TRANSPORT PROBLEMS 2024 Volume 19 Issue 4
PROBLEMY TRANSPORTU DOI: 10.20858/tp.2024.19.4.01

Keywords: transport; road transport; deaths in road accidents; multidimensional comparative analyses; security; AI

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THE APPLICATION OF ARTIFICIAL INTELLIGENCE IN ROAD TRAFFIC MANAGEMENT AND ITS SAFETY IMPROVEMENT

Summary. Artificial intelligence (AI) is used in many aspects of life, from personal voice assistants to product recommendations in online stores to advanced diagnostic systems in medicine. All these applications show how AI technology is becoming an increasingly integral part of everyday life. Understanding the basics of AI is key to recognizing its role in traffic management. AI can be used to monitor and control road traffic, prevent traffic jams and road crashes, support vehicle diagnostics, and optimize response times for emergency services and roadside assistance. Particular attention should be paid to reducing the number of fatal road crashes. This goal is to be achieved by integrating AI with autonomous vehicle technology, which should improve or even reduce the number of road accident victims to 0.

1. INTRODUCTION

The 21st century is characterized by the rapid development of digital technology, which has had a tremendous impact on smart global transportation technology. The intelligent traffic management model created by new technological innovations such as big data, the Internet, artificial intelligence (AI), and the so-called blockchain (digital ledger system) provides a wealth of application scenarios [18]. Countries that are interested in effectively managing intelligent transportation systems are successively issuing relevant policies on transportation capacity, new infrastructure, and digital transportation in order to provide guarantees and guidelines for high-quality smart transportation development.

A report by the World Health Organization (WHO) showed that the number of deaths from traffic accidents dropped to 1.19 million in 2021. This was 5% less than in 2010 (1.25 million deaths) [20]. The decrease in deaths was evident even though the number of motor vehicles in the world has more than doubled, road networks have expanded, and the Earth's population has grown by nearly a billion. So, improvements in road transport safety are evident, but there is still much to do to achieve the goal of the UN Decade of Action for Road Safety 2021–2030 to reduce deaths by 50% by 2030.

The rapid development of cities, especially those that aim to acquire the status of smart cities, has forced investment in integrated and sustainable transport. In addition to the loss of human life, traffic congestion and accidents have a significant impact on the economy, causing losses of productivity and increased healthcare costs. One of the most serious transport-related challenges is traffic congestion, which will increase with the development of cities and directly affect their socio-economic activities based on integrated and sustainable transport. The integration of transport management with advanced

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technology will also greatly help in achieving the goals of smart cities [13]. However, the WHO states that AI could help decrease these numbers by half by 2030.

The European Union (EU) has set a similar goal. In 2018, the European Commission set the target of reducing road deaths by 50% and serious injuries by 2030. This is set out in the Commission's Strategic Road Safety Action Plan and the EU Road Safety Policy Framework for 2021–2030, which also presents road safety plans to achieve zero road deaths by 2050 ("vision zero") [1]. In March 2023, the commission presented a package of proposals on road safety, including updated driving license requirements and better cross-border enforcement of road traffic rules [5].

The EU countries were selected for detailed analysis, with a particular focus on Poland. This choice was dictated by the fact that Poland ranks fourth (after France, Italy, and Germany) in terms of the number of road crashes. In addition, the number of people killed in these road crashes is high, ranking fifth among EU countries (after Romania, Bulgaria, Latvia, and Croatia).

According to statistics from the Police Headquarters, in 2023, there were 20,936 road accidents in Poland, and 1893 people died as a result. This means that last year, as a result of road accidents, on average, five people died every day, 66 were injured, and the average number of collisions was over 1000 a day. Therefore, this is a serious problem in Poland. The term "traffic safety" includes issues related to ensuring the safety of all road users [8, 9], and the ongoing National Road Safety Program for 2021–2030 indicates the most important challenges, such as [14]:

- the implementation of a road traffic safety management system based on the most effective solutions;
- the safe and responsible behavior of all road users;
- increasing road traffic safety by implementing optimal infrastructure solutions and effective speed management;
- a high level of safety for all vehicles on the road;
- quick and effective rescue and post-accident care.

Given the above-mentioned problems, it can be assumed that AI, when used on a large scale, will contribute to the reduction and even elimination of road crashes, including fatal ones. It will also be the basis for the implementation of intelligent transport systems (ITSs), which is already being done in many cities around the world, contributing to the improvement of road traffic safety, with unlimited development prospects.

AI technology is concerned with creating intelligent machines. It can perform tasks that require human intelligence and encompasses a variety of technologies, including machine learning and natural language processing. Understanding the basics of AI is key to recognizing its role in traffic management. Moreover, the integration of AI with autonomous vehicle technology has enormous potential to revolutionize transport, making it economically efficient, safe, and environmentally friendly. Given that many accidents are caused by human error, autonomous cars can reduce the number of crashes; they can also improve traffic efficiency and reduce traffic jams and fuel consumption. This will have a positive impact on environmental sustainability.

The purpose of the paper is to present solutions for the use of AI in traffic management, taking into account innovations resulting from the development of AI, intelligent transportation systems, and research on autonomous vehicles. The authors try to answer the research problem of how AI can be used to improve traffic safety, including the reduction of traffic accidents, especially those with fatal consequences. This article presents the issue of the development of intelligent transportation systems, along with the question of the development of AI. The possibility of its use to reduce traffic problems and the number of traffic crashes is also pointed out. The final part of the article presents the development of research on autonomous vehicles, which can contribute to increased safety in the transportation of people and goods.

2. RESEARCH METHODOLOGY

Industry 4.0 is setting new standards for solutions related to information and communication technologies that process, collect, and transmit information in electronic form. For the analysis of general concepts, the authors used the desk research method. This is a method known as "desk research," which involves reaching for foundational data (e.g., websites, archives) for inclusion in the research process. Sources of foundational data have many advantages for social researchers. First and foremost, using them generates little cost because the available analyses are cheaper than performing surveys or generating reactive data. Moreover, in the case of desk research, there is no influence of the researcher on the subject of the study. It was assumed that the research would be based mainly on the analysis of available studies and materials enabling the review and organization of information about AI, ITSs, and autonomous vehicles. The authors studied domestic and foreign scientific publications, transport industry magazines, and materials published on websites that concerned the practical use of the above-mentioned systems. The primary research focused on statistical analyses of the number of road crashes in the EU, including fatalities.

The purpose of using this method was to obtain data on the effects of actions to use AI to improve road safety. The desk research analysis made it possible to preliminarily determine the relationships between documents, the results of actions taken by relevant institutions, and other parameters that could be checked.

The results show that AI, which is rapidly entering many areas of modern human life, will be widely applied in transport. Many cities around the world have already integrated ITSs, which have contributed to the development of smart cities. The widespread use of autonomous vehicles may further revolutionize the standard of living and the way people communicate, contributing to an increase in safety. However, this does not mean that the processes taking place are fully safe, which should also be remembered when becoming fascinated with AI and its derivatives.

3. DEVELOPMENT OF INTELLIGENT TRANSPORT SYSTEMS

The concept of ITSs results from the use of modern technological and organizational solutions in transport. These systems facilitate the control of the road network and increase the safety of drivers and passengers. Traffic management using IT solutions is called an ITS. At the 1st World Congress of Transport Systems in Paris in 1994, the following definition was adopted: ITSs are systems of various technologies (telecommunications, information, automation, and measurement) that are related to different types of transport and traffic management. They are used to protect the safety and mobility of passengers and goods, as well as to improve the quality of transport services and increase the efficiency of the entire urban transport system (including the reduction of operating costs and the improvement of the city's competitiveness) while limiting the degradation of the natural environment [7].

The advantages of ITSs according to international literature are:

1. The integration of information technologies (Internet of Things (IoT), cloud computing, Big Data, mobile Internet) [11].
2. Processing of real-time traffic information using information technologies.
3. Cooperation between people, vehicles, roads, and the environment for road safety.
4. The use of traffic information as an application service to improve the performance of existing road facilities [2].

Polish scientific literature [8] lists the following scope of services provided by ITSs:

1. Market services, including supporting transport planning (obtaining orders, completing shipments, etc.) and monitoring shipments.
2. Traffic management, including the enforcement of traffic regulations, incident management, and infrastructure management (traffic control, the creation of intelligent intersections).

3. Vehicle management, including information on road conditions, automated vehicle driving, advanced vehicle condition monitoring systems, the implementation of necessary administrative activities, automatic inspections of vehicles along the route for safety, and monitoring driving safety.
4. Public transport management, including the management of transport and vehicles used in public transport.
5. Safety management, including information about accidents, information about the transport of dangerous goods, and the management of rescue operations.
6. Electronic toll collection, including electronic toll collection systems for the use of transport infrastructure.
7. Customer service, including information for travelers and drivers before and during trips and electronic ticket sales.

The implementation of effective ITSs will result in an increase in street capacity, a reduction in time losses during movement, and improvements in road traffic safety, the effectiveness of rescue services, and environmental quality.

It is worth noting that ITSs are not free from disadvantages. First of all, even gradually implemented systems generate substantial costs, which are often not directly related to an increase in income from the use of public transport. Moreover, in most cases, urban infrastructure is not adapted to the implemented system, which often causes chaos on the roads, long-term renovations, or system failures.

4. OPERATION AND APPLICATION OF AI IN COMMON USE

AI, despite its common use in scientific discourse and public information, is not easy to define precisely. In general, it is a branch of computer science dealing with the construction of machines and algorithms whose operation is characterized by features typical of intelligence (i.e., the ability to spontaneously adapt to dynamic environmental conditions, learn, engage in abstract reasoning, and make complex decisions. The subject of AI involves the study and determination of rules that control the intelligent behavior of human beings and their subsequent application in computer programs and algorithms. Hence, the field of computer science that conducts research on intelligence by modeling intelligent behaviors and computer programs that simulate these behaviors is called AI [15].

Computer science is not the only field in which research on AI is conducted. Due to the specificity of this issue, work in this field also involves psychologists, mathematicians, cognitive scientists, and even philosophers. At the same time, it should be emphasized that the concept of AI is ambiguous and refers not only to a branch of science but also to the material products of its research (i.e., machines and devices using algorithms similar to human reasoning processes), as well as to advanced computer techniques used for “teaching” machines.

One of the first people to use the term "artificial intelligence" was John McCarthy in 1956, who defined this term as "the science and engineering of creating intelligent machines" [19]. More contemporary definitions describe AI as “the ability of a system to correctly interpret external data, learn from it, and use this knowledge to perform specific tasks and achieve goals through flexible adaptation” [7].

AI is used in many aspects of our lives, from personal voice assistants to product recommendations in online stores to advanced diagnostic systems in medicine. Such applications show how AI technology is becoming an increasingly integral part of everyday life. Currently, the main goal of researchers working on AI is to construct machines and computer programs that can perform specific functions of the human mind and senses and are not subject to algorithmization (i.e., reducing them to a closed sequence of specific activities that are necessary to perform one task).

All these and future attributes of AI have their applications and are used in various aspects of road traffic management, especially in terms of the number of road accidents.

5. ROAD CRASHES AS A THREAT TO ROAD SAFETY IN THE EU

Road crashes recorded in EU countries still pose a serious threat to human life and health, as indicated by the results of statistical research. This research began by outlining data on the number of road crashes in 31 European countries from 2020–2022 (Fig. 1).

The data presented in Fig. 1 show that from 2020–2022, there was an increasing trend in the number of road crashes in the 31 considered European countries. The increasing trend can be described by the following linear function: Y= 18270.67+929.5*x. In 2020, a total of 19,162 crashes were recorded in 31 EU countries. This number increased to 20,206 in 2021 and 21,021 in 2023.

For illustrative purposes, Fig. 2 presents the number of crashes between 2020 and 2022 in EU countries.

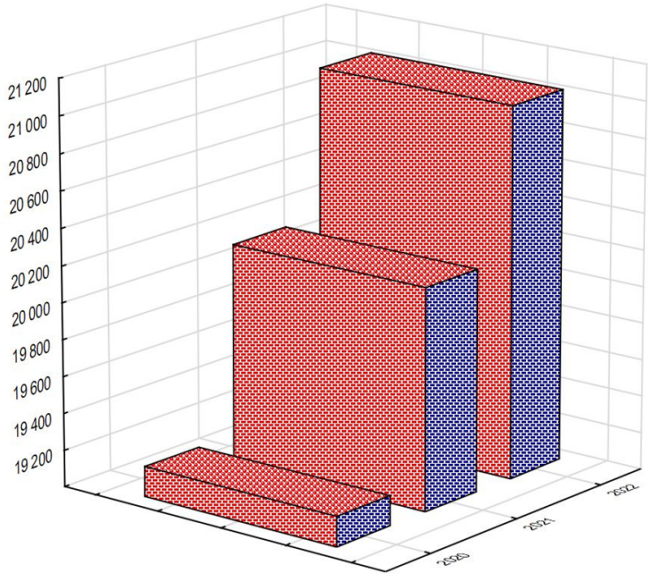

Fig. 1. Bar chart of the number of road accidents in 31 European countries in total between 2020 and 2022. Source: [6]

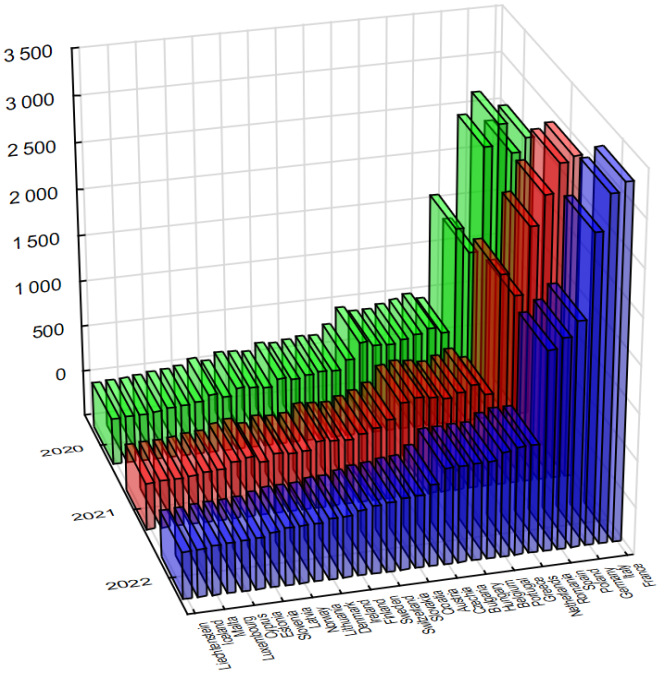

Fig. 2. Number of road accidents in 31 respective EU countries between 2020 and 2022. Source: [6]

The analysis shows that the largest number of crashes among the 31 considered countries in 2022 took place in France (3260). In second there was Italy, (3159 crashes). Germany was ranked third (2788 crashes). Poland was in fourth place (1896 crashes). It was observed that in 23 of the 31 European countries, there was an increasing trend in the number of crashes between 2020 and 2022, while there was a decreasing trend in the remaining eight.

Regarding fatalities recorded as a result of road crashes, the data presented by the European Road Safety Observatory (ERSO) for 2021 [3] shows that approximately 19,900 people died and over 900,000 were injured. Fig. 3 shows the average rate of road crash fatalities per million inhabitants. In the EU in 2021, this index was 45, whereas it was 59 in Poland. For comparison, in 2010, the average index was 67 in the EU and 103 in Poland.

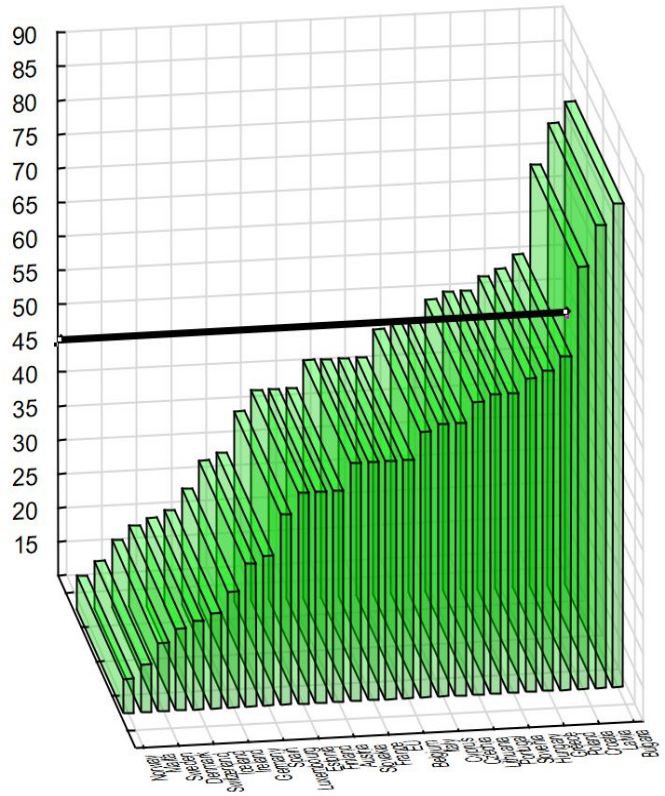

Fig. 3. Average road fatality index in the EU per million inhabitants. Source: [22]

Across the EU, the number of road fatalities in 2023 decreased by 1% compared to 2022, and approximately 2360 fewer fatalities occurred (-10%). Since 2019, the number of road deaths has decreased slightly in Spain, France, and Italy but has increased in Ireland, Latvia, the Netherlands, Slovakia, and Sweden. However, over the last four years, Belgium, the Czech Republic, Denmark, Hungary, and Poland are on track to achieve the target leading to the reduction of road deaths and serious injuries by 50% by 2030 [3].

6. USE OF ARTIFICIAL INTELLIGENCE IN ROAD TRAFFIC MANAGEMENT

In recent years, AI has begun to play a key role in road traffic management. Owing to its ability to analyze enormous amounts of data in real time, AI contributes to increasing the efficiency, safety, and flow of road traffic, constituting the basis of ITSs [10].

AI in road traffic management uses advanced algorithms to analyze data from various sources, such as cameras, motion sensors, GPS data, and information from social media. Such data is then processed to optimize traffic lights, predict traffic patterns, and respond to changing road conditions. This makes

dynamic traffic management possible, which results in reduced congestion, improved road capacity, and increased road safety [12]. AI systems can analyze road accident data to identify the most common causes of collisions and suggest changes to road infrastructure or signposting that could prevent future accidents. Additionally, AI can be used to monitor drivers' behavior and detect dangerous situations, such as driving under the influence of alcohol or driver fatigue. Increasingly, AI is being used in the following areas:
- automatic accident detection: AI systems can be used to monitor road traffic and automatically detect crashes. By analyzing data from cameras and sensors, AI may quickly identify emergency situations and notify emergency services;
- response time optimization: AI can analyze data on road traffic, weather conditions, and incident locations to determine the most efficient routes for roadside assistance vehicles. This can significantly shorten the response times and the time required to arrive at the scene of the accident;
- support in vehicle diagnostics: AI can be used for remote vehicle diagnostics, which allows for the faster identification of problems and more effective provision of roadside assistance services at the scene of the accident.

Cities throughout the world are already implementing AI systems for road traffic management. In Singapore, for example, AI systems are used to monitor and respond to traffic congestion, allowing traffic to be quickly redirected and delays minimized. In Europe, cities such as Amsterdam and London are using AI to analyze traffic patterns and optimize traffic lights, which contributes to smoother traffic flow.

In the future, AI in roadside assistance may be closely linked to the development of autonomous vehicles and the Internet of Things (IoT). Vehicles equipped with advanced AI systems will be able to automatically communicate with roadside assistance centers in the event of a breakdown or accident.

7. AI INTEGRATION WITH AUTONOMOUS VEHICLES

One way to reduce the number of road crashes in the world is to introduce autonomous vehicles to the market. The development and integration of autonomous vehicles are of great importance at the meeting point of technology, safety, and social impacts. However, achieving benefits depends on technological, governmental, and ethical solutions, as well as the level of AI implementation. Autonomous vehicles will be able to communicate with traffic management systems, which will allow for even greater optimization of traffic flow. They will also be able to adjust their routes and speeds in real time to respond to changing road conditions, helping to reduce congestion and improve safety. This is not a cheap or easy issue to implement, as it requires enormous amounts of funds and time to adapt the road infrastructure.

The issue of widespread use of autonomous vehicles requires a lot of advanced research in this area. The most advanced research in this field has been conducted in the United States since 2014. To encourage innovation and better understand the performance and limitations of autonomous vehicles, the country's Department of Motor Vehicles (DMV) has begun testing autonomous vehicles through the Autonomous Vehicle Tester (AVT) program. Within such a program, test vehicles require the presence of a human in the driver's seat who can take control of the vehicle at any time [4]. The present research analyzed data obtained from the DMV's website regarding collisions related to autonomous vehicles in the United States. Manufacturers of autonomous vehicles who test them must report a collision that resulted in property damage, injury, or death within 10 days of the incident to the DMV [4]. The data studied in the article is only available in this aspect from the DMV's website in the United States. The data downloaded for the study contained in the reports is used by the DMV to solve existing problems and is the foundation for exploring new possibilities in the context of managing autonomous vehicles.

The information presented in Fig. 4 shows that from January 2018 to April 2024, 651 collisions involving autonomous vehicles were recorded in the United States. By far, the most collisions were

recorded in 2022, and the fewest were recorded during the COVID-19 pandemic in 2020. Data on autonomous vehicle collisions in 2024 covered the period from January to April.

The above-mentioned analysis indicates that the number of collisions in respective months is irregular, oscillating around the median of 105 collisions per year.

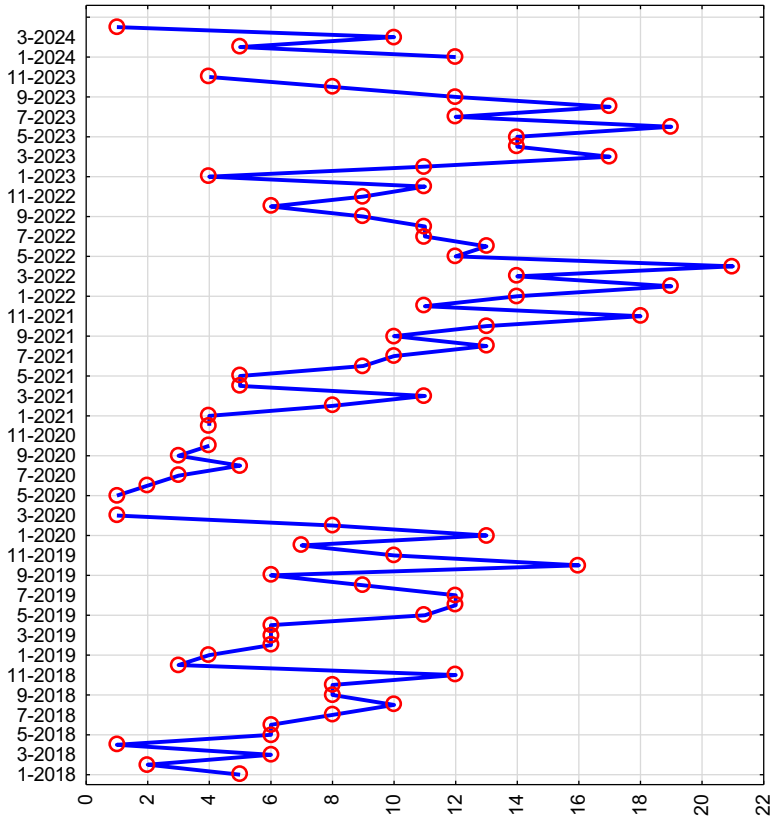

Fig. 4. Line graph of the number of collisions involving autonomous vehicles in the United States from January 2018 to April 2024. Source: [4]

For research purposes, the above-mentioned data was compared in a group of the same months using a box plot.

The highest number of collisions involving autonomous vehicles in the United States occurred in the same month of August, with an arithmetic mean of 10.6. The lowest number for the same months are December and April, with an arithmetic mean of 8. Leaps in the number of collisions of autonomous vehicles in the same months prove the existence of the phenomenon of seasonality.

Then, the existence of a trend in the data under consideration was investigated. Fig. 6 presents data on the sum of collisions using autonomous vehicles between 2018 and 2024.

The information presented in Fig. 6 shows that in 2018 (75 collisions) and 2019 (105 collisions), there was an increasing trend in the analyzed data. In 2020 (i.e., during the outbreak of the COVID-19 pandemic), a strong decline in the number of collisions was observed (44). Then, from 2021 (117 collisions) to 2022 (150 collisions), an upward trend was observed. In 2023, a decrease in the number of collisions was recorded compared to 2022 (132). From January to April 2024, 28 collisions involving autonomous vehicles were recorded.

The above-mentioned data indicate that despite the strong increase in the number of autonomous vehicles in use in the United States, the number of collisions has not increased proportionally. It is worth emphasizing that a collision does not equal an accident. A collision mainly concerns a road crash in which no death or bodily injury occurs. To conclude, if we want to reduce the number of road

expenses globally, including in Europe, it is worth starting the process of implementing autonomous vehicles in road transport in its various branches in terms of the use of research results, including various suggestions obtained from the United States.

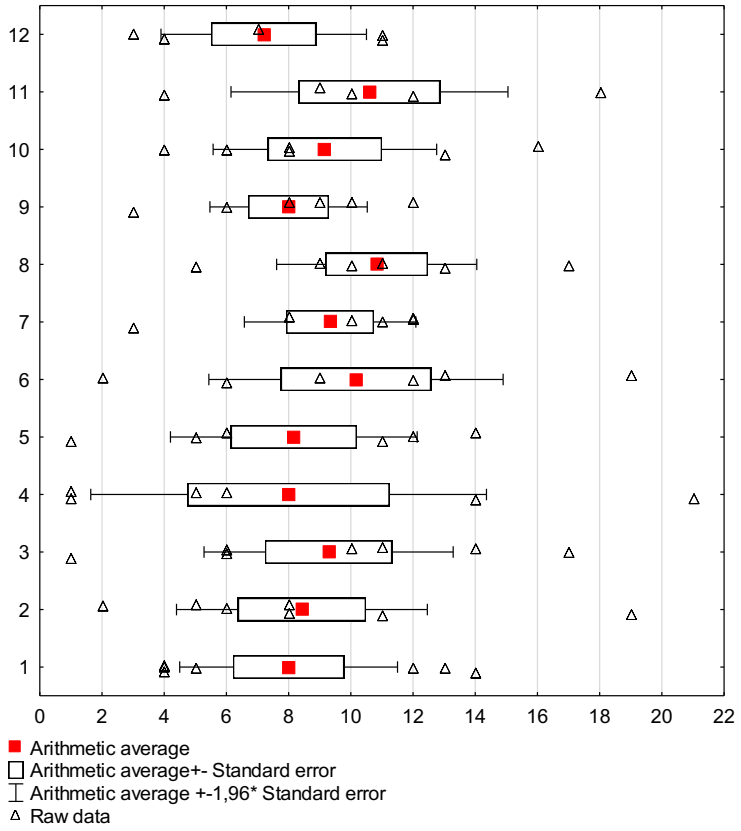

Fig. 5. Box plot of the number of collisions with autonomous vehicles in the United States from January 2018 to April 2024 in the group of dependent variables in the same months. Source: [4]

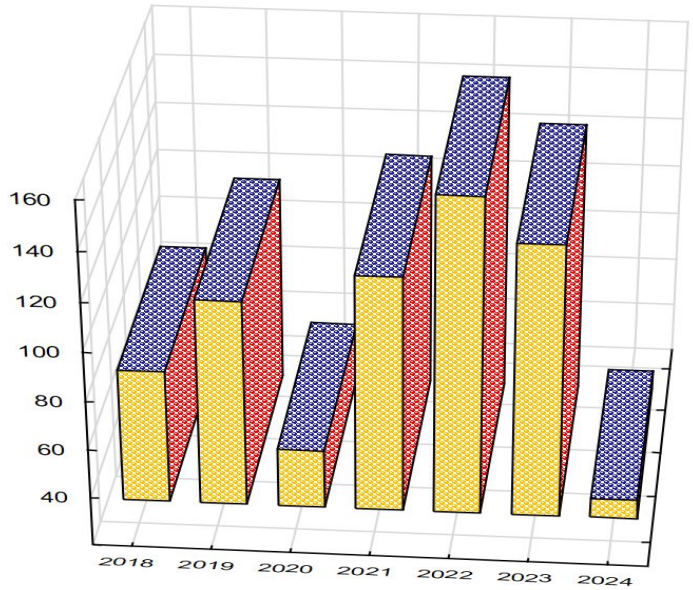

Fig. 6. Bar chart of the numbers of collisions involving autonomous vehicles in the United States between 2018 and 2024 (2024 covers the period from January to April). Source: [4]

The implementation of autonomous vehicles in Europe and around the world has several advantages and disadvantages. One advantage is improved passenger safety. Another is reduced costs related to the transport process itself by eliminating salaries for drivers. It should be remembered that it is possible to take control of this type of vehicle through hacker attacks, which poses a serious threat to people and road infrastructure. Such instances may take the form of terrorist attacks. It is worth emphasizing that autonomous vehicles are designed to be as safe as possible. Nevertheless, hacker attacks can target GPS systems, Lidar, communication networks, and other key technologies used in smart cars [17].

Adapting the road infrastructure to the needs of autonomous vehicles requires high financial outlays and time to install appropriate sensors and build lanes intended only for this type of vehicle.

8. PROSPECTS FOR THE USE OF AI IN ROAD TRAFFIC MANAGEMENT

Road safety is one of the priorities in the world due to the increase in the number of deaths due to collisions or road accidents. The increase in the number of vehicles on roads requires the development of optimal solutions to maintain the safety of people on the roads.

The future of road traffic management using AI seems promising. Further development of ITSs is expected, enabling them to respond in real time to changing road conditions and the needs of road users. Regarding the development of autonomous vehicle technology, there will undoubtedly be an increase in the cooperation of AI with vehicles, creating an even more integrated and safe transport system.

The application of AI concepts to road safety sounds exciting and greatly improves road safety, but it also has many weaknesses. The current state of knowledge lacks a method to quantitatively evaluate the effectiveness of AI. Thus, IT infrastructure is important in this regard.

Implementing AI in road traffic management also poses ethical and legal challenges. Privacy and data security issues are crucial, as AI systems require access to substantial amounts of information about road users. Furthermore, there is a need to develop a clear legal framework governing the use of AI in traffic management to ensure the accountability and transparency of these systems. It is important to develop not only national solutions but also European and even global solutions through globalization processes. Road safety depends on many factors. The most important are the behaviors of drivers, passengers, and road users, the quality of vehicles, and the state of road infrastructure. AI and autonomous vehicles have advantages, but there are also drawbacks that need to be worked out. The application of modern technology is possible in rich countries. On the other hand, in poor countries, there will continue to be a high number of traffic crashes and fatalities.

9. CONCLUSIONS

AI has enormous potential to transform traffic management. From optimizing traffic lights to improving road safety, AI offers new opportunities for highly urbanized environments where people and goods move on a mass scale. It also presents an opportunity for local communities where road safety is threatened by drunk drivers, including cyclists, and poor road infrastructure. The use of AI will therefore improve an effective and safe environment for drivers, passengers, and pedestrians, as well as the automotive fleet. AI can also help to personalize travelers' experiences. For example, AI systems can recommend routes to drivers tailored to their respective preferences, taking into account factors such as avoiding traffic jams, travel speed preferences, or even interest in tourist spots along the route. AI can also help meet sustainability and ecology goals. By optimizing traffic, AI can contribute to reducing exhaust emissions and improving air quality in cities. Additionally, better traffic management can reduce fuel consumption, which is beneficial from both an economic and ecological point of view. While challenges such as integration with existing infrastructure and ethical issues

remain, the future of AI-enabled traffic management appears promising and full of opportunities that will impact the safety of its users.

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Received 05.07.2023; accepted in revised form 22.11.2024