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AUTONOMOUS CARS, DEVELOPMENT OF MODERN TRANSPORT TECHNOLOGY

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Abstract – The article presents selected issues from the conducted research and analyzes in the field of the development of autonomous vehicles, carried out under the project: Polish road to Automation of Road Transport. The development of autonomous cars is a global challenge for the automotive industry. The creation of a fully autonomous vehicle capable of transporting passengers and goods without the participation of a driver has become a priority goal of automotive concerns. The huge costs incurred by automotive concerns for the development of autonomous vehicles prove the progressing automotive revolution, which will have a significant impact on the shape of future transport systems, transport based on autonomous transport. Very often in the literature there are overly optimistic forecasts for the development of autonomous vehicles, as well as overestimating the benefits they are to bring, without pointing to the costs and problems of their implementation and functioning in the real transport system. The publication presents forecasts for the development of autonomous vehicles as well as the related risks and advantages of their implementation. The factors that have a significant impact on the development of these vehicles are also outlined[1].

Key words – autonomous vehicles, vehicles technology, forecasts

JEL Classification – O14, O18, O22, O31, O32

INTRODUCTION

The autonomy of a vehicle means its ability to independent braking, acceleration, overtaking, avoiding maneuvers, as well as all other maneuvers that have been performed by the driver so far. Depending on the degree of automation, autonomous vehicles will reduce or even eliminate human involvement in driving. According to the SAE classification [8], there are several levels of autonomous vehicle classification, as shown in the table below. Final Level 5 is only a fully autonomous vehicle that does not require a driver.

Due to the anticipated wide impact of road transport autonomy on many areas of socio-economic life, its in-depth analysis and planning of the implementation method is required, which will enable obtaining maximum benefits with minimum expenditure and maximization of effects for society and economy. Anticipating the time of product preparation for implementation gives the opportunity to achieve maximum benefits by preparing for this situation. Therefore, a wide range of the conducted analysis of the literature [1-7] is extremely useful in the correct assessment of the situation.

Automation of transportation is inevitable and will have a significant impact on different spheres of life, similar to the introduction of the Internet. The future advantages of autonomous vehicles include:

- shortening the travel route to the destination and travel time (thanks to the use of navigation systems and up-to-date road information about congestion, detours, weather conditions, etc.), and consequently reducing the emission of exhaust gases in the city (if the autonomous vehicle is a combustion vehicle) and reducing noise emissions,
- reducing the number and the effects of road

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collisions and accidents by reduction of driver fatigue and supporting driver's decisions in emergency situations (faster response to a threat), etc.,
- optimization of drivers' working time through the use of the so-called connected vehicles - among others use of the platooning (only one driver in the first vehicle in the column), improving mobility, in particular of elderly people and people with disabilities who have difficulties or cannot drive a traditional vehicle, better cooperation of vehicles with the traffic control and management systems operating in cities in order to improve the efficiency of using the existing road network, shorten the travel time, better use of vehicles (including the development of the idea of an automated version of "car-sharing"), improve the functioning of the priority system for transport vehicles collective and rescue vehicles,
- implementing new methods of organizing public transport. This applies, for example, the construction and operation of autonomous buses or innovative transport systems and parking lots.

The threats related to the safe implementation of autonomous vehicles include:
- problems of human-machine interfaces and human takeover of control over the vehicle in situations where the autonomous system signals such a necessity (a person must first assess the circumstances and then react adequately to the road situation),
- lack of an extensive database on the behavior of autonomous vehicles, in complex, real, national road conditions, depending on the type, arrangement and condition of road infrastructure, lighting, as well as weather conditions and behavior of other road users, including in critical situations,
- low level of knowledge and skills, impeding the safe use of autonomous vehicles,
- lack of knowledge on the long-term impact of autonomous vehicles on the practical skills of drivers, important from the point of view of road safety,
- cybersecurity, privacy and personal data protection issues (the vehicle can be used to carry out a terrorist attack). The data can be used to track the user or obtain private and sensitive data about himself.

The further part of the article discusses the issues related to autonomous vehicles that will relate to the presented classification (SAE).

Some benefits, such as reduced driver stress, can occur with Level 2-4 automation, but most benefits require Level 5 automation, and some only occur when they are shared, or if have dedicated lanes. The following matrix summarized the benefits provided by various AV types.

Various types of autonomous vehicles provide different types of benefits. Many benefits require Level 5 and shared vehicles.

Development forecasts for autonomous vehicles

As a result of a review of research and literature analyzes on issues related to modern technology, such as the autonomous vehicle and its development, many valuable research results, information and conclusions were obtained from various projects. Some of them are also presented in this article.

The forecast of the development of autonomous vehicles can be presented in the form of an innovation curve, as illustrated in Table 3. An initial concept usually experiences development, testing, approval, commercial release, product improvement, market expansion, differentiation, maturation, and eventually saturation and decline. Autonomous vehicle technology will probably follow this pattern.

According to the presented curve, autonomous vehicles are currently under development and testing. Many current vehicles have level 2 and 3 technologies such as cruise control, hazard warning and automated parking. Tesla's Autopilot offers automated steering and acceleration in limited conditions. Several companies are running Level 4 pilot projects that test autonomous vehicles under certain conditions [9-10], but despite this progress, many technical improvements are needed before vehicles can operate autonomously under all normal conditions.

Autonomous vehicle technologies will need to go through several more stages to become widely commercially available, reliable and affordable, and therefore common in the vehicle fleet. Because vehicles can impose significant external costs, such as congestion and crash risks, they have higher testing and regulation standards than most other technological innovations such as personal computers and mobile phones. Under optimistic conditions testing and approval will only require a few years, but if the technology proves to be unreliable and dangerous, for example, if autonomous vehicles cause crashes, it may take longer [9].

Table 1. Vehicle autonomy classification, SAE J3016 of 2014

SAE	SAE name	SAE narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of dynamic driving task	System capability (driving modes)	BASt level	NHTSA level
Human driver monitors the driving environment								
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the dynamic *driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1	**Driver Assistance**	the *driving mode* specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes	Partially automated	2
Automated driving system ("system") monitors the driving environment								
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes	Highly automated	3
4	**High Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes	Fully automated	3/4
5	**Full Automation**	the full time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**	Fully automated	

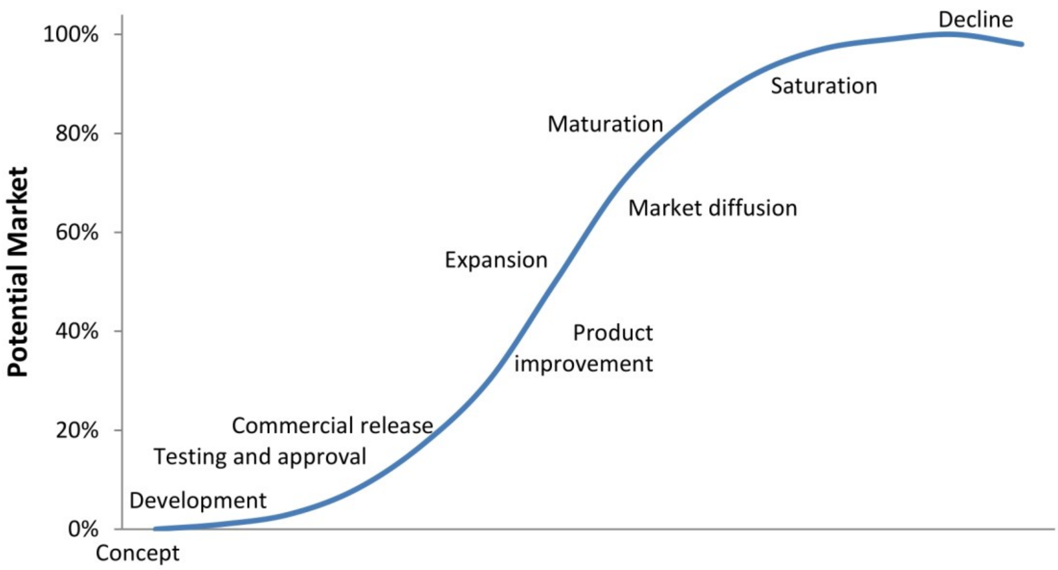
Source: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems, On-Road Automated Vehicle Standards Committee, J3016_201401, SURFACE VEHICLE INFORMATION REPORT, Issued 2014-01 [8]

Table 2. Autonomous Vehicle Benefits

Autonomous Vehicle Types	Mobility for Non-drivers	Reduced Driver Stress	User Savings	Occupant Safety	External Benefits
Level 1-4 private vehicles		ν		?	
Level 5 private vehicles	ν	ν		ν	?
Shared autonomous vehicles	ν		ν		ν
Shared autonomous rides	ν		ν		ν
Dedicated AV lanes			ν		

Source: Todd Alexander Litman (2021), Autonomous Vehicle Implementation Predictions Implications for Transport Planning, Victoria Transport Policy Institute [9]

Table 3. Innovation Curve



Source: Todd Alexander Litman (2021), Autonomous Vehicle Implementation Predictions Implications for Transport Planning, Victoria Transport Policy Institute [9]

Although current technologies allow vehicles to operate autonomously on highways, in good weather, achieving 95% operability (vehicles are unable to reach desired destination a few times each month) will be difficult [9, 11]. Achieving 99.9% operability (vehicles are unable to reach desired destinations only about once a year) will be far more difficult.

Operating a vehicle on public roads is complex due to the frequency of interactions with often unpredictable objects including potholes, vehicles, pedestrians, cyclists and animals. As a result, autonomous vehicles require more complex software then aircraft (Figure 1). Producing such software is challenging and costly, and it is sure to have errors. There will be certainly system failures, some causing severe accidents.

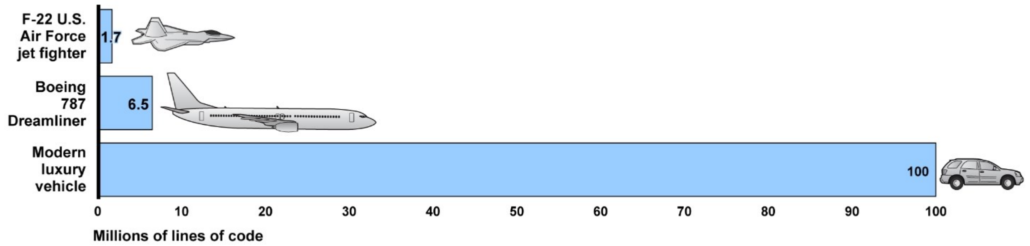


Fig. 1. Aircraft and Automobile Software Code Compared

Source: GAO (2016), Vehicle Cybersecurity: DOT and Industry Have Efforts Under Way, but DOT Needs to Define Its Role in Responding to a Real-world Attack, GAO (www.gao.gov); **at** https://bit.ly/1ruZi09 [12]

Table 4. Vehicle Technology Deployment Summary

Technology	Deployment Cycle	Typical Cost Premium	Market Saturation Share
Automatic gearboxes	50 years (1940s-90s)	$1,500	90% U.S., 50% worldwide
Air bags	25 years (1973-98)	A few hundred dollars	100%, due to federal mandate
Hybrid vehicles	25+ years (1990s-2015+)	$5,000	Uncertain. Currently about 4%.
Subscription services	15 years	$400 annual	5-10%
Navigation systems	30+ years (1985-2015+)	$500 and rapidly declining	Uncertain; probably over 80%.
Electric vehicles	100+ years	$10,000 for high-performance	Probably 80%+

Source: Todd Alexander Litman (2021), Autonomous Vehicle Implementation Predictions Implications for Transport Planning, Victoria Transport Policy Institute [9]

The problem of the speed of implementing the development of modern car systems and technologies is very well illustrated by the following examples, they include (Table 4) [9]:

- Automatic Transmissions [13]. First developed in the 1930s, it took until the 1980s for me reliable and affordable. When optional, they typically cost $1,000 to $2,000. They are included in 90% of new vehicle in North America, and 50% in Europe and Asia.
- Hybrid Vehicles [14]. These became commercially available in 1997 but were initially unreliable and expensive. Their performance has improved, but typically adds about $5,000 to vehicle prices. In 2016 they represented about 2% of total vehicle sales.

Other examples are included in Table 4.

New technologies usually require several decades between commercial availability to market saturation.

Because autonomous vehicle technologies are more complex and costly than these technologies, their market acceptance and penetration are likely to take longer [9, 15]. New vehicles are becoming more durable, which reduces fleet rotation. As a result, new vehicle technologies normally require three to five decades to penetrate 90% of vehicle fleets. Deployment may be faster in developing countries where fleets are expanding, and in areas with strict vehicle inspection requirements, such as Japan's control system. Annual mileage tends to decline with vehicle age: vehicles average approximately 15,000 miles in their first year, 10,000 miles in their 10th year, and 5,000 miles in their 15th year, so vehicles over ten years represent about 50% of vehicle fleets but only 20% of mileage.

Table 5 present prediction of autonomous vehicle sales, fleet and travel market penetration, assuming that Level 5 [8] vehicles become commercially available in the 2030s but are initially expensive and have limited performance. During next decade only a minority of new vehicles are likely to be fully autonomous, with market shares increasing as their performance improves, prices decline, and consumers gain confidence. By 2045 as much as half of new vehicle sales and 40% of vehicle travel could be autonomous. Without support, market saturation will probably take several decades, and a part of the drivers may continue to choose human operated vehicles due to costs and preferences. These results are approximately consistent with other researchers' estimates [9, 15-17], although slower than the optimistic predictions by some industry experts.

Figure 2 illustrates these deployment rates, including higher and lower estimates. If autonomous vehicles follow previous vehicle technologies, it will take one to three decades for them to dominate new vehicles sales, and one or two more decades to dominate vehicle travel, and even at saturation a portion of vehicle travel may continue to be human operated.

An important planning issue is whether autonomous vehicles will increase or reduce total vehicle travel and associated traffic problems. 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 can increase vehicle travel. This additional vehicle travel provides marginal consumer benefits, and since vehicle travel imposes significant external costs, much of the additional vehicle travel is likely to be economically inefficient: its user benefits will be less than total incremental costs. Alternatively, autonomous operation may facilitate vehicle sharing, allowing households to reduce vehicle ownership and vehicle travel. This suggests that AVs will increase vehicle travel in suburban and rural areas, and reduce it in urban areas. Their net impacts will depend on transport and land use development policies. With current policies, vehicle travel and sprawl are likely to increase 10-30%. More efficient pricing, and roadway management which favors shared vehicles, can reduce vehicle travel and associated problems [9].

Table 5. Autonomous Vehicle Market Penetration Projections

Stage	Decade	New Sales	Fleet	Travel
Development and testing	2020s	0%	0%	0%
Available with large price premium	2030s	2-5%	1-2%	1-4%
Available with moderate price premium	2040s	20-40%	10-20%	10-30%
Available with minimal price premium	2050s	40-60%	20-40%	30-50%
Standard feature included on most new vehicles	2060s	80-100%	40-60%	50-80%
Saturation (everybody who wants it has it)	2070s	?	?	?
Required for all new and operating vehicles	?	100%	100%	100%

Source: Todd Alexander Litman (2021), Autonomous Vehicle Implementation Predictions Implications for Transport Planning, Victoria Transport Policy Institute [9]

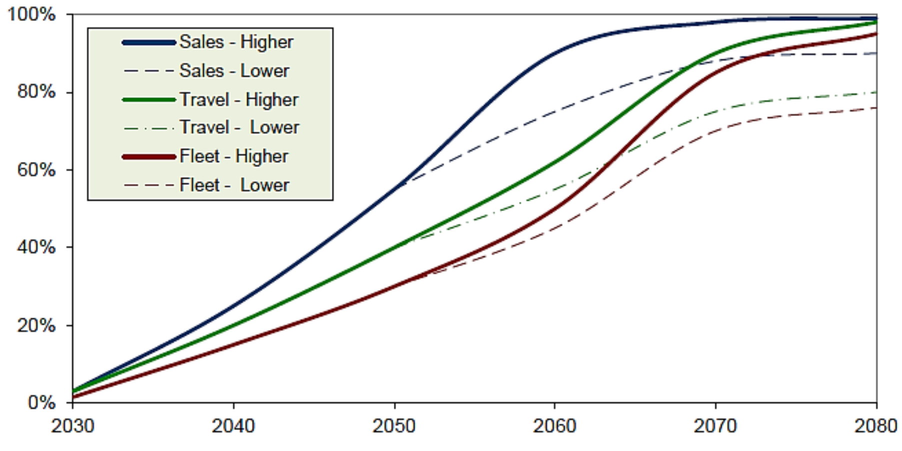


Fig. 2. Autonomous Vehicle Sales, Fleet and Travel Projections

Source: Todd Alexander Litman (2021), Autonomous Vehicle Implementation Predictions Implications for Transport Planning, Victoria Transport Policy Institute [9]

Another critical issue is the degree that potential benefits can be achieved when only a portion of vehicle travel is autonomous. Some benefits, such as improved mobility for affluent nondrivers, may occur when autonomous vehicles are uncommon and costly, but many potential benefits, such as reduced congestion and emission rates, reduced traffic signals and lane widths, require that vehicles operate autonomously in dedicated lanes [9].

Due to the high labor costs, commercial vehicles are likely to be automated most quickly, particularly for long-haul travel on limited access highways. However, commercial drivers provide various services, including passenger assistance and security, monitoring and maintenance and loading, so some vehicle operator jobs will change but not disappear.

Significantly faster implementation would require more rapid development, deployment and fleet rotation than previous vehicle technologies. For example, for most vehicle travel to be autonomous by 2045, almost all vehicles produced after 2035 would need to be autonomous, new vehicle purchase rates and spending would need to increase significantly so fleet rotation that normally takes three decades can occur in one decade, and many otherwise functional vehicles would be scrapped simply because they lack self-driving capability [9].

Shared mobility services, such as carsharing and ridehailing, are already reducing the need for vehicles ownership and parking demand in some situations [18].

The following factors affect the speed of autonomous vehicle deployment [9]:

- The speed of technological development. Level 4 technologies (vehicles able to operate autonomously in limited conditions) are currently available, but significant technological progress is needed before vehicles can operate autonomously under all normal conditions. Reliable Level 5 operation may be available in five years or may require another 25 years.
- Testing and regulatory approval. Testing and approval standards are currently under development, but several more years may be required for these standards to be adopted in most jurisdictions, and additional time will be required for large-scale testing.
- Additional costs. Autonomous vehicles require additional equipment and services which add costs. For the foreseeable future (one to three decades) autonomous operation will only be available in relatively expensive new vehicles, adding thousands of dollars in annual expenses compared with human-operated vehicles. High additional costs will reduce the portion of new vehicles that have this technology, reducing the speed of fleet penetration.
- Consumer travel and housing preferences and development practices. Currently, most North American households live in automobile-dependent communities and own private vehicles. Autonomous vehicle sharing is most appropriate for households that live in multi-modal communities where they travel less than about 6,000 annual miles by automobile. As a result, shared autonomous vehicle travel will become more common if many households are able to move into multi-modal communities. Consumer acceptance may be reduced by safety fears, privacy concerns, or preferences, resulting in a significant portion of vehicle travel remaining human-driven even after market saturation.
- Service quality and affordability. If autonomous taxis are reliable, comfortable and affordable, many people may shift from owning to sharing vehicles. However, if they are unreliable, uncomfortable or expensive, more households will continue to own private vehicles.
- Public policies. Implementation could be accelerated if public policies encourage autonomous vehicle development and purchase, if road and parking pricing, and roadway management favor shared vehicles, if highway lanes are dedicated to autonomous vehicle platooning, if development policy enables more resilient development, if autonomous operation is required for new vehicles, or if governments support scrapping a major portion of functional vehicles because they lack autonomous driving capability.

An interesting combination is included in the Table 6, it is a calendar of problems with the forecast of their solution in the field of autonomous vehicles.

The above list identifies the different needs and requirements to achieve the goals of autonomous vehicle implementation plan.

Optimistic forecasts often ignore significant obstacles and costs. Many technical problems must be solved before autonomous vehicles can operate reliably under all normal conditions [11, 20].

Statistics from the PwC report [21], indicate that in Europe only in 2035 the share of level 4 and 5 autonomous cars may amount to approximately 14%. This increase will be greater in China, reaching around 34%. However, before this happens, the industry must overcome key technological barriers.

Table 6. Autonomous Vehicle Planning Issues

Issue	Analysis Required	Policies Required	Time
Reliability and safety	Evaluate reliability and safety. Establish regulatory framework.	Define performance, testing and data requirements for AV operation on public roads.	2020-30s
Overall travel impacts	Investigate travel changes, and likely benefits and costs.	Transport management to reduce congestion, accidents and emissions.	2020-40s
Local vehicle traffic impacts	Investigate changes in motor vehicle traffic and their impacts.	Decongestion pricing, vehicle restrictions, HOV priority, and policies that favor shared rides.	2020-40s
Safety	Investigate new risks, crash impacts particularly to other road users.	Regulate AVs to ensure safety for all road users. Price and manage roads for safety.	2020-60s
Mobility for nondrivers	Autonomous vehicle availability and affordability to non-drivers.	Policies that ensure that AVs serve people with disabilities and low incomes.	2020-30s
Impacts on vehicle sharing	Quality of shared autonomous vehicles and rides.	Regulate and encourage shared autonomous vehicles and rides.	2030-40s
Energy and emission impacts	AV fuel type and consumption. Impacts on total vehicle travel.	Encourage efficient and electric AVs. Price and manage roads to minimize total vehicle travel.	2030-60s
Parking and passenger loading	Impacts on vehicle ownership and use, and parking and loading needs.	Reduce parking requirements and efficiently manage parking and curb space.	2040-50s
Roadway design	Impacts on roadway traffic and design needs.	Zmień projekty jezdni. Rozważ utworzenie pasów AV. Określ ich finansowanie i ceny.	2050-70s
Plan for mixed traffic	Degree of conflicts between AVs and other road users.	Develop polices and facility designs to minimize conflicts and risks.	2040-60s
Autonomous vehicle mandates	Potential benefits of mandating AVs.	If benefits are very large, require all vehicles to be AVs and restrict human driving.	2060-80s

Source: Henaghan Jennifer (2018), Preparing Communities for Autonomous Vehicles, American Planning Association (www.planning.org)**; at** https://bit.ly/2piKBhX**, Larco Nico, et al. (2018), AVs in the Pacific Northwest: Reducing Greenhouse Gas Emissions in a Time of Automation, Urbanism Next Center** (https://urbanismnext.uoregon.edu)**: at** https://bit.ly/2MHIXix [19-20]

Along with the development of autonomous vehicles, we observe an increase in the number of cars powered by alternative fuels in relation to, for example, diesel [22]. These changes in the near future will also have an impact on the choice of technology supporting the selection of an appropriate fuel for an autonomous car, e.g. electricity.

There are many forecasts presented in various reports, studies and publications. They often differ and it is difficult to definitively indicate a specific date for the implementation of autonomous vehicles.

When analyzing the development of autonomous vehicles, it is also worth paying attention to the future costs of their operation. Currently, a set of optional vehicle accessories, such as remote starting, adaptive cruise control, active lane assist and safety cameras, typically cost several thousand dollars, and subscriptions to navigation and security services, such as OnStar and TomTom, cost $150-750 annually.

Since failures could be deadly, autonomous vehicles will need robust and redundant components, installed and maintained by specialists, increasing maintenance costs. Current advanced driver assistance system sensors (cameras, radar and ultrasound) approximately double minor collision damage costs, typically adding $3,000 to a repair bill [23], suggesting that autonomous vehicles will increase vehicle repair costs.

Table 7. Autonomous Vehicle Equipment and Service Requirements

All Autonomous Vehicles	Shared Autonomous Vehicles
• Sensors (optical, infrared, radar, laser, etc.). • Automated controls (steering, braking, signals, etc.) • Software, servers and power supplies. • Short range vehicle-to-vehicle communication networks, plus Internet access for maps, software upgrades and road reports. • Navigation. GPS systems and special maps. • Critical component maintenance, repair and testing.	• Dispatching and fleet management. • Business administration and insurance. • Business profits. • Security. • Frequent cleaning and repairs. • Delays and empty vehicle-miles for passenger loading.

Source: Todd Alexander Litman (2021), Autonomous Vehicle Implementation Predictions Implications for Transport Planning, Victoria Transport Policy Institute [9]

Autonomous vehicles require different equipment and services that will cost, a few examples are presented in the table 7.

Optimists often assume that most autonomous vehicles will be electric, which they predict will have low operating costs (less than 5₵ per mile), but these are underestimates. Vehicle batteries must be replaced approximately every 100,000 miles, which currently costs $3,000-15,000, or 3-10₵ per vehicle-mile [9]. This may decline with production innovations, but probably not much, since future vehicles will require increasingly sophisticated batteries, to maximize performance. Electric vehicles currently pay no fuel taxes; cost-recovery road-user fees would increase electric vehicle operating costs 5-10¢ per vehicle-mile. Incorporating these factors increases electric vehicle operating costs to 10-25₵ per mile, similar to fossil fuel vehicles [9].

Experience with previous vehicle innovations, such as automatic transmissions and airbags, suggests that autonomous driving capability will initially be available only on higher priced models and will probably take decades to become standard on lower-priced models. This suggests that autonomous driving capabilities will probably add several thousand dollars to new vehicle purchase prices and hundreds of dollars in additional annual services, maintenance and repair costs. In total this should add a few thousand dollars in annualized expenses, at least for the first few decades of their commercial availability, until competition and depreciation make these technologies available on cheaper models and used vehicles [9]. Advocates argue that these additional costs will be offset by insurance and fuel cost savings [9, 25], but that seems unlikely.

This indicates that for the foreseeable future private autonomous vehicle costs will probably average (total annual costs divided by annual mileage) $0.80-$1.20 per vehicle-mile, which may eventually decline to $0.60-$1.00 per mile as the technology becomes available in cheaper models. Shared autonomous vehicles (self-driving taxis) will probably cost $0.50 to $1.00 per vehicle-mile, and shared autonomous rides will probably cost $0.20-0.40 per passenger-mile [9, 26]. This is cheaper than human-operated taxis and taxis ($1.50 to $3.00 per mile), but more expensive than personal vehicle operating costs or public transit fares (20-40¢ per passenger-mile).

CONCLUSIONS

Autonomous vehicles will require years of testing and regulatory approval, and must become affordable and attractive to consumers. Motor vehicles are expensive, durable and tightly regulated, so new vehicle technologies usually take decades to penetrate fleets. Autonomous driving can pose new problems: camera, phone or computer failure can be frustrating but is rarely fatal. In contrast, motor vehicle system failures can be frustrating and fatal for passengers and other road users. As a result, the development of autonomous vehicles is likely to take longer and there is likely to be less net benefit than the optimists predict.

Currently, practically every new car is equipped with various driving assistance systems. Such systems can already control speed and track on highways, but the driver must be ready to react at all times. On the other hand, in level three vehicles you can take your feet off the pedals, let go of the steering wheel, and not even watch the road if it's a straight and well-marked route. However, only the level fourth and fifth, i.e. cars in full control of the situation, are considered to be the full level of automation. However, their implementation will require the development of common standards. One technology platform developed as a result of the exchange of experiences of all manufacturers would allow the unification of security standards and significantly increase the trust in autonomous technologies.

Transportation professionals have important roles to play in autonomous vehicle development and deployment. We must anticipate how new technologies and services are likely to affect road, parking and public transit needs, and how to respond to minimize problems and maximize total benefits. We can help define the standards they must meet to legally operate on public roads. We should evaluate their benefits and costs and develop policies to maximize net benefits and ensure that their deployment supports strategic community goals.

It is also worth noting, although it was not addressed in the article, that the ongoing Covid-19 pandemic is of great importance for the development of autonomous vehicles. It has brought with it supply chain disruptions in all sectors of industry, including the development of autonomous vehicles. Car manufacturers had to stop production and redirect research and development resources into strategic areas of activity to recover from the crisis unscathed and resume normal operation as soon as the epidemic situation allows for it. In particular, the development of fully autonomous level 4 and level 5 car technology has been delayed as a result of Covid-19.

The analysis shows that there are still many obstacles to overcome on the road to implementing autonomous vehicles, especially level 4 and 5. These include not only technological issues (including cybersecurity), but also legal or, above all, social issues related to the lack of trust in artificial technology.

SAMOCHODY AUTONOMICZNE, ROZWÓJ NOWOCZESNEJ TECHNOLOGII TRANSPORTOWEJ

Artykuł prezentuje wybrane zagadnienia z prowadzonych badań i analiz w zakresie rozwoju pojazdów autonomicznych, realizowanych w ramach projektu pt.: Polska droga do automatyzacji transportu drogowego. Rozwój samochodów autonomicznych stanowi globalne wyzwanie dla przemysłu motoryzacyjnego. Stworzenie pojazdu w pełni autonomicznego zdolnego do transportu pasażerów i towarów bez udziału kierowcy stało się priorytetowym celem koncernów motoryzacyjnych. Ogromne koszty jakie ponoszą koncerny motoryzacyjne na rozwój pojazdów autonomicznych świadczą o postępującej rewolucji motoryzacyjnej, która będzie miała istotny wpływ na kształt przyszłych systemów transportowych, przewozów opartych na autonomicznym transporcie. W publikacji zaprezentowano prognozy rozwoju pojazdów autonomicznych oraz wiążące się z tym zagrożenia i zalety ich wdrożenia. Zarysowano również czynniki, które mają istotny wpływ na rozwój tych pojazdów.

Słowa kluczowe: samochody autonomiczne, technologia samochodów, prognozy

REFERENCES

[1] Zhang W., Wang K. (2020). “Parking Futures: Shared Automated Vehicles and Parking Demand Reduction Trajectories in Atlanta”, Land Use Policy, Vol. 91. https://doi.org/10.1016/j.landusepol.2019.04.024

[2] Fulton L., Compostella J., Kothawala A. (2020). “Estimating the Costs of New Mobility Travel Options: Monetary and Non-Monetary Factors, National Center for Sustainable Transportation”. https://doi.org/10.7922/G20R9MN8

[3] Papa E., Ferreira A. (2018). “Sustainable Accessibility and the Implementation of Automated Vehicles,” Urban Science, Vol. 2/1. https://doi.org/10.3390/urbansci2010005

[4] González-González E., Nogués S., Stead D. (2020). Parking Futures: Preparing European Cities for the Advent of Automated Vehicles, Land Use Policy, Vol. 90. https://doi.org/10.1016/j.landusepol.2019.05.029

[5] Nadafianshahamabadi R., Tayarani M., Rowangould G. (2021). “A Closer Look at Urban Development Under the Emergence of Autonomous Vehicles: Traffic, Land Use and Air Quality Impacts, Journal of Transport Geography, Vol. 94. https://doi.org/10.1016/j.jtrangeo.2021.103113

[6] Nunes A., Hernandez Kristen D. (2020). “Autonomous Taxis & Public Health: High Cost or High Opportunity Cost?”, Transportation Research Part A, Vol. 138, pp. 28-36. https://doi.org/10.1016/j.tra.2020.05.011

[7] Sohrabi S., Khreis H., Lord D. (2020). “Impacts of Autonomous Vehicles on Public Health: A Conceptual Model and Policy Recommendations”, Sustainable Cities and Society, Vol. 63. https://doi.org/10.1016/j.scs.2020.102457

[8] SAE (2014), Levels of Driving Automation Are Defined in New SAE International Standard J3016, Society of Automotive Engineers (www.sae.org); at www.sae.org/misc/pdfs/automated_driving.pdf

[9] Litman Todd A. (2021). Autonomous Vehicle Implementation Predictions Implications for Transport Planning, Victoria Transport Policy Institute.

[10] CPUC (2020). Autonomous Vehicle Pilot Permits

Issued, California Public Utilities Commission. www.cpuc.ca.gov/avcissued, (access: 11.11.2021)
[11] Leonard John J., Mindell David A., Stayton Erik L. (2020). Autonomous Vehicles, Mobility, and Employment Policy: The Roads Ahead, MIT Work of the Future, https://workofthefuture.mit.edu, (access: 12.11.2021)
[12] GAO (2016). Vehicle Cybersecurity: DOT and Industry Have Efforts Under Way, but DOT Needs to Define Its Role in Responding to a Real-world Attack, GAO, www.gao.gov, https://bit.ly/1ruZi09, (access: 24.11.2021)
[13] Healey James R. (2012). "Stick Shifts Popular Again, Despite Lower Gas Mileage" , USA Today, 30 April, www.usatoday.com, https://bit.ly/2FoFPdc, (access: 11.11.2021)
[14] Dirksen S. (1997). "Air Bags: History of American Technology", Bryant University Community Web, http://web.bryant.edu/~ehu/h364proj/sprg_9 7/dirksen/airbags.html, (access: 04.03.2018)
[15] Lavasani M., Jin X. (2016). "Market Penetration Model for Autonomous Vehicles on the Basis of Earlier Technology Adoption Experience," Transportation Research Record 2597, pp. 67-74. https://doi.org/10.3141/2597-09
[16] Grush B. (2016). "Driverless Cars Ahead: Ontario Must Prepare for Vehicle Automation, Residential and Civil Construction Alliance of Ontario (RCCAO), https://bit.ly/2DFNNwy, (access: 12.05.2019)
[17] Simonite T. (2016). "Prepare to be Underwhelmed by 2021's Autonomous Cars: Ford, Uber, and BMW Promise Fully Self-Driving Cars in Five Years-But They Will Probably Only Work in Very Limited Areas", MIT Technology Review, https://bit.ly/2PZxH6X, (access: 11.11.2021)
[18] Deluca A. (2018). Ending the Search for Parking, Urbanism Next, https://bit.ly/2q6uTWD, (access: 24.11.2021)
[19] Henaghan J. (2018). "Preparing Communities for Autonomous Vehicles". American Planning Association, https://bit.ly/2piKBhX, (access: 09.11.2021)
[20] Larco N., et al. (2018). "AVs in the Pacific Northwest: Reducing Greenhouse Gas Emissions in a Time of Automation, Urbanism Next Center", https://bit.ly/2MHIXix, (access: 15.11.2021)
[21] Knight W. (2020). "Snow and Ice Pose a Vexing Obstacle for Self-Driving Cars," Wired Magazine, www.wired.com/story/snow-ice-pose-vexing-obstacle-self-driving-cars, (access: 24.11.2021)
[22] Transport przyszłości - perspektywy rozwoju transportu drogowego w Polsce 2020-2030. (2020). PwC, Związek Pracodawców Transportu i Logistyka Polska.
[23] Menes M. (2021). Stan i kierunki rozwoju wodoryzacji gospodarki ze szczególnym uwzględnieniem transportu, WKiŁ, Warszawa, ISBN 978-83-206-2043-6
[24] AAA (2018). Advanced Driver Assistance Systems (ADAS) Repair Costs, Fact Sheet, AAA News Room, https://bit.ly/39JO6CI, (access: 08.11.2021)
[25] Intellias (2018). How a Self-Driving Car Could Save You Money, https://bit.ly/36ZVBDD, (access: 14.11.2021)
[26] Nunes A., Hernandez K.D. (2020). "Autonomous Taxis & Public Health: High Cost or High Opportunity Cost?, Transportation Research Part A, Vol. 138, pp. 28-36. https://doi.org/10.1016/j.tra.2020.05.011