

Keywords: road safety; autonomous vehicles; ADAS

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ESTIMATED ASSESSMENT OF THE POTENTIAL IMPACT OF DRIVER-ASSISTANCE SYSTEMS USED IN AUTOMATED VEHICLES ON THE LEVEL OF ROAD SAFETY IN POLAND

Summary. Strengthening road safety in the face of the enormous development of the automotive in recent decades is crucial. The safety benefits of automated vehicles are paramount. Automated vehicles have the potential to remove human error in road traffic, which will help protect drivers and passengers, as well as pedestrians and bicyclists. The carried-out forecasts are pioneering for Polish road traffic conditions. In England, studies have been carried out to determine the estimated impact of autonomous vehicles on road safety in simulated traffic conditions on the motorway. In Poland, preliminary forecasts of the reduction in the number of road accidents were made; however, they were based on other assumptions. Therefore, estimating the impact of using autonomous vehicles in order to increase the level of road safety is an innovative activity for Polish road conditions. For the purposes of this article, available statistical data on vehicles registered in Poland, their equipment with advanced driver-assistance systems as well as accident data and their causes were analyzed. A diagnosis of Road Safety in Poland in 2018 (base year for further estimations) was made, taking into account the trend of recent years together with an indication of the most common causes of road accidents. These data were compiled with statistical data from other countries about the influence of driver-support systems on traffic safety. Possible potential for increasing Road Safety in Poland by the year 2030 was estimated. The analyses were prepared assuming different types of processes related to traffic, road safety, and the recent development of the passenger car fleet in Poland. Presented results show four scenarios of road safety change, where the number of accidents is reduced with statistical average of 5000 reduction in the year 2030. These expectations are based on various predictable factors connected with upgrade of car fleet quality and take into account changes in road safety observed in recent years. Based on the current trend of driving automation and rapid development of driver-support systems, the provided estimations were found reliable and likely. The conducted research shows the benefits and the need for the use of driver-assistance systems in vehicles as they can measurably affect the level of road safety.

1. INTRODUCTION

According to estimates by the World Health Organization, each year 1.24 million people around the world are killed in road traffic accidents, whereas the number of injured ranges between 20 and 50 million [1]. The road safety benefits are paramount. Automated vehicles have the potential to remove

human error in road traffic, which will help protect drivers and passengers, as well as pedestrians and bicyclists. In Poland, preliminary forecasts of the reduction in the number of road accidents were made; however, they were based on other assumptions [2]. Therefore, the results of the forecasts presented in the paper are pioneering for Polish road traffic conditions. In England, studies have been carried out to determine the estimated impact of autonomous vehicles on road safety in simulated traffic conditions on the motorway [3]. In addition to road safety reasons, autonomous vehicles pose opportunities pertaining to transportation policies. AV technologies can decrease the transportation cost and increase accessibility and mobility, especially to low-income households and persons with mobility issues [4]. Of course, transport activities should be properly planned so that they could resolve problem of routing and rebalancing a shared fleet of autonomous vehicles. It is essential to providing on-demand mobility within a capacitated transportation network, where congestion might disrupt throughput [5]. In Poland, preliminary forecasts of the reduction in the number of road accidents were made; however, they were based on other assumptions. Therefore, estimating the impact of using autonomous vehicles to increase the level of road safety in Poland is an innovative activity in this regard. The presented forecasts were prepared as part of the work on the AV-PL-ROAD project. The results of the research carried out as part of the project will allow to emphasize the positive effects of the implementation of such systems in a significant number of vehicles on Polish roads. The presented forecasts and guidelines on how to achieve the intended goal may constitute the basis for the creation of a coherent strategy in this regard by the relevant state administration bodies. It is not known whether the results of the research, including the forecasts presented in this article, will somehow influence the creation of transport policy in this area by appropriate institutions. However, it should be hoped that each research and project carried out in this field is a valuable source of knowledge. If the driver-assistance systems are able to reduce the number of events by even a few percent, it will be a measurable social and economic benefit. Obviously, this action will also bring Poland closer to the achievement of the main EU road safety program, which assumes the reduction of fatalities and seriously injured by 50% in 2030 compared with 2020.

Currently, most manufactured vehicles are equipped with systems such as anti-lock braking systems (ABS), traction control, tire pressure sensors, and airbags. Technological development more and more often allows the use of advanced driver-assistance systems (ADAS). The aim of these systems is to improve driving comfort as well as increase road safety. The level of advancement of particular driver-assistance systems may vary depending on the manufacturer. Until recently, these systems were exclusive to premium class cars.

It is estimated that the majority of traffic accidents are caused by human error [6, 7], and therefore, the uptake of safety systems into the car fleet is very important.

However, it cannot be forgotten that improving transportation safety on the roadways thanks to the use of AV is highly dependent on the ability of human drivers to maintain situation awareness and intervene in circumstances that the automation cannot handle. The specificity of automation shows that even as it improves, system autonomy is increasingly likely to reduce the ability of drivers to provide needed oversight [8]. Therefore, the question arises how to approach this problem comprehensively. However, it is anticipated that even in a scenario where drivers' skills deteriorate in the future owing to the widespread use of driver-assistance systems, the benefits will still outweigh the losses from possible system failures. A lot depends on the willingness of drivers to use these systems and a positive perception of these technologies. Moreover, current perceptions of autonomous vehicles are essential. Thus, attention has turned to gauging public perceptions of these autonomous vehicles. To date, surveys have focused on the public as potential passengers of autonomous cars, overlooking other road users who would interact with them. Sex, age, and risk taking had varied relationships with the perceived risk of different vehicle types and general attitudes toward autonomous cars. For instance, males and younger adults displayed greater acceptance. Future studies should therefore continue to investigate people's perceptions from multiple perspectives, taking into account various road user viewpoints and individual characteristics [9].

This paper presents the accident statistics in Poland over the past decade, alongside with an analysis of the main contributory factors to determine the potential impact of these technologies on the level of road safety. It is necessary to analyze the driver-assisting systems, identify the systems with

the greatest potential impact on the road safety, and estimate the number of vehicles equipped with these systems together with determining the potential for reducing the number of road accidents. The forecast for reducing the number of accidents by the 2030 shows potential to reduce them by approximately 5 000, thanks to the use of autonomous systems in passenger cars that support the driver. These estimates were calculated taking into account the potential share of passenger cars equipped with these systems in 2030. This reduction represents approximately 15% of all accidents, taking into account incidents that occurred in 2018, which is the base year for the estimates conducted.

2. CHARACTERISTICS OF ROAD SAFETY IN POLAND IN THE LAST DECADE

Road safety is a very important issue from the point of view of socio-economic development. Limiting the number of accidents is primarily aimed at reducing the number of people killed and injured. Of course, improving road safety also reduces the costs associated with the treatment and rehabilitation of injured people that are recovering after accident. The number of people with disabilities as a result of an accident is also decreasing. A NHTSA study showed that motor vehicle crashes in 2010 costed \$242 billion in economic activity, including \$57.6 billion in lost workplace productivity, and \$594 billion due to loss of life and decreased quality of life due to injuries [10]. The costs of road accidents are huge each year. Social benefits, significant material benefits, and minimizing the costs of lost benefits are also important aspects related to road safety. Prevention of road accidents is connected with the development of the motorization. Until the mid-twentieth century, due to the fewer number of cars on the road and lower speeds achieved, this issue was not analyzed in such detail. During this time, traffic regulations evolved as motorization developed. Unfortunately, for years, Poland has been one of the EU's top countries for road-accident fatality rates. Despite that, it has made significant progress in the last thirty years, with a fatality reduction of more than 60%. During this period, tools for forecasting fatalities were developed and used to identify the main factors that have helped to reduce deaths [2].

Currently, detailed statistics are available, and numerous government and scientific institutions deal with the issue of improving the road safety. According to the [11] National Police Headquarters information, the data for 2018 are as follows. On the public roads, in traffic zones and residential areas, 31 674 road accidents occurred, in which 2862 people were killed and 37 359 people were injured (of which 10 963 people were seriously injured). In addition, police received 436 414 reports regarding road collisions. The data presented in the annual reports also refer to plans and forecasts for the implementation of the National Road Safety Plan 2013-2020. Fig. 1 presents an assessment of the National Road Safety Plan objectives implementation in the year 2018.

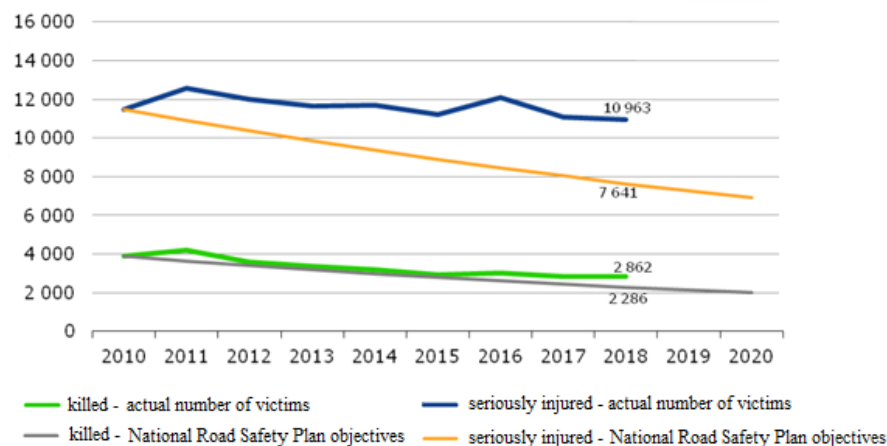


Fig. 1. Measuring achievements of the National Road Safety Plan 2013 - 2020 objectives in the 2018 [11]

The analysis of the road safety statistics from 2018 requires to determine the trend prevailing in recent years. Over the past ten years, the highest number of road accidents and their victims were

recorded in 2009. In 2010, there was a decrease compared with the previous year, whereas in 2011, there was a further increase in number of road accidents. From 2012, there has been a decrease in the number of road accidents and their victims, until 2016, when the number increased again. In 2017, there was a significant decrease compared with the previous year, whereas in 2018, the number of accidents and injuries decreased, but the number of people killed increased.

The pattern of accidents in 2018 is similar to the previous years. The number of accidents involving pedestrians, accidents caused by young drivers, and accidents related to speeding still pose the main threat to life and health of road users. This obviously requires further, intensive corrective actions and intervention in all areas of the road safety.

In 2018, the highest number of road accidents occurred in October (9.9% of the total), May (9.7%) and July (9.6%), whereas the greatest number of people (11.1%) killed in accidents was in October. Accidents in the autumn months are mainly associated with worsening weather conditions, and thus the driver's task becomes more difficult. The increased number of accidents during the summer, as well as in the month of May, is associated with significant traffic caused by holiday and leisure trips. Moreover, the time of day is important, as almost 50% of accidents took place between 13:00 and 20:00, which is linked to peak traffic flows during these hours.

Despite the fact that weather conditions affect the number of accidents, the largest number of accidents occurs in good weather conditions. This may be related to the tendency of drivers to speeding in good weather conditions, and accidents at higher speeds are more likely to result in fatalities [12]. On the contrary, in worse weather conditions, pedestrians are more exposed and they become less visible; therefore, they are more often victims of an accident.

The vast majority of accidents occur in built-up areas: 22 560 such incidents corresponded to 71.2% of all accidents with 1 252 people killed and 25 698 people injured. The number of accidents outside the built-up area was less than 30%; however, more people were killed in them than in built-up areas, i.e., 1610 people (56.3% of total people killed), and 11 661 people were injured.

The main causes of road accidents on straight road sections are listed as follows:

- inappropriate speed in relation to the traffic conditions – 3 234 accidents,
- failure to comply with the right-of-way rule – 2 165 accidents,
- inappropriate and dangerous behaviour towards pedestrians – 1 796 accidents,
- dangerous (too short) distance between vehicles – 1 624 accidents, and
- inappropriate overtaking - 944 accidents.

The main reasons for accidents at priority intersections were as follows:

- failure to comply with the right-of-way rule – 4 699 accidents,
- inappropriate behaviour towards pedestrians – 1 072 accidents, and
- inadequate speed in relation to the traffic conditions – 568 accidents.

Analyzing the causes of accidents, among all the factors that determine road safety (human, road – infrastructure, vehicle), human error is the most commonly reported. In 2018, 27556 accidents were the fault of drivers, i.e., 87% of all accidents. As a result of these accidents, 2177 people were killed and 33261 were injured. The most common were accidents referred to as "collision of vehicles in traffic". In 2018, there were 17041 such accidents, which represented 53.8% of all accidents; in this type of accident, 1269 people were killed (44.3% of all killed) and 21 877 people were injured (58.6% of all injured). Another common type of traffic accident was "running over pedestrian". In the same year, 7 242 such accidents (22.9% of total) were reported, in which 792 people (27.7%) were killed and 6 800 were injured (18.2%). There is still a lot to be done in terms of road safety, and driver-assistance systems can eliminate some of the errors directly related to the human factor. The systems with potentially greatest impact on the road safety are presented the following section.

3. SYSTEMS WITH THE GREATEST POTENTIAL IMPACT ON THE ROAD SAFETY

The set of activities aimed at the development of modern vehicles is primarily the following:

- development of devices supporting the actions of the driver (maintaining the set speed and distance);

- detection of conflict situations;
- development and implementation of autonomous vehicles, electric and hybrid vehicles, and vehicle sharing systems; and
- communication of vehicles with external devices, including communication with another vehicle V2V, with the road infrastructure V2I, with the traffic control system V2C.

According to the presented statistics, the largest number of accidents is caused by human error. Therefore, minimizing, supporting, or eliminating the human factor could increase the level of traffic safety. In 2018, the most numerous groups of perpetrators of accidents were drivers of passenger cars (74.8%), which corresponds to 20 622 road accidents, in which 1 547 people were killed and 25 614 people were injured. Systems that allow driving automation may be a great opportunity to reduce the number of accidents. The most common causes of road accidents include failure to comply with the right-of-way rule in the road traffic, inadequate speed in relation to the traffic conditions, or dangerous distance between vehicles. The following table shows the systems that could be used to avoid certain types of accidents. Table 1 shows the systems that could potentially prevent specific causes of road accidents. Driver-assistance systems are also listed in the table no. 1 and have been combined with the most common causes of road accidents in Poland. The ability to reduce the most common causes of road accidents is very important. Of course, the effectiveness of these systems can only be determined when the driver is able to operate the system, the system is on, and there is no system failure. Therefore, drivers training is extremely important in order to teach them how to use the driver-assistance system. These activities require a lot of work on the part of vehicle manufacturers, equipment manufacturers, distributors, and car dealers.

Another task that allows to achieve the goals of increasing road safety is social acceptance for such systems. It is impossible to take advantage of the available driving-assistance systems when they are turned off by the driver. Presenting estimates that show the positive effect of the use of driver assistance systems on road safety can increase trust and social acceptance of these systems.

To ensure the highest level of road safety, it is necessary to know the way the system works and its capabilities [13]. Systems listed in Table 1 are described in the following section.

3.1. Autonomous Emergency Braking/Automatic braking system

The main task of the system is to monitor the space in front of the vehicle and detect any obstacles. Most systems, currently installed in vehicles, are based on the joint operation of cameras and radars. Some car models are also equipped with stereoscopic cameras and infrared projectors located at the front of the car, e.g., in the headlights. The space in front of the car is monitored all the time and the collision probability is calculated. The vehicle's speed and position as well as its trajectory are analyzed. When an obstacle is detected, the system sends information about the danger to the driver, then moves the brake pads toward the brake discs and increases the pressure in the braking system to strengthen braking power. In the lack of a driver response, the system will attempt emergency braking. Most vehicles, at speeds between 10 and 30 km/h [14-18], can stop in front of an obstacle. At higher speeds, the system's task is to reduce the effects of collisions by reducing speed during the incident and its severity. However, it should be kept in mind that the system was developed for low speeds. Depending on the make, the upper operating limit of the system is 65 - 80 km/h. Most systems detect large objects, such as vehicles, but there are also solutions that can detect pedestrians or cyclists [14-18].

3.2. Blind Spot Warning Systems

This system significantly helps to perform the traffic lane change maneuver. The system's task is to detect vehicles in the so-called blind spot, both to the left and right and vehicles approaching from behind at high speed. If danger is detected, the driver receives a warning. Usually, it involves lighting the diode mounted in the exterior mirror. If, additionally, the driver turns on the turn signal during this time, the messages intensify: the LEDs start to flash and an acoustic signal is generated. In some vehicles, the steering wheel also vibrates. The system is usually based on the data obtained from the

radar or cameras located in the rear bumper or under the exterior mirror. A space of about 3.5 m on both sides of the vehicle is monitored (Fig. 2). The speed at which the system activates oscillates around 10-15 km/h [14-18]. The system is deactivated at approximately 140 km/h. In most vehicles, this system is connected to the systems supporting reversing from the parking space due to the use of the same sensors [13-18].

Table 1

Systems that could potentially prevent specific causes of road accidents

Cause of the accident	Systems that can prevent the cause of accident
Failure to comply with the right-of-way behaviour in the road traffic	Autonomous Emergency Braking/Automatic braking system Blind spot detection Lane Keeping Assist Cross Traffic Alert
Inadequate speed in relation to the traffic conditions	Autonomous Emergency Braking/Automatic braking system Adaptive Cruise Control/Active cruise control Traffic Sign Recognition System Speed assistance systems
Inappropriate and dangerous behaviour towards pedestrians at a pedestrian crossing	Autonomous Emergency Braking/Automatic braking system Adaptive lights/ Adaptive headlights Traffic Sign Recognition System Night vision camera/Night vision systems
Dangerous distance between vehicles	Autonomous Emergency Braking/Automatic braking system Adaptive Cruise Control/Active cruise control

3.3. Lane-keeping assistant and lane-change assistant

These systems require cameras located in the mirrors, which constantly monitor the position of the vehicle in the lane. When it detects that the vehicle is approaching lane boundary without the turn signal on, a warning to the driver is provided. Depending on the vehicle, these can be visual and/or sound signals. More advanced systems also keep the vehicle automatically in the lane. Depending on the manufacturer, the systems operate in different speed ranges. The system's lower operating limit is between 15 and 30 km/h [13-18].

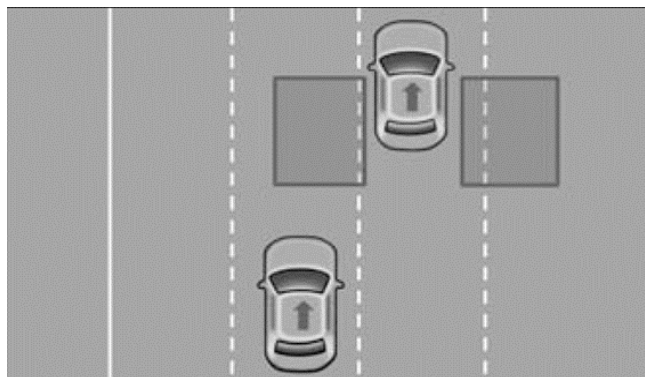


Fig. 2. Zone monitored by the blind spot detection system [14]

3.4. Reversing aid

The system turns on automatically when reverse gear is engaged (Fig.3). Sensors mounted at the rear of the vehicle, usually on the bumper, monitor the space along the vehicle sides. When the transverse movement is detected, a visual or sound warning is generated. If the driver does not react, the vehicle may attempt to brake. Systems manufactured for the Ford [16] make operate when the vehicle reverses at a speed of up to 8 km/h, and the object behind vehicle moves at a speed of 8-30 km/h.

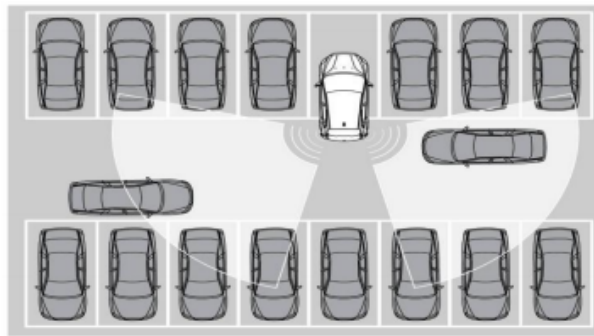


Fig. 3. Operating principle of the reversing aid [13]

3.5. Adaptive, active cruise control

This system allows to set automatic speed adjustment depending on the current traffic situation. The pre-set speed adapts to vehicles in front to keep a safe distance. Thus, the vehicle equipped with this system will slow down when the other vehicle that is running at a lower speed, appears in the same lane. If the traffic lane in front of the vehicle is empty, the system will accelerate to the pre-set speed. Some vehicles, e.g. Volkswagen makes [17], are also able to reduce the speed before road bend. In most vehicles, the system operates in the speed range of 30–210 km/h. As standard, operation of the system is based on the radar. The radar emits a wave and receives it after reflection from the vehicle ahead. Phase shift or reflected wave delay is used to determine the distance between vehicles. Based on this, the relative speeds of both vehicles are determined, so that the system can take appropriate action. In built-up areas, the system with which Skoda vehicles are equipped, can brake with a delay of 8 m/s² and 6 m/s² outside built-up areas [18].

3.6. Road sign recognition system

The task of the system is to recognize the passing road signs and provide information to the driver. In most vehicles, the system reads speed limit signs, limit cancellations, and no overtaking signs.

Some vehicles also recognize traffic bans, warning signs, signs for vehicles with a trailer, or plates placed under the signs informing about e.g. hourly ranges in which a given restriction applies.

The information is displayed on the on-board computer screen. When the driver exceeds the permitted speed limit, a sound signal is emitted and the sign icon is displayed e.g. in red color.

As standard, this system is based on the analysis of the image recorded by a camera mounted in the base of the rear-view mirror. Some systems can compare the read information with the data contained in GPS navigation. This allows the system to inform the driver when the speed limit changes after passing the intersection. Some vehicles are only equipped with a map-based system. In such situations, in cases of newly opened roads or time marking, the information displayed may not be correct.

4. ESTIMATING POTENTIAL CHANGES IN THE NUMBER OF INDIVIDUAL TYPES OF ACCIDENTS DEPENDING ON THE NUMBER OF VEHICLES EQUIPPED WITH THE DRIVER-ASSISTANCE SYSTEMS

To estimate the reduction in the number of accidents depending on the number of vehicles equipped with a driver assistance system, the first thing to do is to evaluate the number of passenger cars equipped with these systems now and over the next decade. In the years 2014–2018, the average annual growth of passenger cars in relation to the entire car fleet was 3.6%. Assuming such a percentage increase year-to-year, in 2030, the number of passenger cars would be around 26.5 million. On the contrary, PwC firm analysts estimate that more efficient use of cars will cause their number to reduce. According to these assumptions, it is estimated that out of approximately 280 million vehicles registered in Europe, only 200 million will remain in 2030 [19]. In line with such assumptions, the car

life cycle should increase, which will be significantly linked to the autonomy in transport and mutual communication between vehicles. Thanks to the systems used, it is assumed to systematically reduce the number of traffic incidents. The costs of vehicle repair and maintenance will also be reduced, and fewer collisions and accidents will have a positive effect on the distance travelled by individual passenger cars [20]. These data indicate that there will be a decrease in the number of passenger cars by approximately 30% within 12 years, i.e., on average 2.5% per year.

Owing to the political system changes, Polish individual automotive market is relatively young and will probably continue to further development and making up for many years of delays arising over the last few decades. In such a situation, intermediate assumptions should be made, according to which, owing to the autonomization, the market will develop all the time, but slightly slower than in the recent years. Taking into account two values, i.e., the current percentage of the development trend of passenger cars' fleet in Poland (an increase of 3.6% per year) and possible decrease in their number due to autonomy (mentioned earlier decrease by 2.5% per year), the difference of these values can be assumed (an increase of 1.1% per year) as an indicator of growth for the passenger car fleet in Poland over the next decade. According to the adopted assumptions, in 2030, 19 805 400 passenger cars will be registered and used in Poland. The forecast for the total number of passenger cars in Poland until 2030, presented in another source by Jan Burnewicz [21], indicates that this number may increase up to 23 million cars. To average the assumptions, the numerical value of the passenger car fleet in Poland for these two calculations is estimated as 21 402 700 cars in 2030.

Having determined the estimated size of the passenger car fleet in 2030, the impact of using collision avoidance systems in the vehicles, at the level of the road safety in such a time perspective, should be considered. Examining the trend of recent years for various road incidents, in most cases, a systematic, although slow decrease in the number of incidents is noted. Over ten years (2009-2018) the number of accidents decreased by 12 522 incidents; it is a decrease of about 28 percentage points.

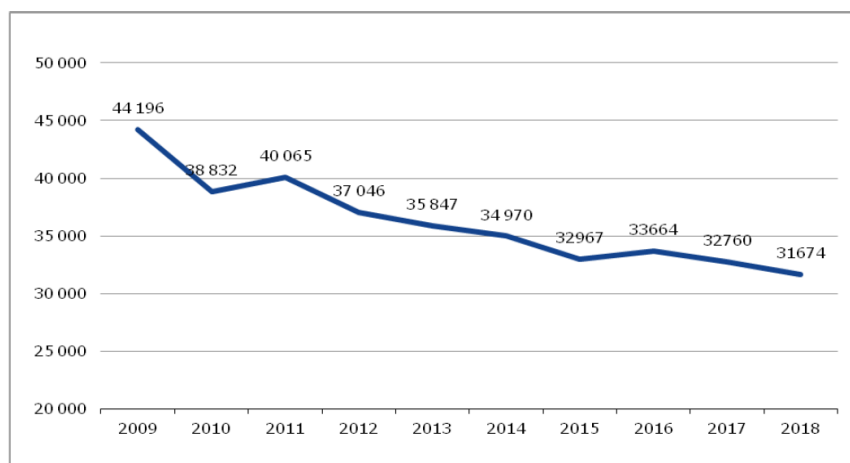


Fig. 4. Number of accidents in the years 2009-2018 [22]

According to Fig.4, there were 2.8% fewer accidents year on year. If this trend was maintained until 2030, the number of accidents would decrease by another 33.6%, i.e., lower by more than 9000 accidents.

These are estimates that relate to all accidents, regardless of their types, causes, or type of vehicles involved in the incident. In order to relate these data to the effectiveness of collision-avoidance systems, they should be correlated with other estimates, described later in the article.

The application of collision-avoidance systems can have a major effect on the level of road safety, especially over the next ten years. Currently conducted activities are aimed at increasing the autonomization of transport, but at present, these activities are at initial stages of intensive research and initiatives of this type. The potential for using these systems to increase road safety is enormous. In June 2019, two American research institutes, Highway Loss Data Institute and Insurance Institute for Highway Safety [23], conducted research on the effectiveness of selected systems, which provide real benefits of using collision avoidance technology. During the research, the institutes relied on a

comparison of data reported by the police (regarding collisions and accidents) and data on insurance claims from users of vehicles equipped or not equipped with a given driver-assistance technology. Information on the operating effects of five driver assistance systems is as follows:

- Forward Collision Warning (system warning of possible collision with a vehicle in front), allows to achieve the following:
 - 27% fewer rear collisions,
 - 20% fewer rear collisions resulting in an injury to someone from the accident/collision participants,
 - costs of claims from damage to other vehicles lower by 9%, and
 - costs of claims for injuries suffered by people in another vehicle lower by 16%.
- Forward Collision Warning Plus auto-brake – FCW Plus (an alert system about a possible collision with a vehicle in front, together with the use of an automatic braking system), allows to achieve the following:
 - 50% fewer rear collisions,
 - fewer rear collisions by 56%, as a result of which an accident/collision participant was injured,
 - lower by 13% costs of claims for damage to other vehicles, and
 - lower costs of claims, by 23%, for injuries suffered by people in another vehicle.
- Lane Departure Warning (lane keeping assistant) enables to achieve the following:
 - 11% fewer collisions/accidents involving a single car, as well as those related to frontal and side impacts, and
 - 21% fewer people injured as a result of collision/accident involving a single car, as well as those related to frontal and side impacts.
- Blind Spot Detection (blind spot warning system) allows to achieve the following:
 - fewer accidents/collisions, by 14%, related to the lane changes,
 - fewer accidents/collisions, by 23%, related to the change of lane as a result of which an accident/collision participant was injured,
 - lower by 7% costs of the claims for damage to other vehicles, and
 - lower costs by, 8%, for injuries sustained by people in another vehicle.
- Rear Automatic Braking (automatic braking system when reversing) enables to achieve the following:
 - fewer collisions/accidents, by 78%, when reversing (in combination with the camera and parking sensors),
 - less costs of claims, by 12%, resulting from damage to the vehicle, and
 - less claim costs, by 30%, arising from damage to another vehicle.
- Rear-view Cameras allow a 17% reduction in the number of collisions/accidents when reversing.
- Rear Cross-Traffic Alert (system observing space behind the car entering perpendicularly the transverse road) allows a 22% reduction in the number of collisions/accidents when reversing.

Moreover, in England, the safety impact of connected and autonomous vehicles on motorways was evaluated. However, the evaluation of their safety impacts has been a major challenge owing to the lack of real-world CAV exposure data. More specifically, the developed CAV control algorithm allows a CAV, for the first time, to have longitudinal control, search adjacent vehicles, identify nearby CAVs, and make lateral decisions based on a ruleset associated with motorway traffic operations. A motorway corridor within M1 in England is designed in simulation program and employed to implement the CAV control algorithm. Five simulation models were created, starting with the model of CAV market penetration 0%. The results show that CAVs bring about compelling benefit to road safety as traffic conflicts significantly reduce even at relatively low market penetration rates. Specifically, estimated traffic conflicts were reduced by 12–47%, 50–80%, 82–92%, and 90–94% for 25%, 50%, 75%, and 100% CAV penetration rates, respectively. The results indicate that the presence of CAVs ensured also efficient traffic flow [3].

Currently, initiatives implemented in Europe include an integrated approach to the road safety policy together with vehicle and infrastructure safety measures based, among the others, on combined and automated mobility. Looking at it from a Polish perspective, the European Commission intends to introduce mandatory safety functions that will reduce the number of accidents and allow the development of connected and automated driving concepts. According to these guidelines, new car models would be equipped with such systems, as e.g. advanced emergency braking system, lane-keeping assistant, or pedestrian and cyclist detection system. According to information on these initiatives, the use of such systems will save up to 10500 people within 10 years and avoid 60000 accidents in which victims are seriously injured. These projections cover the period 2020–2030, and the actions are expected to contribute to achieving the EU's long-term goal of bringing the number of fatalities and persons seriously injured to zero by the 2050. This is the so called "Vision Zero". Reaching the goals of Vision Zero requires the use of new ideas, as well as new technologies and management systems. Management systems should take into account human behaviour–road user, modern vehicles, safe road infrastructure, mobility management, and development of the road safety system. The strategy proposed by the commission aims to make Europe a global leader in the field of fully automated and connected mobility systems. Thanks to these solutions, transport is to be safer, cleaner, cheaper, and more accessible to the elderly and people with reduced mobility [24]. According to the European Parliament's forecasts, in 2025, automated vehicles should account for 20% of all cars sold in the world [25, p. 2]. In turn, according to data from the PwC report, in 2030, there will be 27.1 million autonomous cars of levels four and five in the European Union. In 2017, around 275.3 million passenger cars were registered in the European Union [19, p. 211]. Of these, 32.6 million were, the so-called, connected vehicles, which are partly autonomous and can be assumed to have been fitted with simple driver-assistance systems. This figure represents 11% of all passenger cars [20].

In order to analyze the reduction in the number of incidents due to the use of driver assistance systems, the current number of vehicles on the Polish market equipped with such systems should be calculated. Assuming that most of the autonomous systems are relatively new, the analysis should take into account primarily passenger cars up to 4 years old, which constitute 12.1% of the entire passenger car fleet. Another reference point for estimating this number is the market share of, so-called, premium makes, whose cars are often equipped with the latest systems available on the market. In the report of the Polish Automotive Industry Association [19], it can be read that the increase in registration of premium makes has allowed to gain about 14% of the entire market.

If the aforementioned data were referred to the Polish passenger car fleet, various development variants could be created regarding the number of cars equipped with the driver-assistance systems.

In the so-called "Optimistic variant", it could be assumed that all premium makes are equipped with such systems. However, the 14% market share of these cars is relatively high and it seems that not all cars classified as premium make have autonomous driver-assistance systems. This share seems too high due to the characteristics of the Polish passenger car fleet and the period since these types of systems have been introduced. For example, new passenger cars of premium makes from 5 years ago (2014 year) were equipped only with simple support systems (SAE Level 1). In fact, only in the last few years has there been more intensive development of autonomous systems in vehicles that are designed to support the driver. That is why older vehicles classified even as so-called premium makes will not always be equipped with these systems.

The second variant is the estimated share of this type of cars in the range of 10-11%. Adopting such a percentage is based primarily on the analysis of the number of passenger cars in the entire fleet in the age of up to four years old and on the data available in the PwC report specifying the number of so-called connected cars. For similar reasons as described before, this percentage seems a bit too high for the Polish car fleet. Many new vehicles belong to the lower segments and usually they are not yet equipped with this type of systems. In Poland, in 2017, there were 22569.9 thousand registered passenger cars (rounded up to 22.6 million). Assuming an index of 11% of vehicles equipped with driver-assistance systems, about 2.4 million passenger cars would be equipped with such systems in 2017, which is a relatively high result.

Another variant is based on the analysis of passenger cars from individual market segments, for which it can be assumed that new vehicles should be equipped with driver-assistance systems. These

vehicles mainly include minibuses, large MPVs, large SUVs, sport and cabriolet/convertible cars, as well as F, E, and D segment vehicles. For the aforementioned segments, an index of 75% of cars equipped with this type of assistance systems was adopted. A 25% index was adopted for small and medium segment vehicles. This index applies to the first registrations of new passenger cars in 2017–2018. Taking into account the aforementioned assumptions and calculations, it can be assumed that in 2018, 143 440 passenger cars equipped with autonomous systems supporting the driver were registered. In the entire passenger car fleet, this sum accounts for 0.83%. A similar percentage share can be used for the estimates in subsequent years, but it is not the current percentage of market share. Assuming that these systems have been used for several years (e.g. Lexus introduced the Lexus Safety System for the first time in 2015), and assuming that in the years 2014–2018, number of cars equipped with autonomous systems assisting a driver were growing at level 0.83% every year, in 2018, the estimated market share of these cars was 4.15%, i.e. 720 805 passenger cars.

In connection with the presented estimates and assumptions, it seems the most appropriate to assume the share of this type of vehicles in the entire passenger car fleet in Poland at the level of 4.15% in 2018. Therefore, the first estimated value of reducing the number of accidents assumes the number of accidents reduced by the value of increasing the number of vehicles with autonomous systems by about 0.83% every year. According to the presented assumptions, in 2030, the number of passenger cars equipped with autonomous systems will be 3019921.

Another variant specifying the reduction in the number of accidents by the 2030, taking into account the increase in the number of passenger cars equipped with autonomous systems divided into different age groups is the progressive one. Adopting the progressive variant for analysis, three age groups of passenger cars were taken into account, which were included in the forecast until 2030: cars up to 4 years old, 5–10 years old, and 11–20 years old. For example, estimates for the last age group start from 2026, when this age is reached by cars equipped with systems currently being implemented in new passenger cars. For this variant, the percentage of cars in each of the age groups was adopted in accordance with the age structure of passenger cars at the end of 2018 [19, p. 24]. In total, for the 2030, a projected number of 3883670 passenger cars equipped with autonomous systems aimed at avoiding collisions was obtained. This number represents 18.15% of the total estimated passenger car fleet. Assuming the results obtained in this variant, the number of accidents will reduce by approx. 1.17% year on year.

The third variant is average and defines the reduction in the number of accidents by the 2030, taking into account the increase in the number of passenger cars equipped with autonomous systems by trend in registration of specific age groups of passenger cars. In this option, the analysis of the percentage share of passenger cars by age structure was based on the trend of the last 10 years. According to the forecast, in 2030, a total of 3647038 passenger cars will be travelling on Polish roads equipped with autonomous driver-assistance systems designed to avoid collisions. This number represents 17.04% of the total estimated passenger car fleet. The number of accidents will be reduced by approx. 1.07% on a year-to-year basis, due to the increase in the number of vehicles with autonomous systems by the same value year-to-year.

The fourth variant, the most optimistic, assumes the adoption of a coefficient of 2.78%, year-to-year, in the reduction of accidents, which was calculated when analyzing the types of traffic incidents in 2018. In 2018, approximately 878 accidents were avoided due to the type of accident and thanks to the use of autonomous systems in 4.15% of passenger cars. Estimated number of accidents by the types, that were avoided, accounted for 2.78% of all accidents in 2018. This value is very close to the trend that has occurred in recent years (2.8 percent decrease in the number of accidents) and will allow to reduce the number of accidents in 2030 to about 22.5 thousand (see table no. 2).

Adopting the aforementioned data, the potential to reduce the number of road incidents for such a percentage of passenger cars equipped with these systems should be determined. In later section, a potential reduction in the number of accidents according to four estimates is shown. The compilation of estimates is shown in Table 2 [Authors' own compilation].

The forecast for reducing the number of accidents by the 2030 shows potential to reduce them by approximately 5 000 (average value for four estimates), thanks to the use of autonomous systems in passenger cars that support the driver. These estimates were calculated taking into account the

potential share of passenger cars equipped with these systems in 2030. This reduction represents about 15% of all accidents, taking into account events that occurred in 2018, which is the base year for the estimates conducted

Table 2

Forecast of reducing the number of accidents by the 2030, in accordance with the assumptions adopted for all the described forecasts and average values for these variants

Year	Estimated number of accidents reduced by approx. 0.83% from year to year	Estimated number of accidents reduced by approx. 1.07% from year to year	Estimated number of accidents reduced by approx. 1.17% from year to year	Estimated number of accidents reduced by approx. 2.78% from year to year	Average for four estimates
2018 (base year)	31 674 (base data)	31 674 (base data)	31 674 (base data)	31 674 (base data)	31 674
2019	31 411	31 335	31 303	30 793	31 211
2020	31 150	31 000	30 937	29 937	30 756
2021	30 891	30 668	30 575	29 105	30 310
2022	30 635	30 340	30 217	28 296	29 872
2023	30 381	30 015	29 863	27 509	29 442
2024	30 129	29 694	29 514	26 744	29 020
2025	29 879	29 376	29 169	26 001	28 606
2026	29 631	29 062	28 828	25 278	28 200
2027	29 385	28 751	28 491	24 575	27 801
2028	29 141	28 443	28 158	23 892	27 409
2029	28 899	28 139	27 829	23 228	27 024
2030	28 659	27 838	27 503	22 582	26 646

It seems that the estimates for the four variants presented in the table are not exaggerated, and it is assumed that their credibility is quite high. The reduction of accidents at the level of 15%, thanks to use of the driver assistance systems, in the average result of four estimates, seems to be correct. The estimated market share for vehicles equipped with these systems does not exceed 20% in 2030, and the reduction in the number of accidents is 15%. These results are similar or a bit worse than the results of simulation studies investigating a similar dependency that were carried out in England (25% market share, 12-47% fewer accidents) [3]. Lower estimated market share of vehicles with this type of systems compared with Western European countries is associated with the wealth of the Polish society and accessibility of new, well-equipped vehicles. Positive changes in this respect will intensify and will continue, but Poland will still have to catch up distance in this respect. Moreover, the process of educating the society on appropriate road safety behaviours is delayed because the development of individual motorization has a shorter history than in other Western European countries. Therefore, the presented assumptions seem correct, despite the fact that the reduction of accidents by 5,000 (15% lower accident rate) till year 2030 is not such a significant value. It does not change the fact that the more widespread use of driver assistance systems will save many lives and obtain measurable social and economic benefits.

5. SUMMARY

With the increase in vehicle automation, human participation in the control process decreases. Certain activities are carried out by the system, and the role of the driver is to control the road situation and respond appropriately (as soon as possible) in an emergency. Elimination or minimization of the human factor in the vehicle control process could have a positive effect on the level of the road safety. In order to ensure the highest level of safety, it is necessary to know how the system works and its capabilities. Therefore, it seems necessary to design systems ensuring the highest level of understanding [26].

Some of the driver-assistance systems, in accordance with the guidelines of the European Parliament, will be compulsorily installed in new vehicles. There is a second point that remains, as many drivers as possible should be persuaded to actively use these systems. Unfortunately, equipping a vehicle with a driving-assistance system, is not always synonymous with the tendency of drivers to turn on these systems. Therefore, the effectiveness of these systems should be described as often as possible, what could encourage drivers to widespread use them. Among other things, such publications may influence the awareness of drivers. This information should be disseminated to the widest possible audience, as these systems help save lives and reduce the severity of accidents.

The estimates presented were based on numerous expert analyses. The process of combining forecasts contained in the expert analyses, including individual assumptions, allows to work out a kind of compromise expectations in relation to the studied phenomenon. The conclusions from the forecast for 2030, which are presented in this article, have been prepared assuming various types of processes related to the road traffic, development of the car fleet, and road safety in Poland. These processes are predictable, which means that their condition can be determined based on current trends and future determinants with a high degree of probability. The presented forecast is an objective characteristic of the possible future scenarios for reducing the number of accidents and development of the fleet of passenger cars equipped with autonomous driver-assistance systems. The forecast presents several variants of estimating this phenomenon, both more and less optimistic.

The presented research results show the need for further research related to the development, testing and evaluation of driving-assistance systems. Various educational campaigns for road safety are currently being carried out, among them there could be campaigns showing the advantages of such systems. The sooner education starts in this regard, the better results and the greater social confidence in new technologies will be achieved in the future.

Acknowledgment

The publication presents fragments of analyses performed as part of the AV-PL-ROAD “Polish Road to Automation of Road Transport” project, financed by the National Centre for Research and Development. The article has been presented on 13th International BRD GAMBIT 2020 Conference. Co-funded by the Science Excellence programme of the Ministry of Science and Higher Education.

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