards another direction to avoid a crash.

Table 4. The effect of AVs on the environment is uncertain for passenger vehicles, as both reduction in energy use and increased usage by passengers may occur.

Stakeholder	Type	Current cost per year		Potential benefit from AVs	
		US (in bln USD, 2007)	NL (in bln USD, 2007)	US (in bln USD, 2007)	NL (in bln USD, 2007)
Environment (passenger vehicles)	Greenhouse gas emissions	–87	–2.1	Unknown (both up and downsides)	
Environment (trucks)	Greenhouse gas emissions	–49	–1.1	+44	+1.0

Important drivers of the acceptance of AV technology are cybersecurity and reliability of the AV systems

The algorithm needs to be programmed and trained to do this. This programming of basic rules is done by people; they decide what the AV will do. To test the effectiveness of these rules, the algorithm is trained by data and testing in real life situations. The results are analyzed by people who then tweak the algorithm's architecture so that it makes better decisions.

A recent article in *Science* indicated that there are many challenges when defining these algorithms, as moral decisions will need to be made for instance when choosing between who will be killed in a crash: the pedestrian crossing the street, or the passenger in the vehicle (called self-sacrifice). Or, how will an autonomous vehicle decide in a split second whether it will drive into two elderly persons or a young child at a high speed? Which of these lives are worth more, and can the algorithm be trained to make this decision? Furthermore, at what level of accuracy do we accept this in society, and will this influence us to eventually use autonomous vehicles?

Programmers currently working on these algorithms were asked how they would deal with these situations in a survey. They indicated that they would not approve regulations mandating self-sacrifice; such regulations would make them less willing to buy an autonomous vehicle ([Bonne16]).

Other important drivers of acceptance are cybersecurity and reliability of the AV systems. Even though AVs may be safer on a per km basis, the question is: what will be the economic and social impacts if a large incident occurs in which multiple AVs are hacked? On top of this, system failures, where the computers or algorithms behind AVs stop functioning, could result in inabilities to drive anymore.

These elements are critical drivers for the other social and economic impacts identified, as it will determine the level of penetration of AVs and therefore the social and economic impacts of AVs.

CONCLUSION

Autonomous vehicles have the potential to impact society significantly in the coming years. On the positive end, the number of vehicle crashes could be reduced, and travel time can be used more effectively which could result in an annual societal benefit of more than $750 billion in the US alone.

Although AVs have the potential to improve energy use of vehicles and therefore reduction in carbon emissions, rebound effects could mitigate this effect due to uptake in use of road vehicles. This could furthermore also mitigate the positive effect AVs could have on congestion. Car sharing, flexible commuting times and working from home are therefore key considerations to optimize the impact AVs may have.

Many sectors will be impacted by the introduction of AVs: not only will jobs disappear in certain sectors, there will be a shift of jobs between different sectors. This effect may result in an annual cost of more than $350 billion annually in the US alone. Transitioning the skillsets of the affected groups is therefore key to avoid such societal costs.

All of these impacts are driven by the acceptance of AV technology. This acceptance will depend on people's trust in the system, including the moral decisions made when developing the algorithms used in AV technologies, as well as the (cyber)security elements and reliability of the systems. Collaboration between different disciplines and stakeholders in the AV space is therefore key, in order to lead to the most optimal transitioning of this new technology!

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