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Exhaustive Investigation of the Promises and Perils of Autonomous Mobility Technology

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Abstract

The technology of autonomous driving systems has the potential to bring significant benefits in terms of safety, mobility, and congestion, as well as land use and energy consumption. In this paper, the authors present both the promises and possible dangers of the large-scale implementation of autonomous vehicle technologies in the current road traffic networks. The effects of autonomous mobility technology are complex and require careful consideration. While there is great potential to transform transportation and offer significant improvements in many areas, there are also risks and challenges that need to be addressed to ensure safe, efficient, and equitable deployment of the technology.

Keywords

autonomous vehicles, sustainable mobility, vehicle safety, road traffic management, intelligent transportation

1 Introduction

Autonomous mobility technology has the potential to transform transportation by providing safer, more efficient, and more convenient options for people to move around. However, with these promises come some perils that need to be carefully considered and addressed.

Among the promises, we can mention the safety, efficiency, convenience, or accessibility aspects of the technology. It is quite clear that autonomous mobility has the potential to reduce the number of accidents caused by human error, optimize traffic flow and reduce congestion while providing on-demand transportation service with improved accessibility (Cao and Zöldy, 2020), however, there are some potential challenges regarding the widespread use of autonomous mobility as well. The issue of cybersecurity, the questions that will arise concerning liability, the negative impact on the labor market, or social equity problems are just a few, but perhaps the most important viewpoints that will be assessed in the present study.

In the following parts of the study, starting with Section 2, we will provide a detailed description of the safety aspects of the technology. Section 3 will cover the effects on overall mobility, while Section 4 will discuss the impact on everyday traffic congestion. Additionally, Section 5 will detail the spaces that will be freed up, Section 6 will address the important aspect of overall energy consumption and emissions, and finally, Section 7 will conclude by discussing how the entire transport system will be transformed.

2 Effects on road traffic safety

Although the frequency of road accidents is constantly decreasing, such incidents remain a major problem in global public health (Bureau of Transportation Statistics, 2023). Every year, about 1.35 million people die from traffic accidents worldwide, and between 20 and 50 million people suffer some kind of injuries, imposing billions of euros of private and social costs.

In the European Union (EU), in 2016, more than 2 million road accidents were registered, which led to more than 1 million injuries and more than 18,900 deaths, representing a total of about 500 billion euros. of costs (Blincoe et al., 2015). While across the EU Member States, there was a decrease in accidents of about 36% in the last decade, the overall target to halve the number of deaths related to traffic accidents by 2030, is still a long way to go.

The upper graph of Fig. 1 shows the variation graph of the number of deaths, accidents, and injuries related to

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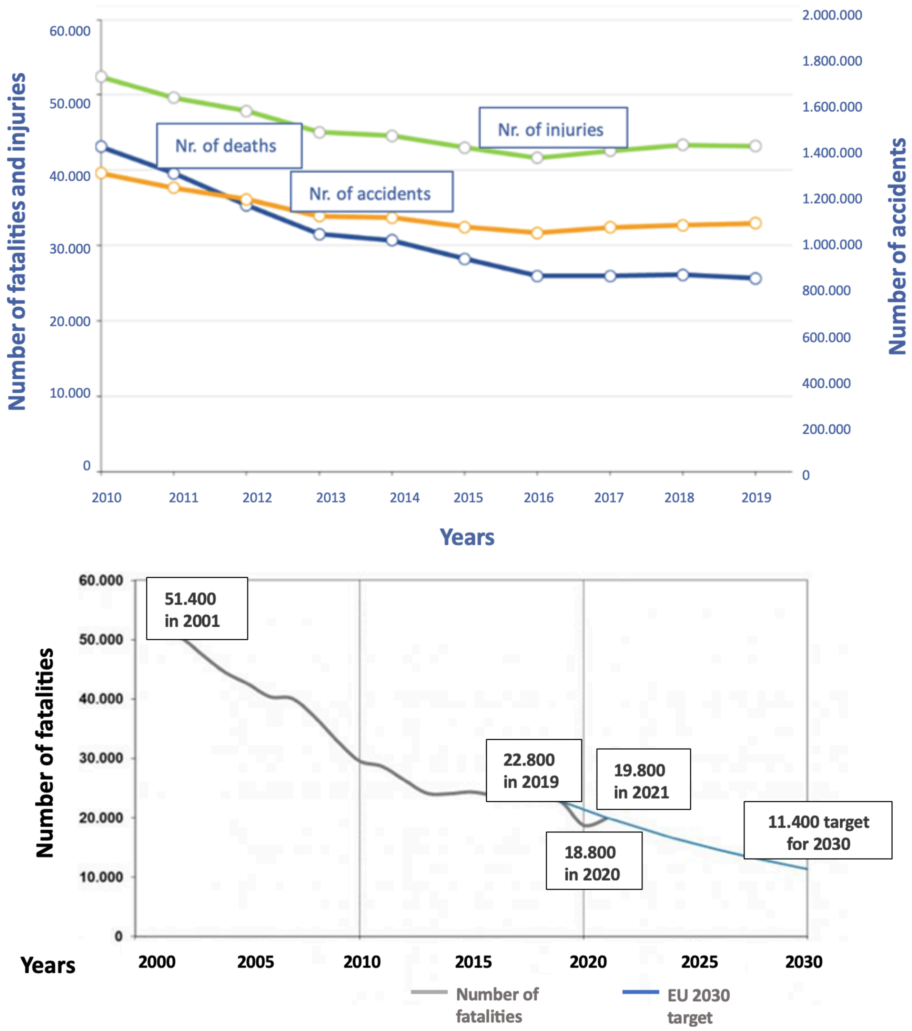

Fig. 1 Downward trend in the number of road traffic fatalities in the EU (adapted from European Commission, 2023)

road traffic between 2007 and 2016 in the member countries of the European Union. It can be seen that the number of the three parameters decreases as the years progress, especially the number of deaths, from almost 45,000 to about 35,000. This decrease was significant but only until 2013. In the last three years leading up to 2016, a rise in the respective parameters was observed due to a significant increase in the number of vehicles present in road traffic. On the lower graph of Fig. 1, respectively, a clear downward trend of road traffic fatalities is shown, an all-time low point representing the global pandemic's peak, when overall traffic was at its lowest point, as well as a prognosis until 2030, forecasting around 15,000 road deaths for the year 2030 - a target that is one-third of the number of fatalities compared to 2020.

On average, in the EU there were 44 road deaths per million inhabitants in 2021, representing an increase of 1,000 deaths (5% increase) compared to 2020, but 3,000 fewer fatalities (13% decrease) compared to the pre-pandemic period of 2019. Fig. 2 shows the statistics of deaths in the various member countries of the European Union in 2021, specifying a general average of 44 road deaths per million inhabitants. It can also be seen that more than half of the countries present on the graph exceed this value, Hungary being in the last third of the countries in this regard.

In Hungary there were about 50,000 road accidents, of which 20,000 were accompanied by bodily harm, respectively there were 56 road deaths per million inhabitants in 2021, which is significantly above the EU average (World Health Organization, 2022). Following a 25% reduction in 2020 (mostly due to an overall traffic decrease related to the global pandemic), Hungary recorded its lowest number of road fatalities on record. However, in 2021 the number increased again by 18%, thus achieving an overall 10% decrease between 2019 and 2021. This fact can also be seen from the comparison of Fig. 3 regarding road traffic accidents in every EU Member State.

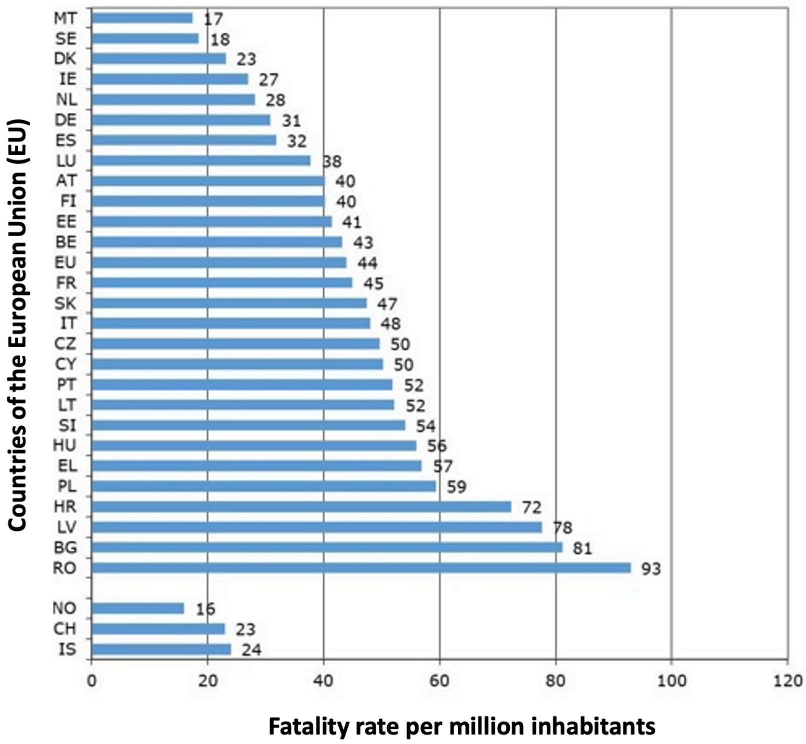

Fig. 2 Number of road fatalities per million inhabitants by country in the EU (adapted from European Commission, 2023)

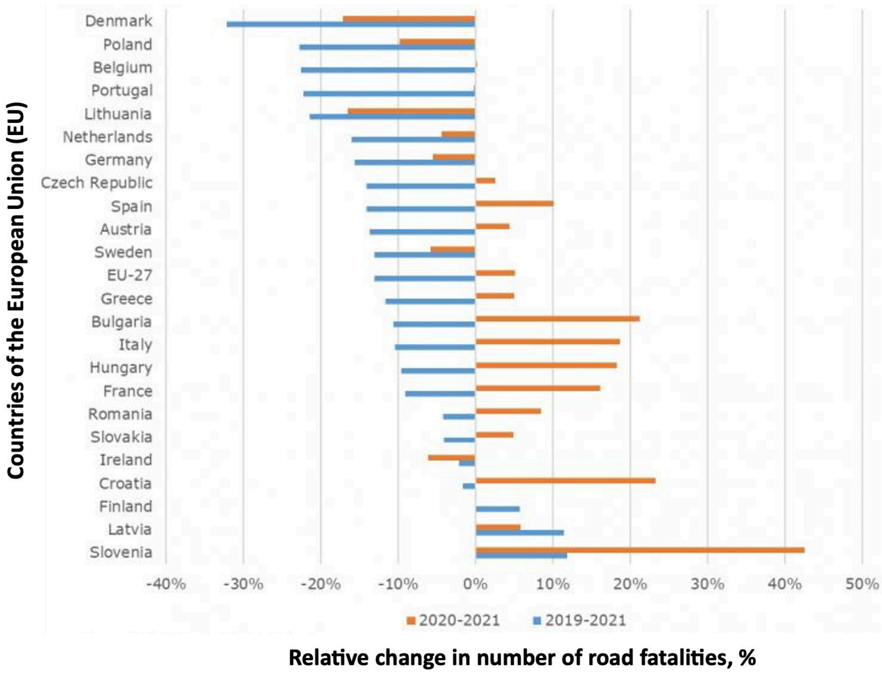

Fig. 3 Short-term trend in the number of road fatalities in 2021, compared to 2019 and 2020 (adapted from European Commission, 2023)

After analyzing the traffic accidents from the point of view of these statistical data, the following conclusions were reached:

- road traffic accidents are the eighth cause of death worldwide, meaning that every 24 seconds there is a fatal accident on public roads;
- traffic accidents are the main cause of death of children between 5 and 14 years and young adults between the ages 15 and 29;
- road traffic accidents cost most countries 3% of their gross domestic product;

- more than half of the total deaths caused by road accidents are linked to vulnerable road users (pedestrians, cyclists, and motorcyclists).

Fig. 4 presents a statistic related to the place of occurrence of road accidents in the case of the respective countries. 52% of road traffic fatalities, represented with orange color, occurred in extra-urban areas, while 40%, represented with blue, in urban areas, as well as 8% on highways. Car occupants (drivers and passengers) accounted for 43% of all road deaths, while pedestrians accounted for 20%, users of powered-two-wheelers (motorbikes and mopeds) 18%, and cyclists 10% of total fatalities. Within city areas, pedestrians accounted for the largest share of victims (37%), users of powered two-wheelers 18%, and cyclists 14% of total fatalities, meaning that almost 70% of total fatalities in metropolitan regions are vulnerable road users.

In most cases, a much higher number of accidents occur outside of cities than in urban areas due to higher travel speeds. However, in many countries, the situation is exactly the opposite, with more fatal accidents reported in urban areas than outside of them. The main cause of this is the non-respect of speed limits (Török, 2023).

Fig. 5 shows another important statistic, namely that the majority of fatal accidents, which occurred in the European Union in 2016, did not happen due to unfavorable weather conditions - they represented only 20...30% of total accidents (Blincoe et al., 2015). In the largest proportion, more than 70%, these accidents happened in dry road conditions, caused by human errors, for example driving too fast and misjudging the behavior of other drivers, as well as driving in a tired state, or under the influence of alcoholic beverages or other substances - the latter representing approximately 30% of all deaths related to road accidents (World Health Organization, 2022).

Moreover, Fig. 6 shows that there is a clear decrease in deaths resulting from road accidents in the last 20 years, from 1996 to 2016. Fig. 7 presents that in 2016 for most of the EU Member States, road traffic safety was already significantly improved compared to 2007, except in the case of four member countries of the European Union. The orange color is associated with the percentage decrease and increase, in terms of the number of victims involved in road accidents, while the blue color is associated with accidents with bodily injuries.

Many factors contributed to reducing these accident, injury, and death rates - including the gradual adoption of motor vehicle safety technologies, such as modern front airbags introduced in 1984, anti-lock braking systems (ABS) in 1985, electronic stability control (ESC) in 1995, side airbags for head protection in 1998, respectively forward collision warning (FCW) systems in 2000 (Glassbrenner, 2013).

The Insurance Institute for Highway Safety (IIHS) has estimated that if all vehicles had autonomous emergency braking (AEB) and FCW systems, there would be 43% fewer rear-end striking crashes of all severities, 64% fewer rear-end striking crashes with injuries, and 68% fewer rear-end striking crashes with third-party injuries (Cicchino, 2018). Similarly, with blind-spot warning systems (BSW) around

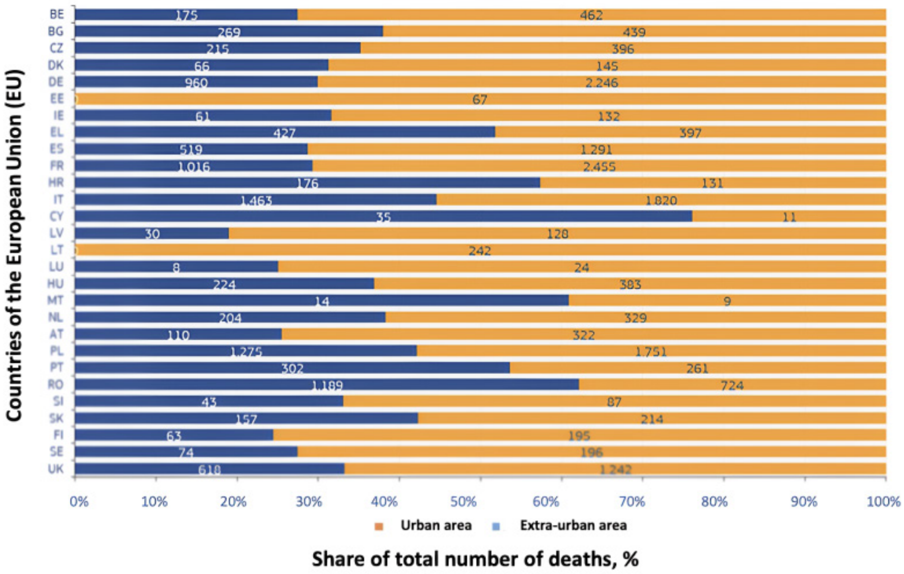

Fig. 4 The percentage variation of the number of deaths in urban areas, respectively outside urban areas, in the case of Member States of the EU (adapted from European Commission, 2023)

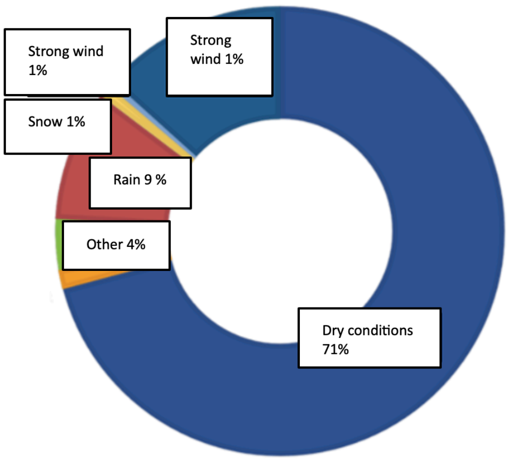

Fig. 5 The number of deaths related to the weather conditions in the EU (adapted from European Commission, 2023)

14–23% of lane-change crashes could be avoided, with rear cross-traffic assist braking (RCTB) 78% of backing crashes could be reduced, or with automatic high beams (AHB) around 20% single-vehicle nighttime crashes could be prevented (Moore et al., 2023). These active safety systems are generally associated with only as low as Level 0 or Level 1 vehicle automation, so with higher driving automatization even more positive results could be obtained (Highway Loss Data Institute, 2012).

As a result, the implementation of autonomous driving systems is likely to significantly reduce the frequency of traffic accidents by using real-time data and advanced algorithms to avoid accidents caused by distracted or impaired drivers. However, an important safety aspect to

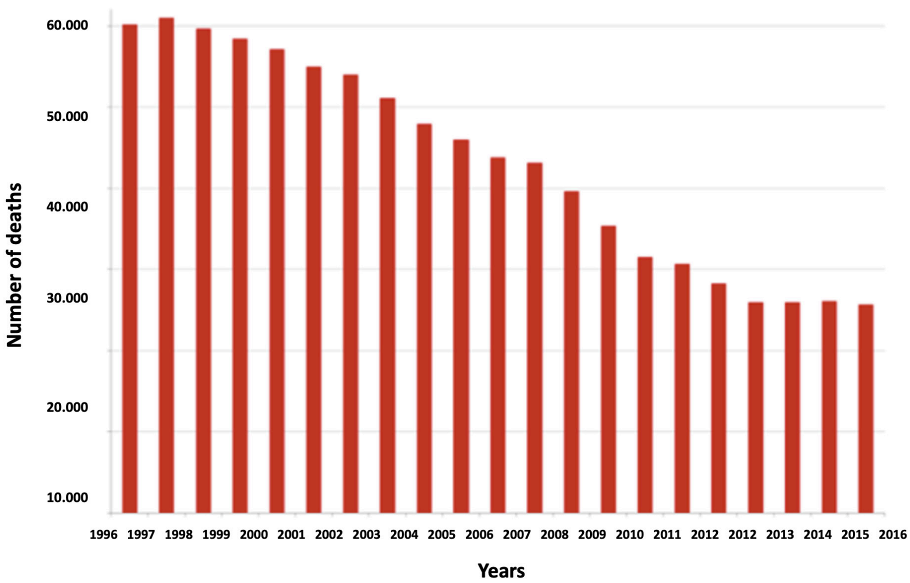

Fig. 6 Victims of road traffic in the EU between 1996-2016 (adapted from European Commission, 2023)

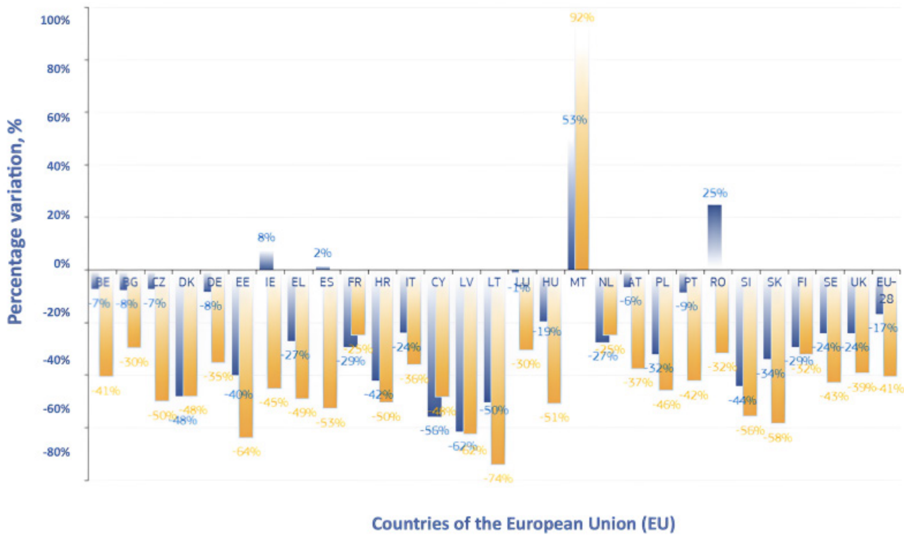

Fig. 7 Comparison of percentage variation in the number of accidents with injuries, respectively deaths, related to the Member States of the EU, between 2016 and 2007 (adapted from European Commission, 2023)

consider is the question of liability in the event of an accident. Manufacturers, software developers, and operators could all potentially share liability, leading to legal and financial disputes due to the complexity of determining who is responsible for the accident.

As road vehicle automation technology advances and primary active control of the vehicle will increasingly be taken over by the automated driving system, and thus the rate of traffic accidents will decrease in direct proportion. However, the safety benefits will depend on the level of automation. For example, dynamic brake support (DBS), a Level 1 feature which in the event of a sudden brake pedal application helps to reduce the stopping distance to the smallest possible value, significantly improves safety results, but does not correct driver errors in the situations in which no stopping decision is taken (Fernandes and Nunes, 2012).

3 Effects on mobility

Autonomous mobility technology has the potential to significantly impact and increase mobility for those who are currently unable to drive (Cao and Zoldy, 2021). Level 4 autonomous driving, in which case the vehicle no longer requires the presence of a human driver, would allow the transport of people who are unable to drive (children, the elderly, those without a driver's license, blind or disabled people), bringing benefits to these groups of people such as independence, reduced social isolation and transportation barriers, as well as access to essential services.

Moreover, the technology could significantly reduce the cost of transportation, especially in shared mobility services, such as ride-sharing or autonomous shuttle services. This can make transportation more affordable and accessible to a broader range of people, while also improving overall safety in public transit. Regarding changes in travel behavior, as people could choose to work, sleep, or engage in other activities during their commutes instead of driving, a shift in travel demand could occur, thus impacting transportation planning and infrastructure due to the use of autonomous vehicles (Burns, 2013).

However, there are also potential challenges to consider, such as the technological obstacles presented during the development and deployment of autonomous mobility, including software reliability, cybersecurity, and sensor performance. As autonomous mobility technology relies on advanced computer systems and networks, it is extremely vulnerable to cyber-attacks. Hackers could potentially gain access to the system and take control of the vehicle, putting passengers at risk.

Moreover, employment impact could be also an issue, affecting the labor market, particularly in the transportation industry, for drivers of trucks, buses, and taxis. It is important to consider the impact on employment, and to develop appropriate transition programs to mitigate negative consequences, while also paying attention to social equity, by distributing equally all the benefits of the technology across all communities and social classes (with special attention to low-income and marginalized communities), thus minimizing the possibility to leave people behind due to lack of access or affordability (Zmud et al., 2013).

4 Effects on traffic congestion

Because autonomous vehicles can communicate with each other and adjust their speed and route in real-time based on traffic conditions, traffic congestion could be drastically reduced by optimizing traffic flow and reducing bottlenecks on the road, thus obtaining increased efficiency in road traffic management (Fernandes and Nunes, 2012). Since human error is also a major cause of traffic congestion, whether due to driver distraction, confusion, or lack of experience, by using self-driving technologies also traffic congestion can be reduced, leading to smoother and more predictable traffic flow.

The fewer vehicles on the road, the lower will be the occurrence of traffic congestions and the chances of road users having an accident will be also lower. Autonomous driving technology of Level 3, or higher, is likely to substantially reduce traffic congestion and affect all road users (Barth and Boriboonsomsin, 2009). Also, by engaging in other activities during daily commute instead of driving, will result in a shift in travel demand, reducing congestion especially during peak periods.

In addition, autonomous vehicles can safely operate at closer distances than human-driven vehicles, reducing the gap between vehicles and allowing more cars to use the same road space. This can lead to more efficient use of existing roadways and potentially reduce the need for new road construction. A shift to shared mobility services is also expected to happen, such as ride-sharing or autonomous shuttle services, representing yet another way of helping to reduce congestion by decreasing the number of cars on the road.

On the other hand, however, there are some challenges as regards the effects on traffic congestion as well. Firstly, a reduced driving cost may lead to an eventual overall increase in the total number of kilometers driven, or so-called vehicle miles traveled (VMT). People may be more willing to take longer trips or travel more frequently if they are not required to drive themselves, leading to an increase in real congestion due to more efficient vehicle operation and reduced delays. Secondly, in the short term, the introduction of autonomous vehicles may cause additional congestion as people adjust to the new technology and share the road with both autonomous and human-driven vehicles.

5 Effects on the use of land

Autonomous mobility technology has the potential to significantly affect the use of land, particularly in urban areas. An important effect of autonomous vehicles may be to increase the willingness to commute, to travel longer distances to and from work. This could cause people to live further from the urban centers, which can lead to more dispersed and lower density living areas, more efficient use of land around metropolitan regions, as people no longer need to live close to public transportation or own a personal car.

According to estimations, approximately 30% of the spaces in the central districts of 41 major cities in the world were dedicated to car parking alone (Shoup, 1997). At Level 4, an autonomous vehicle would simply be able to drop off its passenger at a designated location without the need to park. This could free up land currently used for parking lots and garages, allowing a more sustainable development of cities.

Reducing congestion on roads will pave the way for more efficient use of existing infrastructure. Land currently used for roadways, parking, and underserved by public transportation could be repurposed for other uses, such as developing new neighborhoods and commercial centers. Lastly, another opportunity for economic growth will arise from the increased demand for last-mile delivery centers. With the rise of e-commerce and delivery services, there is an increased need for last-mile delivery centers, where goods can be stored and then delivered by autonomous vehicles. This could lead to an increase in demand for industrial and warehouse land, particularly near urban centers.

6 Effects on energy consumption and pollution emissions

Autonomous vehicles have the potential to improve energy consumption required for various propulsion systems (classical or alternative) by about 4 to 10%. This is due to the fact that acceleration and deceleration of the vehicle can be achieved more efficiently than by a human driver (Zöldy and Zsombók, 2018), as well as the minimized distances between vehicles in traffic (Barth and Boriboonsomsin, 2009). Additionally, a large number of autonomous vehicles traveling close together on a proportion of the road can considerably reduce air resistance force acting on the vehicles in the road train, resulting in significant improvements in both fuel consumption energy required for travel and travel time (Veza et al., 2022). Average travel speeds can be higher as well (Fernandes and Nunes, 2012).

The systems used by autonomous vehicles, such as global positioning systems (GPS) and wireless vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communications, has the potential to reduce the time spent searching for parking spaces or waiting at intersections (non-directed or traffic-lighted). This can have a positive influence on energy consumption and pollution emissions, resulting in a more sustainable, viable, and ecological vehicle transport system (Pyper and ClimateWire, 2014).

Another problem that could be solved with the implementation of autonomous cars is the reduction of environmental pollution caused by traffic, through the use of alternative fuels on a large scale. The decrease in the frequency of road accidents would allow the construction of lighter vehicles, and thus many of the problems that have limited the use of vehicles with electric and other alternative propulsion (Bouguerra and Layeb, 2018) would be diminished - especially their generally low range (Burns, 2013). As the frequency of accidents is reduced, cars and trucks could become much lighter, as vehicle crashworthiness requirements will also change, which would further reduce consumption.

In addition, one of the main challenges of electric-powered vehicles is the lack of a widespread refueling (recharging) infrastructure. However, autonomous vehicles with Level 4 capabilities could potentially offer a solution by allowing for self-recharging, thereby reducing the need for charging infrastructure with fewer filling stations than would otherwise be necessary (Hawkins et al., 2012). However, the effects on overall energy consumption will depend on the energy source used. If autonomous vehicles are powered by renewable energy sources, such as solar or wind power, they could greatly reduce energy consumption and pollution emissions. On the other hand, if they are powered by fossil fuels, their emissions may be similar to or even greater than those of traditional vehicles.

7 Transforming the transport system

In general, the use of cars, namely how many minutes we use them a single day, given that they are available throughout the whole day, is very low. Based on the average usage of a car, it sits still for more than 22 hours a day, as illustrated in Fig. 8. Of course, the times of use may vary depending on the environment of residence, but the proportions in principle do not change significantly.

Furthermore, even when cars are used, they are often not used efficiently, as generally, only one or two people travel in a vehicle at a time. Cars used in this way occupy significant space, as can be seen in Fig. 9, compared to other means of transportation, such as buses or bicycles. Efficient resource utilization in the field of transportation is an important objective. With this in mind, ride-sharing modes have emerged as a transition between traditional public transportation and individual transport.

With the advent of autonomous vehicles, the differences between modes of transition (taxi, car-sharing and carpooling) will disappear. Instead, a new service will emerge that can provide door-to-door services for multiple people in a single vehicle. This is not a substitute for public transport, but rather a complement to it, because traditional means of public transport (train, metro, tram or bus) will remain in those places where many passengers need to be transported at the same time, however, they will be autonomously driven, especially in areas with limited transportation options (Alatawneh and Torok, 2023).

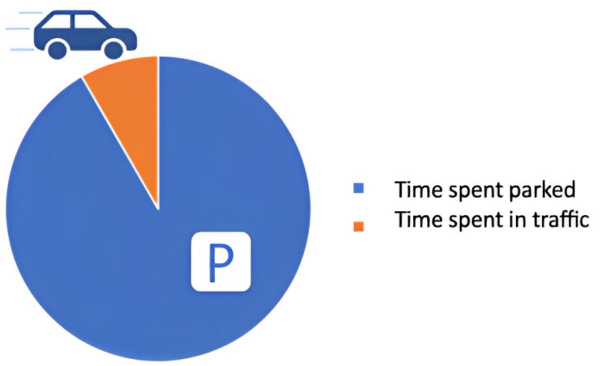

Fig. 8 General use of vehicles (adapted from BME Automated Drive, 2023)

Fig. 9 Suggestive situation regarding the spaces occupied by different means of transport (adapted from BME Automated Drive, 2023)

In addition, with the widespread introduction of autonomous vehicles, it is expected that fewer people will want to own personal vehicles as they will have faster and more convenient transportation options, leading to a significant decrease in the use of personal vehicles and vehicle owners. The proportion of traditional public transport users will also slightly decrease. The advantages of using carpooling or car-sharing services, where the same car is used by several people, fuel costs are shared among passengers, and several people travel at once, are that both can be more convenient and faster than public transport, as well as cheaper than taxis or using personal vehicles (BME Automated Drive, 2023).

In this way, both the purchase and maintenance costs of vehicles can be saved, which will have a direct positive effect on the economy. However, the role of walking, cycling, and sharing, especially in the central areas of cities, will remain significant for short journeys (Burns, 2013). However, it should also be remembered that giving up ownership of personal vehicles is expected to be a slow process, as most people do not see vehicles as mere utility objects. Fig. 10 shows current and future transport modes classified based on the number of passengers carried.

8 Conclusions

Autonomous mobility technology is still in the early stages of development, and there are many technical and regulatory challenges that need to be addressed before it can be widely deployed. However, with continued research and development, it has the potential to significantly improve the way we move people and goods in the future (Barabás et al., 2017).

Advantages related to safety, efficiency, convenience, accessibility, as well as challenges concerning cybersecurity, liability, negative impact on labour market, or social equity were all assessed in the present study, obtaining a detailed investigation about the long-term implementability of the autonomous driving systems in our current road traffic system.

While the exact effects of the introduction of autonomous vehicles are uncertain due to the technology still being in its early stages and requiring further development,

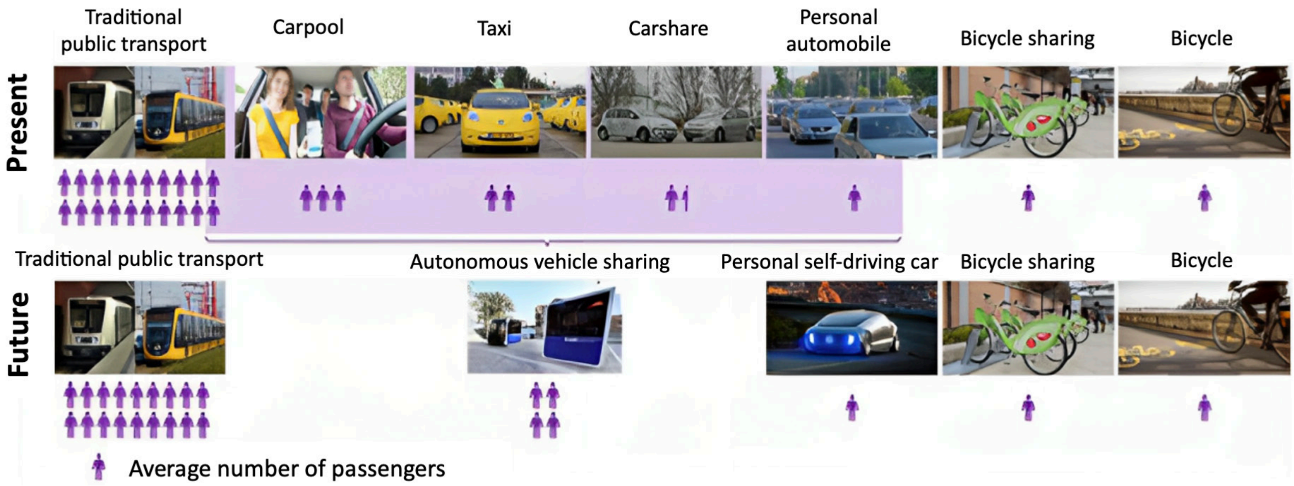

Fig. 10 Current and future transportation technologies and possibilities (adapted from BME Automated Drive, 2023)

it is likely that the benefits they will bring, such as reducing road accidents, increasing mobility, and reducing energy consumption and environmental pollution, will outweigh their likely disadvantages and costs, thus revolutionizing transportation as we know it today.

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