Autonomous Vehicles and Road Safety

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Abstract. The article is about participation of autonomous vehicles in traffic and their impact on road safety. The aim of the article is to present the opportunities of using autonomous vehicles to meet the needs related to the movement of persons and goods, in the context of improving road safety. Road transport is the most popular branch of the transport, which is reflected in its share in generating fatalities at all transport processes. Entry into service of the autonomous vehicles for transport of people and goods, can contribute to improving road safety indicators and, consequently, to reduce the social, economic and environmental costs incurred in connection with road traffic. Reducing or eliminating the impact of the human factor from the decision-making process regarding the quality and way of participating in road traffic may prove to be a landmark step in reducing road deaths.

Keywords: Road safety · Autonomous driving

1 Introduction

The availability of road infrastructure, relatively low purchase costs of means of transport and ease of gaining permission to drive road vehicles cause, that road transport is one of the most frequently used modes of transport. Having regard to all the advantages of this branch, one cannot forget about the costs incurred in connection with road traffic, i.e. social, economic, environmental. Research indicate the dominant share of road transport in generating fatalities at all transport processes related to the movement of people and goods. To ensure the safety of transport processes, including road safety, with increasing number of journeys, it seems currently the most urgent challenge facing the road users, manufacturers of means of transport and operators managing road infrastructure. The concept of safety is equated with a lack of risk, confidence, serenity and certainty. Abraham Maslow puts the need for safety as one of the fundamental just after physiological needs. On the other hand, the contemporary society have strongly established need for mobility that is associated with the risk of safety threats.

2 Losses Related to Road Traffic

The level of road safety in highly developed countries is seen as one of the elements of the quality and comfort of life [2]. According the World Bank data, in connection with traffic accidents during the year in the world nearly 50 million people are injured, and

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about 1.2 million people die, of which 70% in developing countries. According to WHO, the lack of determined actions to improve road safety in the next 10 years in developing countries will bring about to die more than 6 million people, and 60 million will be injured. Traffic accidents in 2004 accounted for the ninth cause of premature death, and in 2030 will be the third (Fig. 1).

The leading causes of burden of disease, world, 2004 and 2030 [1]

2004	% DALYs	Rank		Rank	% DALYs	2030
Lower respiratory infections	6.2	1.		1.	6.2	Unipolar depressive
Diarrhoeal diseases	4.8	2.		2.	5.5	Ischaemic heart disease
Unipolar depressive	4.3	3.		3.	4.9	Road traffic accidents
Ischaemic heart disease	4.1	4.		4.	4.3	Cerebrovascular disease
HIV/AIDS	3.8	5.		5.	3.8	COPD
Cerebrovascular disease	3.1	6.		6.	3.2	Lower respiratory infections
Prematurity and low birth weight	2.9	7.		7.	2.9	Hearing loss, adult onset
Birth asphyxia and birth trauma	2.7	8.		8.	2.7	Refractive errors
Road traffic accidents	2.7	9.		9.	2.5	HIV/AIDS
Neonatal infections and other	2.7	10.		10.	2.3	Diabetes mellitus
COPD	2.0	13.		11.	1.9	Neonatal infections and
Refractive errors	1.8	14.		12.	1.9	Prematurity and low birth weight
Hearing loss, adult onset	1.8	15.		15.	1.9	Birth asphyxia and birth trauma
Diabetes mellitus	1.3	19.		18.	1.6	Diarrhoeal diseases

Fig. 1. The leading causes of premature death in the world [1] (Calculations based on the rate of DALYs (Disability Adjusted Life Years), which is the sum of years of potential life lost due to premature death and the years of productive life lost due to disability.)

Road traffic accidents are also economic losses, which globally give approximately 500 billion US dollar a year. In the European Union, road accidents are the first cause of external reasons death of people up to 45 years of age, generating a yearly loss of over 200 million EUR. In Poland, road accidents cost more than 30 billion PLN a year, that is about 2% of GDP [3]. All this makes road transport as the most dangerous branch of transport, posing the greatest risk of loss of life while during move, as well as generating significant losses in the economic dimension.

3 The Safe System

In the IV European road safety programme, announced in 2010: “Towards a European road safety area: policy orientations on road safety 2011–2020”, it is assumed that the road users are the primary part of road safety system, and such a system should take into account the human errors and inappropriate behaviour and correct it as far as possible [4]. The idea of a safe system of man-vehicle-road is also the main goal of the Global Plan For The Decade Of Action For Road Safety 2011–2020, adopted by the General Assembly of the United Nations in 2010. A safe system means the creation and development of the road transport system, which is better able to adapt to the man, his errors and weaknesses. The starting point is to accept the fact that a man, as a road user, makes mistakes, and accidents cannot be completely eliminated. Presented approach assumes that human limitations should provide the basis for creating a system of road transport, and road infrastructure and vehicles should cooperate, taking into account these limitations. Safe system of man-vehicle-road requires integration through speed management systems, vehicles, and the design of road infrastructure. The safety system approach assumes a significant shift of responsibility for road safety from road users on those who create the road transport system, for example road operators or vehicle manufacturers.

The results of the research carried out by Volvo shows that the main causes of road accidents are combinations of factors: in 90% driver related, in 30% associated with the road and its surroundings, in 10% associated with the vehicle. This is confirmed by the results of research into the factors affecting the formation of road accidents, carried out at the Institute of Transport Economics in Oslo (TØI). It shows that by a combination of factors, the cause of traffic accidents is a man in 91.5%, road in 26.3%, and a vehicle in 6.7% (Fig. 2).

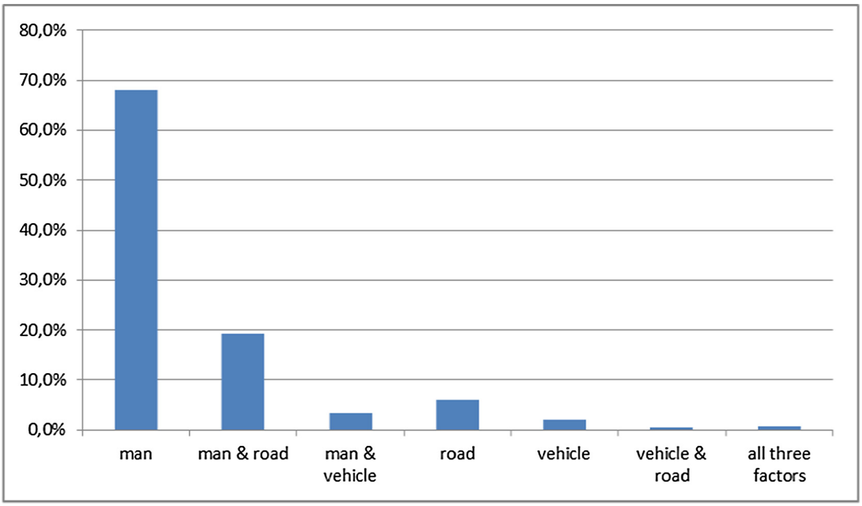

Fig. 2. Factors affecting the occurrence of road accidents [5]

Fully autonomous driving means transferring the driving task to a computer system and thus eliminating the human factor which is at the root of many road accidents. According to the European Commission, automated driving will increase road safety significantly, as human error is involved in more than 90% of all traffic accidents on Europe's roads; in which more than 40,000 people are killed and 1.5 million injured every year [6]. The data clearly show that the man is the main factor affecting the formation of road accidents. Reduce or eliminate its impact from the decision-making process regarding the quality and way of participating in road traffic may prove to be a landmark step in efforts to improve road safety.

4 Automated Vehicle Classifications

In the literature many different definitions are used: *automated, autonomous, self-driving, driverless* vehicles. *Automated vehicles* are those that use on-board equipment to perform one or more driving tasks automatically. *Self-driving* vehicles are designed to drive autonomously, without the control of a human driver. That means, that *self-driving* vehicles are a wider family of automated vehicles. Another distinction is the degree to which the automated vehicle is *autonomous*, relying solely on its on-board equipment to collect information, take decisions and inform tasks, or *connected*, i.e. in communication with other vehicles, personal devices (e.g. smart phones) or the surrounding traffic infrastructure to collect information and perform driving tasks [7]. Although some differences, all these concepts are strictly linked with each other. In common sense, the term *autonomous vehicle* applies to the vehicle, which certain functions associated with its move are carried out automatically, without human intervention, or with his limited participation. Having this on mind there are several classifications of automated vehicles, proposed by different sources.

The Society of Automotive Engineers (SAE International) created a six level classification (standard J3016) of road vehicles spanning from level 0 – no automation to level 6 – full automation. The classification considers a vehicle's capability to control its position, understand different environments and allow the driver to dedicate attention to other activities during the journey (Table 1) [8].

The American National Highway Traffic Safety Administration (NHTSA) provides a different classification of automation, which consists of five levels of automation (Table 2).

These two classifications are very similar to each other. The main difference is that SAE International distincts high and full level of automation, while NHTSA consider both classes as level 4 – full self-driving automation. The OECD International Transport Forum adapted the SAE taxonomy of automated and autonomous driving. The division of vehicles developed by the European Commission is limited to two groups:

- automated vehicle – technology that allows the driver to pass the on-board systems part of the responsibilities associated with driving,
- autonomous vehicle – fully automated, equipped with technology to perform all of the functions associated with driving without human intervention.

Table 1. Levels of driving automation for on-road vehicles by SAE's standard J3016 [7]

Level	Description
Level 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
Level 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
Level 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
Level 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 of intervene
Level 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 not respond appropriately to a request of intervene
Level 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

Table 2. Levels of autonomous driving by NHTSA [9]

Level	Description
Level 0: no automation	The driver is in complete and sole control of the primary vehicle controls (brake, steering, throttle, and motive power) at all times, and is solely responsible for monitoring the roadway and safe operation of all vehicle controls
Level 1: function-specific automation	Automation at this level involves one or more specific control functions; if multiple functions are automated, they operate independently of each other. The driver has overall control, and is solely responsible for safe operation, but can choose to cede limited authority over a primary control (as in adaptive cruise control), the vehicle can automatically assume limited authority over a primary control (as in electronic stability control), or the automated system can provide added control to aid the driver in certain normal driving or crash-imminent situations (e.g., dynamic brake support in emergencies
Level 2: combined-function automation	This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of controlling those functions. The driver is still responsible for monitoring the roadway and safe operation, and is expected to be available to take control at all times and on short notice (e.g. adaptive cruise control and automated steering working together to guide the car's movements)
Level 3: limited self-driving automation	Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions, and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time
Level 4: full self-driving automation	The vehicle is designed to perform all safety-critical driving functions and monitor road-way conditions for an entire trip

The European Road Transport Research Advisory Council (ERTRAC) has drafted an Automated Driving Roadmap providing definitions of the different automation systems and the expected date of their possible deployment. According to the roadmap, fully autonomous vehicles may be deployed in 2026–2030 (Table 3).

Table 3. Automated driving roadmap by ERTRAC [10]

Level number	Automation performance	Date of possible deployment	Specification
Level 0	Park distance control	Already deployed	The system assists the driver to manoeuvre into tight spaces by communicating distance from obstacles by means of acoustic or optical signals
Level 1	Park assist	Already deployed	The system automatically steers the car into parallel and bay parking spaces, and also out of parallel parking spaces. The driver retains control of the car at all times
Level 2	Traffic jam assist	2015/2016	The function controls the vehicle longitudinally to follow the traffic flow in low speeds (lower than 30 km/h). The system can be seen as an extension of the Adaptive Cruise Control with Stop & Go functionality, i.e. no lane change support
Level 3	Traffic jam chauffeur	2017–2018	Conditional automated ariving up to 60 km/h on motorways or similar roads. The system can be activated in a traffic jam scenario. It detects a slow-driving vehicle in front and then handles the vehicle both longitudinally and laterally. Might include lane change functionality
Level 4	Highway pilot	2020–2024	Automated driving up to 130 km/h on motorways or motorway-like roads from entrance to exit, on all lanes, including overtaking movements. The driver must deliberately activate the system, but does not have to monitor it constantly. Vehicle-to-vehicle communication, cooperative systems, ad-hoc convoys can be created
Level 5	Fully automated vehicle	2026–2030	Able to handle all driving without any input from the passenger

All provided ratings indicate that fully autonomous vehicles currently do not exist, because each of them requires specific human support. However, in literature the term of *autonomous vehicle* is being used for determining vehicle movement process, there is somewhat automated.

5 Possibilities and Limitations Associated with the Use of On-Road Autonomous Vehicles

The use of on-road autonomous vehicles to meet the everyday needs of mobility raises many emotions, questions and discussions on ethical, legal, financial, economic and technical dimensions. The first death involving the autonomous vehicle took place on the 7th of May 2016 in the city of Williston, Florida, United States. Tesla Model S vehicle with autopilot function enabled was on the dual carriageway, while a truck with a semi-trailer was traveling through a junction across its direction. Tesla hit the trailer, as the on-board devices of the vehicle did not detect the white trailer against the bright sky. An additional adverse factor in this situation was high location of the trailer in conjunction with its position relative to the road. A speeding vehicle entered under the trailer, and the driver, Joshua Brown, who at the time watched movie on the onboard DVD player, was killed on the spot. It should be noted, that by the time of this event the Tesla autonomous vehicles (level two by NHTSA) overcame a total route length of 130 million miles. According to data from the NHTSA, casualty on American roads happens statistically every 97 million miles.

An event which happened in Williston is important for at least two reasons. The first, it shows the weaknesses of used technology indicating, that it is still the early stage of its development. The second, it shows the interdisciplinarity of road safety issues, which in combination of man-vehicle-ITS-road takes on a new dimension. It is therefore possible to determine that the proliferation of autonomous vehicles will be the solution to the problem of road traffic accidents?

Admission to traffic the autonomous vehicles is associated with a number of restrictions.

The first is the issue of the adjustment of traffic rules. The United Nations Economic Commission for Europe (UNECE) has modified the record of Article 8 of the Vienna Convection on Road Traffic, regulating the issues of vehicle roadworthiness. According to the amendment, the autonomous vehicles can be permitted to road traffic, provided that they meet the construction requirements stated in the UNECE regulations, and the driver will be able to take control of the vehicle and turn off the autopilot device. Also the regulation was changed, which instructs to turn off the autonomous driving mode when speed of 10 km/h is exceeded [12, 13]. So far in the United States it is permitted by law for autonomous vehicles to participate in road traffic in California, Nevada, Tennessee, Michigan and Florida (Fig. 3).

In Europe, the legal provisions allowing autonomous vehicles to participate in road traffic are introduced in Spain, Italy, Greece, Sweden, the United Kingdom and Finland. Still unregulated issue is additional marking of autonomous vehicles, for example in Nevada (US) it is the red color of the number plate. The challenge seems to be also determining the responsibility in case of a road traffic accident. This will also require changes in driving education and licensing.

In the behavioural context, unknown remains the possible human reaction to depriving him the possibility of autonomous decision, as regards style and way of driving, and use of road infrastructure. The authors of a report prepared by European Transport Safety Council (ETSC), Brussels based non-governmental organization,

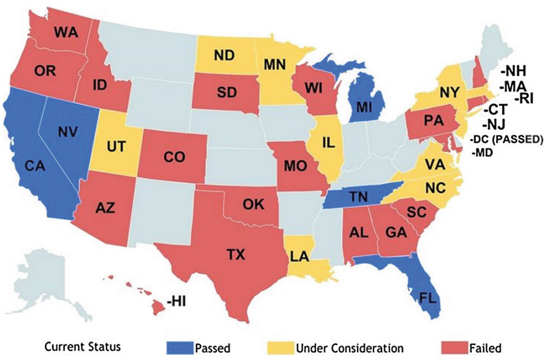

Fig. 3. Legal permission of autonomous vehicles to road traffic in the USA [9, 11]

indicate that in order to the deployed ITS systems could work effectively in improving road safety, there is a need for an in-depth analysis of the mechanisms of behavioural compensation by the driver of this state of affairs [14]. There is a concern that ridding the driver the decision making capabilities while participating in road traffic will affect negatively his psyche and can induce him to extreme behaviour, which could result in potentially dangerous situations.

The limitation of the development of autonomous mobility can also be different behavioural factor, which is the sense of safety of the driver and passengers while driving. The results of tests carried out in 2016, by the editors of one of the oldest British car magazines WhatCar? on a group of 4000 drivers indicate that 27% of them felt that dangerous, and 24% was felt that very dangerous if they had traveled using an autonomous vehicle. Safe or very safe was felt to be less than 25% of those polled. 19.5% of respondents have expressed an interest in the possibility of driving in an autonomous vehicle, while 45% considered this possibility as very little attractive and 23% as not enough attractive [15].

Another restriction of participation of autonomous vehicles in road traffic, can be the choice of "lesser evil" in case of an emergency situation: to protect the driver or the other person, including vulnerable road users, i.e. pedestrians, cyclists, motorcyclists. The results of the tests carried out by a team of researchers from the Center for Research in Management in the Toulouse School of Economics, the Department of Psychology at the University of Oregon and the Media Laboratory of the Massachusetts Institute of Technology, show that 75% of the interviewees considered that the autonomous vehicle should take into account the limitation of the number of victims of a possible accident, or the vehicle should turn and crash in a way, that only the driver was killed, saving 10 people. 50% of respondents felt that the driver should die even if he saves only one human being. However, the results of the study were entirely different when they had to decide from the position of the driver and a passerby. In this case, regardless of the position taken, all the test persons put their safety first. Among the interviewed people there were also ones, that stated that if an autonomous vehicle would have to behave so, that in this case the driver was to be killed instead of the other road users, they would not like to use such a vehicle [16].

An important road safety related restriction with participation of autonomous vehicles indicated researchers with the Transport Research Institute at the University of Michigan. The results of their research indicate that experienced drivers use eye contact and register other subtle signs in order to assess the intentions of the other road users. The lack of such suggestions may cause misunderstanding of the intent of the autonomous vehicle, and consequently dangerous situations [17].

As a serious threat that is accompanying autonomous vehicles in road traffic, it is indicated to be the safety of pedestrians, cyclists and other vulnerable road users. Their behaviour is often unpredictable and sudden, that autonomous vehicles may not cope with so many variables in dense city traffic.

Another serious threat may be a matter of data protection and cybersecurity. In research conducted by the American National Highway Traffic Safety Administration, 50% of respondents expressed their concern before the acquisition of control over the autonomous vehicle by unauthorized people and causing a threat to themselves and other road users [17]. Protection of personal data and privacy is also one of the determining factors for the successful deployment of autonomous driving. Users must have assurance that personal data are not a commodity, and know they can effectively control how and for what purposes their data are being used [6].

Dissemination of autonomous vehicles in road traffic may result in improving of road safety. However achieving a positive effect in this area, will depend on smooth dealing with many obstacles with using autonomous vehicles in traffic and understanding restrictions of human cooperation with machines. All of this poses a serious challenge for man, as a participant of road traffic, but also for vehicle manufacturers, designers and managers of road infrastructure. It will be necessary to create a technical standardisation for international compatibility and interoperability.

In terms of road safety, the most difficult may be the initial phase of dissemination of autonomous vehicles and transitional period, when, on the one hand, technology will require further refinement, the participants of road traffic will have to get used to the new conditions, and, on the other hand, both autonomous and non-autonomous vehicles will participate in traffic. However, researchers from the British Transport Research Laboratory (TRL) indicate that in the longer term refined technology of autonomous vehicles will bring a revolution in the field of road safety. It will reduce the number of fatalities among pedestrians by about 20%, and a significant reduction in the number of road collisions. They also assume, that the number of injuries due to traffic accidents will be reduced to a similar extent as after introduction of obligatory use of safety belts [18].

The possibility of improving safety and fluency of road traffic in the context of fully autonomous vehicles may be the change of the current concept of intersections. Traffic light can be eliminated, and the movement of vehicles in all directions will be able to take place continuously [19]. This solution also reduces the problem of congestion. The potential weakness of this concept is the movement of pedestrians, cyclists, motorcyclists and other vulnerable participants, who can disturb the traffic order posing a threat to themselves and other road users. The success of this concept will also require them to adapt to the prevailing traffic rules. Participation of autonomous vehicles in road traffic may also extort a change in road markings, what may increase the transparency and will be beneficial also for the other road users. Potentially beneficial in

Table 4. Possibilities and limitations associated with the use of on-road autonomous vehicles [own study]

Possibilities	Limitations
Improving of road safety records	Behavioural and ethical issues: human reactions and compensation, eye contact and other subtle signs while assessing the intentions of the other road users
Improving safety and fluency of road traffic	Safety of pedestrians, cyclists and other vulnerable road users
Eliminating of traffic lights – the continuous movement of vehicles possible in all directions	Legal framework: traffic rules, vehicle roadworthiness driving education and licensing responsibility on case of an accident
Reducing the problem of congestion	Software and data processing: the choice of "lesser evil" in case of emergency data protection technical standardisation for international compatibility and interoperability
Change of the current concept of intersections: change of road markings, what will make it more transparent and thus beneficial for the other road users	Cybersecurity and its threats
Increased safety: the ability of communication vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-any other object (V2X)	Infrastructure – needs to be improved

this area, in terms of road safety related to autonomous vehicles, is the ability of communication vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) (Table 4).

The analysis of capabilities and limitations related to the use of autonomous vehicles show a long way yet to overcome, to benefit from the positive effects of such vehicles on the improvement of road safety. 90% of what takes place in road traffic is related to a man, who is the most important, but at the same time, the most sensitive element of the safe system of man-vehicle-road. Even fully autonomous traffic will not be able to eliminate all dangerous traffic incidents and avoid victims of traffic accidents. In road traffic there are not only drivers involved, but also pedestrians, cyclists and other vulnerable road users, which cannot be replaced or eliminated. This would be contrary to the idea of personal freedom, and also to the general trend of promoting foot and bicycle mobility.

6 Conclusion

The current state of development of the technology used by the autonomous vehicles does not allow total to stave off the problem of fatalities and persons injured in road accidents. An intermediate state, which is a period of testing, and deployment of technology does not bring a radical improvement of road safety. A consistent and safe transport system requires the harmonisation of rules related to the use of autonomous vehicles: standardisation of on-board equipment, software, possibility human intervention, as well as rules of liability: driver-user, the vehicle manufacturer, the manufacturer of the vehicle software, road infrastructure administration.

Radical improvement in road safety would require substantial reduction or even elimination of human factor from the decision-making process. Only the introduction and dissemination of vehicles of the fourth level of autonomous driving can largely solve this problem and, consequently, reduce the social, economic and environmental costs connected with road traffic. Fully programmable road traffic is now unacceptable, and the obstacle is not the lack of technology, but behavioural factors underlying human behaviour. Human emotions do not exist in machines. An attempt of revolution in this area by giving ways to autonomous vehicles, and dehumanisation of road traffic can have far reaching consequences not only for the human mental health, but also for the automotive industry, and eventually for the whole global economy. The matter is whether people are ready for it.

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