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EVALUATION OF EXPERIMENTAL SIGNS ON POLISH ROADS BY DRIVERS AND THEIR POTENTIAL BENEFITS IN THE IMPLEMENTATION OF AUTONOMOUS AND CONNECTED VEHICLES

Summary. This article aims to describe the experimental road signs used in Poland on expressways and their understanding by drivers surveyed as part of online and field research carried out at passenger service points. The second part of this article highlights the significance of physical road infrastructure in the deployment of autonomous vehicles (AVs). Various approaches to this issue have been identified, both from the perspective of road infrastructure managers and manufacturers of vehicles and software for AVs. The conclusions determine the value of using experimental markings in Poland in the context of implementing AVs.

1. INTRODUCTION

Road signs are designed to increase safety and improve travel. However, the solution to problems caused by dangerous driving is not an excessive number of signs, which may mislead drivers, but rather the right number of clear, transparent, and legible road signs. A compromise should be sought between the number of road signs and their legibility. Therefore, as part of social consultations and research programs, signs should be made as legible and helpful to drivers as possible. All signs on the road—horizontal, vertical, traditional, experimental, and variable message signs—concern drivers and are important because compliance with them is mandatory. Road signs were created to solve growing problems related to road infrastructure and car traffic. They are also intended to help reduce road accidents by alerting users to potential hazards and regulating behavior through restrictions and rules for different road categories. Road users are expected to understand the importance of road signs enforcing road traffic regulations and the need to comply with the rules indicated by them [1]. However, it is essential to note that road signs may vary significantly over time and across countries. The implementation of uniform road markings will enable the improvement of car traffic through the use of a more legible and intuitive system. The new signage (i.e., the introduction of experimental road markings) in Poland applies to expressways, which are the backbone of all roads and carry the most motor traffic. According to the data of the General Traffic Census 2020/21, the average annual daily traffic on international roads was 25,488 vehicles per day, compared to 8,746 vehicles per day for other national roads. The highest traffic load for the network occurred on expressways. As part of the General Traffic Census results, the percentage of economic traffic was also determined, which on national roads amounted to 91.7%. The characteristics of these roads make it necessary to introduce markings that are simple and legible for all drivers. The actions taken will enable improvements in traffic, increase its efficiency, and reduce the external costs of motor transport [2].

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Road signs will also play an important role in the deployment of connected and autonomous vehicles (CAVs). CAVs along with the electrification of transport and shared mobility, are now considered one of the three revolutions in road transport [3]. This type of vehicle can improve people's lives in a variety of ways, including the possibility of shortening travel time, increasing comfort, reducing travel costs, and reducing fuel consumption and emissions. They will also increase communication accessibility for people with reduced mobility. However, research into the impact of automation on physical infrastructure and road design concepts is still in the initial phase [4, 5].

Much of the research on AVs conducted so far has focused on vehicle technology or digital infrastructure, mainly from the point of view of the vehicle. Focusing primarily on vehicles creates difficulties for the automotive and IT industries in terms of communicating and sharing expectations. Therefore, the infrastructure requirements to facilitate the deployment of autonomous and connected vehicles have not yet been clearly defined [6, 7]. The potential use of autonomous and connected vehicles requires the creation of modern road transport networks. Currently, it is important to understand the basic requirements of road infrastructure for AVs in order to assess the readiness of the existing road network, as well as to prepare roads for the safe operation of these vehicles. Some experts advocate waiting until the technology matures or proves beneficial to the community's overall goals before addressing infrastructure issues [8]. Two approaches can be adopted. The first is characterized by an emphasis on adapting the road infrastructure to the needs of autonomous and connected vehicles, and the second approach assumes that vehicles must adapt to the already existing infrastructure.

2. INTRODUCTION OF EXPERIMENTAL ROAD SIGNS ON EXPRESSWAYS IN POLAND

Despite the development of modern technologies, physical road signs remain a fundamental tool for ensuring driving safety [9]. The incorrect perception and interpretation of the road space are among the causes of errors made by drivers. The effectiveness of road signs is determined by the correct perception of the information provided to road users. Symbolic signs are better understood by drivers compared to symbolic and textual signs [10]. Failure to follow road signs is one of the most common causes of accidents caused by drivers. The main causes of accidents were failure to obey yield signs (4,526 accidents), failure to adjust speed to traffic conditions (4,468 accidents), and failure to give way to pedestrians at a pedestrian crossing (2,251 accidents) [11]. Signs should be placed in the expected places in order to increase the likelihood that drivers will quickly notice them. Therefore, expressway designers should try to ensure that projects are in line with the standards shaping drivers' expectations [12]. Introducing new signs—specifically, experimental signs on expressways in Poland, as in the case described in this article—may initially confuse drivers, but the idea of introducing additional markings is ultimately intended to streamline traffic and improve road safety.

The National Road Safety Council allowed the introduction of experimental signs in the field of directional markings and road route boards. From the beginning of the tests (the first experimental signs were placed in 2013), experimental marking has been implemented on several dozen road sections throughout Poland. The use of the new signage is to improve its readability and intuitiveness and increase traffic safety and travel comfort. Modern signage, which is more adapted to the needs and expectations of traffic users, also allows for increased efficiency in road transport. Differences between standard and experimental signs on expressways are presented below (Fig. 1.) [13]. In accordance with the standard marking, the road junction board (E-20 sign) shows the graphics of the junction, its name, and, at the bottom, the distance in meters. In the experimental marking, the sign was supplemented with the junction number. Posting the junction number facilitates finding the right road and simplifies orientation for drivers.

Fig. 1. Traditional (on the left) and experimental (on the right) sign with the designation of the junction number (E-20a sign)

Other changes in the experimental marking are related to the pre-signpost board (E-1 sign). According to the new patterns, a plate with an exit pictogram and the junction number was added. Each pre-signpost board is placed on expressways 500 m before the exit (Fig. 2.). Further novelty in the experimental marking is the use of vertical countdown markers (F-14 d, F-14 e, F-14 f signs) previously unused for this technical class of road, which inform about the distance of 300, 200, and 100 meters from the beginning of the runway exit at a junction (Fig. 2) [13].

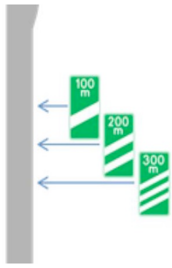


Fig. 2. Experimental marking: Pre-signpost board on the expressway (E-1 sign, on the left) and countdown markers (on the right)

According to the new road sign marking in the place where the exit lane begins, only one signpost board (E-2 sign) was used as part of the experimental marking (instead of two separate boards), which is located over the entire width of the roadway [14]. The sign panels were combined to direct the information placed on the sign to the corresponding lane. Arrows were added to indicate the direction of traffic in a given lane. The last change to this sign is the addition of the junction number, along with the expressway exit pictogram (a small sign located above the upper right corner of the board). The standard marking used two separate and smaller signpost boards. A comparison of these markings is shown in Fig. 3 below [15, 16].

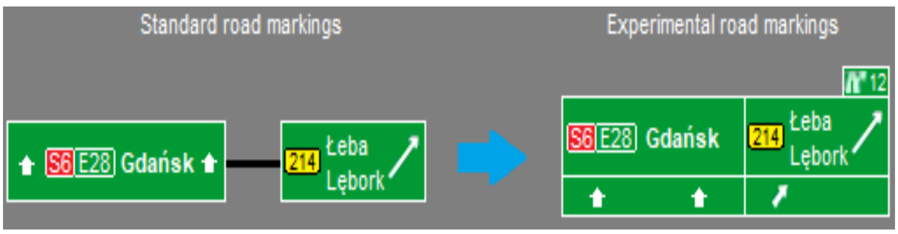


Fig. 3. Standard and experimental markings: Indicator boards on the expressway (E-2 sign)

A new plate, placed above the arrow-shaped signpost (E-3 sign), was also introduced. This sign was placed at the end of the expressway exit. The plate contains the exit pictogram and junction number (Fig. 4.) [13].

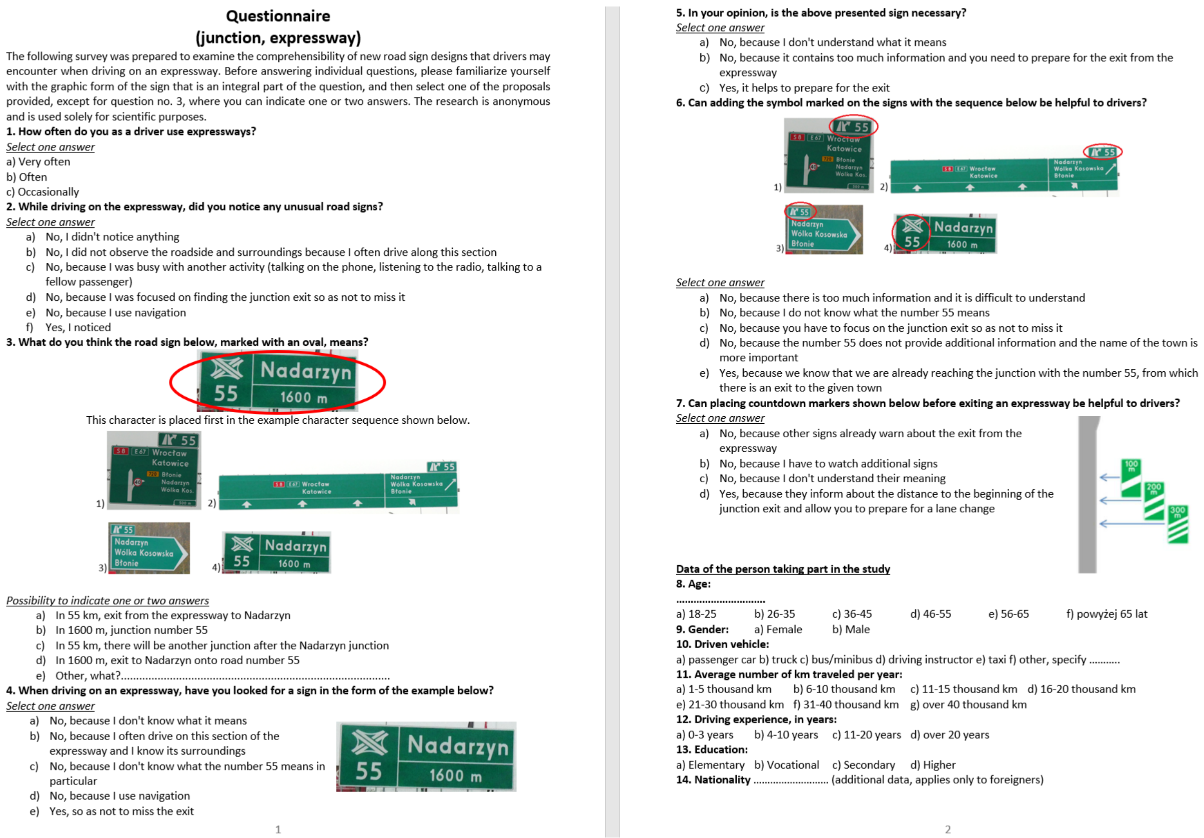
Fig. 4. Experimental marking: Indicator boards on the expressway (E-3 sign)

The next chapter presents the results of the conducted research regarding road experimental signs in Poland.

3. RESULTS OF THE CONDUCTED RESEARCH: OPINIONS OF DRIVERS ON THE EXPERIMENTAL ROAD SIGNS PRESENTED IN POLAND

Survey research was carried out in the “road environment” with different graphic forms of the surveys (i.e., with photos of signs adapted to the place where the research was conducted). The primary objective of the survey research was to assess drivers’ understanding of experimental marking in terms of supplementing the E-20 sign with the junction number and to evaluate the need to introduce additional plates with the junction number on subsequent signs before the junction on expressways. Opinions were also obtained regarding the usefulness of placing countdown markers before exits.

Field studies were conducted at 15 points on expressways throughout Poland. The field research was divided into five stages. The first field stage was completed in the summer of 2021 (until 31/07/2021), the second was completed in the fall of 2021 (until 30/11/2021), the third was completed in the spring of 2022 (until 31/05/2022), the fourth was completed in the fall of 2022 (until 30/11/2022), the fifth was completed in the spring of 2023 (until 31/05/2023). As part of the field surveys conducted in five research stages, the following sample sizes were obtained: In total, there were 5,451 answers. In the first stage, 1,090 questionnaires were obtained; in the second stage, 1,077 were obtained; in the third stage, 1,091 responses were obtained; in the fourth stage, 1,091 were also obtained; and in the last stage, 1,102 questionnaires were collected. In these stages, research was conducted in the environment where the signage appears. This research method allows for the best understanding of the potential impact of the signage being studied on the behavior of road users, as the degree of understanding of non-standard signs may be influenced by location conditions and situations occurring in road traffic (e.g., congestion, high speeds, signs obscured by heavy goods vehicles) in which the survey participants took part. The survey questionnaire used in the conducted research is presented below (Fig. 5). It is an example of a questionnaire for junction no. 55 at the exit to place Nadarzyn.



Questionnaire
(junction, expressway)

The following survey was prepared to examine the comprehensibility of new road sign designs that drivers may encounter when driving on an expressway. Before answering individual questions, please familiarize yourself with the graphic form of the sign that is an integral part of the question, and then select one of the proposals provided, except for question no. 3, where you can indicate one or two answers. The research is anonymous and is used solely for scientific purposes.

1. How often do you as a driver use expressways?
Select one answer
a) Very often
b) Often
c) Occasionally

2. While driving on the expressway, did you notice any unusual road signs?
Select one answer
a) No, I didn't notice anything
b) No, I did not observe the roadside and surroundings because I often drive along this section
c) No, because I was busy with another activity (talking on the phone, listening to the radio, talking to a fellow passenger)
d) No, because I was focused on finding the junction exit so as not to miss it
e) No, because I use navigation
f) Yes, I noticed

3. What do you think the road sign below, marked with an oval, means?

This character is placed first in the example character sequence shown below.

1) 2) 3) 4)

Possibility to indicate one or two answers
a) In 55 km, exit from the expressway to Nadarzyn
b) In 1600 m, junction number 55
c) In 55 km, there will be another junction after the Nadarzyn junction
d) In 1600 m, exit to Nadarzyn onto road number 55
e) Other, what?...

4. When driving on an expressway, have you looked for a sign in the form of the example below?
Select one answer
a) No, because I don't know what it means
b) No, because I often drive on this section of the expressway and I know its surroundings
c) No, because I don't know what the number 55 means in particular
d) No, because I use navigation
e) Yes, so as not to miss the exit

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5. In your opinion, is the above presented sign necessary?
Select one answer
a) No, because I don't understand what it means
b) No, because it contains too much information and you need to prepare for the exit from the expressway
c) Yes, it helps to prepare for the exit

6. Can adding the symbol marked on the signs with the sequence below be helpful to drivers?

1) 2) 3) 4)

Select one answer
a) No, because there is too much information and it is difficult to understand
b) No, because I do not know what the number 55 means
c) No, because you have to focus on the junction exit so as not to miss it
d) No, because the number 55 does not provide additional information and the name of the town is more important
e) Yes, because we know that we are already reaching the junction with the number 55, from which there is an exit to the given town

7. Can placing countdown markers shown below before exiting an expressway be helpful to drivers?
Select one answer
a) No, because other signs already warn about the exit from the expressway
b) No, because I have to watch additional signs
c) No, because I don't understand their meaning
d) Yes, because they inform about the distance to the beginning of the junction exit and allow you to prepare for a lane change

Data of the person taking part in the study
8. Age:
....
a) 18-25 b) 26-35 c) 36-45 d) 46-55 e) 56-65 f) powyżej 65 lat
9. Gender: a) Female b) Male
10. Driven vehicle:
a) passenger car b) truck c) bus/minibus d) driving instructor e) taxi f) other, specify ....
11. Average number of km traveled per year:
a) 1-5 thousand km b) 6-10 thousand km c) 11-15 thousand km d) 16-20 thousand km
e) 21-30 thousand km f) 31-40 thousand km g) over 40 thousand km
12. Driving experience, in years:
a) 0-3 years b) 4-10 years c) 11-20 years d) over 20 years
13. Education:
a) Elementary b) Vocational c) Secondary d) Higher
14. Nationality .... (additional data, applies only to foreigners)

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Fig. 5. Survey questionnaire

The results confirm the influence of the following characteristics of drivers on the level of understanding of the experimental signage: frequency of using expressways, gender, and, to a lesser extent, average kilometers traveled per year. The characteristics of the surveyed people influence the result of the assessment of the level of understanding of signage. For people using the expressway occasionally and driving up to 20,000 km per year, the level of understanding of the E-20 sign with an added junction number was classified as "average level - B" (with a declared level of sign understanding of 50–70%). On the other hand, in the groups of people using expressways very often and often and driving over 20,000 km per year, the qualitative assessment was "satisfactory level - A" (with a declared level of sign understanding of over 70%).

When interpreting each question in detail, it is important to know the frequency of respondents' use of expressways as an indication of the potential experience of drivers. The share of respondents declaring frequent and very frequent use of expressways in individual survey samples was 79.8% (Question 1 of the questionnaire). This means that the assessed road markings should not be surprising for the surveyed group of respondents. At the same time, people who often travel on a given road section know its route, and it can be assumed that they rarely use directional signs at junctions (they do not look for such signs). This may also affect the declared perception of unusual/experimental signs.

Concerning the distribution of answers to the question about noticing unusual signs on expressways (Question 2 of the questionnaire), divided into groups of drivers of passenger cars and drivers of other types of vehicles, significantly different research results were obtained. A more frequent perception of experimental signs was noticed in groups of drivers of heavy goods vehicles and non-passenger vehicles compared to groups of drivers of passenger cars. The comparison results in this regard are as follows: passenger cars – 38.6%, trucks and other – 51.4%. The results, broken down by test phases, are as follows: overall, about 45% of respondents declared that they had noticed the experimental signage with junction numbers on expressways (41.7% of respondents in the first stage, 46.1% in the second stage, 48.1% in the third, 41.1% in the fourth, and 46.7% in the fifth stage) [13].

The next question (Question 3) was about the qualitative assessment of the level of understanding of the E-20 sign with the added junction number. The declared level of understanding of the E-20a sign with the added junction number (E-20a) is satisfactory, as this sign was assessed correctly by 70,4% of respondents in different groups (distance to the junction with a given number). The assessment of a higher level was obtained in the group of truck and other vehicle drivers, while the average level of understanding was obtained in the group of passenger car drivers.

In the next question (Question 4), respondents were asked whether they looked for a sign with the junction number added when traveling on the expressway. The respondents confirmed to an average extent that they were "looking for" the sign in question (E20a sign) while driving on the expressway – 44.4% in Stage I, 42.2% in Stage II, 52.2% in Stage III, 52.4% in Stage IV, and 56.4% in Stage V. This may be influenced by the high share of declared use of in-car navigation when deciding to leave the expressway – 38.9% in Stage I, 31.5% in Stage II, 32.8% in Stage III, 32.2% in Stage IV, and 27.6% in Stage V studies.

Question 5 was intended to obtain respondents' answers as to whether they consider adding the junction number to the sign to be necessary. In this case, the need is understood as a statement that the signage "can be helpful" in making decisions. In the studies of Stage I, 91.5% of respondents stated that such a sign is needed because it allows them to prepare for leaving the expressway. In the studies of the next stages, the share of such statements was 88.2% in Stage II, 86.7% in Stage III, 85.8% in Stage IV, and 87.5% in Stage V. These declarations clearly support the dissemination of the assessed signage.

In Question 6, the survey respondents declared whether it is helpful to introduce a plate with the intersection number on subsequent signs before the intersection, the result obtained in the Stage I study was 76.0% and was better than the results of Stages II (66.4%), III (61.3%), IV (62.9%) and V (67.5%).

Question 7 raised the issue of introducing countdown markers. The research results from all stages confirm the validity of this solution. In the field research in Stages I to V, the following results were obtained, respectively: 92.9%, 89.6%, 91.8%, 91.4%, and 93.2% of indications of the usefulness of placing countdown markers before exits from the expressway. According to the conducted research, the vast majority of respondents are in favor of introducing such signs. Some respondents suggested that signs could be added at a distance of 500 m, possibly even 1000 m, before the junction exit. A previous sign already warned drivers about the exit over a longer distance (Fig. 2), but this does not change the fact that these signs are needed, according to the respondents. They allow drivers to properly prepare for the exit at the junction.

Question 8 referred to the personal data of the surveyed persons. There are large similarities between the samples of surveyed people in Stages I–V in terms of almost all characteristics of the surveyed groups. There are slight differences in the education structure (the share of people with higher education was 37.4% in the first stage, 34.0% in the second stage, 34.9% in the third stage, 40.4% in the fourth stage, and 33.5% in the fifth stage) and in relation to the type of vehicle driven. The share of people driving a passenger car in the first stage of the study was 72.7%, 65.5% in the second stage, 67.6% in the third stage, 65.7% in the fourth stage, and 60.8% in the fifth stage, which may result from the seasons and the influence of tourist traffic. Despite these differences, the surveyed sample can be considered reliable for conducting analyses and comparing their results between all stages. The research was oriented towards achieving its primary goal to determine the effectiveness of experimental signs used on expressways in Poland, assessed mainly through the prism of their impact on the behavior of vehicle drivers. The majority of drivers assess the experimental signs as useful, which suggests that the introduction of this marking as a standard would be beneficial. There are no grounds to justify the removal of the evaluated experimental junction markings [13].

4. QUALITY AND UNIFORMITY OF PHYSICAL ROAD INFRASTRUCTURE IN THE IMPLEMENTATION OF AUTONOMOUS VEHICLES

The role of road infrastructure could be pivotal in increasing traffic efficiency, particularly where it is planned to implement automated and connected vehicles on a larger scale. In mixed traffic, the infrastructure can offer valuable support by providing information to the data network on conventional vehicles that are beyond the reach of the sensors of automated vehicles [17]. The European Union has presented a roadmap for the European Technology Platform (ERTRAC) on the development of road infrastructure to include CAVs alongside human-driven vehicles. The ERTRAC roadmap introduces infrastructure support levels for automated driving (referred to as ISAD). It demonstrates the readiness of the infrastructure to implement CAVs, classifying it into five levels (A–E). Levels D and E are conventional infrastructures, and Levels A to C are digital infrastructures. Various activities aimed at adapting the physical road infrastructure to the operations of CAVs require the provision of a digital twin of physical and digital infrastructure that will be delivered in real time. In addition to static data, such as a detailed layout of lanes in different parts of the infrastructure (streets, tunnels, bridges, and toll gates), the digital twin contains permissible road load, permanent road signs as well as dynamic data, such as temporary roadworks, road conditions, and other known safety-relevant information [17]. However, these developments require close cooperation between the vehicle, infrastructure, and communications sectors, which can cause numerous problems and prolong the time it takes to solve potential problems.

The tasks of autonomous and connected vehicles can be divided into two basic tasks. One is to perform driving activities, including steering, accelerating, decelerating, and braking. The other is to monitor the driving environment. The issues of road infrastructure, including road signs, are primarily related to the second of the above-mentioned tasks. The ability of automated vehicles to assess the traffic environment is limited by the range and capabilities of on-board sensors [6]. In the first stage of implementing automated and connected vehicles, the most emphasis is placed on automating only part of the road network, specifically expressway connections. It may be necessary to overcome the current deficiencies in the perception of AVs by taking actions related to the modification of road infrastructure [18]. Research indicates that during the transition to full automation, the safe operation of L4 vehicles at full performance will depend largely on the type of infrastructure they encounter. Automated driving trials were repeatedly interrupted due to factors related to the road environment and road infrastructure. These factors include poorly marked and unharmonious road markings [19]. There are difficulties in balancing the costs of investing in road infrastructure and meeting the requirements for AVs users. The cost of building infrastructure for a limited number of vehicles would be high and difficult to invest in during the initial stage of deploying these vehicles. Therefore, it seems impossible to support infrastructure for AVs on all classes of roads in the near future [20]. Communication between the connected vehicle and the road infrastructure is based on the exchange of messages between vehicle equipment and roadside devices [21]. More advanced solutions require more software and hardware, which would increase system cost and complexity [5]. The successful implementation of CAVs as part of an intelligent transport system depends on the on-board equipment, the road environment (i.e., road infrastructure, including road signs and intersection signals), and other road users. On-board perception, along with vehicle location and maps, is crucial when traveling through various road environments [22]. According to some opinions, enabling AVs to operate on public roads may necessitate certain modernizations or adaptations of the road infrastructure, which will be tailored to the needs of automated driving technology [23]. The most visible progress in automated driving, both in passenger and freight transport, will be connected to digital infrastructure [24]. The second approach emphasizes the need for CAVs to adapt to the existing road infrastructure. The National Academies of Sciences, Engineering, and Medicine analyzed this issue [25]. This research program presented a framework with four approaches to road infrastructure readiness for CAVs deployment, which is summarized in the following points.

Leaving the current road infrastructure—numerous road signs help the driver monitor the road environment and adjust the driving process to the road conditions. In this case, the road infrastructure is equipped with conventional road markings (vertical and horizontal road signs, variable message signs).

Watching the road—the task of monitoring the road environment will eventually be transferred from a human driver to an automated vehicle. Video cameras, sensors, and optical sensors of such vehicles allow the detection of pedestrians, animals, and road signs, and over time, new content of the visual environment of the road will be added, which will be recognized by the sensors. At this stage, road infrastructure operators may collaborate with the automotive industry to enhance the sensors used in vehicles, thereby improving the process of recognizing the road environment. Of course, performing such actions will require financial outlays and interference with the existing road infrastructure.

Communicating with the road—the development of technologies and communication channels allows the deployment of traffic signals that are delivered to automated and connected vehicles. The road environment is getting smarter as the ability to communicate with other infrastructure and vehicles increases. Sensors are placed around the road to monitor traffic conditions and enable real-time communication.

Simplification of road infrastructure—the design of a safe road environment will change as fleets move towards more connected, autonomous, and automated driving. Changes will take place systematically, but a long period of mixed traffic is anticipated. It seems that, in the first place, separate lanes for these vehicles will be introduced, and eventually, the assumptions of road design will change.

The current development is the first of these points. The devices used to control traffic are the basic physical infrastructure that provides regulatory, warning, and safe driving information. Signs and other road markings are essential infrastructure elements for future CAVs implementation [26]. There is an urgent need to transform the physical infrastructure before implementing CAVs [27]. Unfortunately, altering this infrastructure requires significant expenditures. Therefore, in the first phase of implementing AVs, it is necessary to ensure their optimal cooperation with the existing road markings. The introduction of experimental markings on expressways in Poland may facilitate this. Also, stakeholders from the AVs industry are increasingly reporting a growing demand for consistent, high-quality road signs, lane markings, and lighting, which will support the reliability of vision systems [28]. For example, in the conducted research, surveys, and interviews [29], information was obtained about the most important features in the road environment that would benefit ADS from industry members in California. One of the items mentioned is actual traffic signals. Some participants claimed that actual existing roads must support AVs. These vehicles should be able to move on existing roads without requiring I2V information to be provided by road agencies. Similar to the survey results, the study conducted by Wang, McKeever, and Cha indicated that road markings and road signs are among the most important elements of road infrastructure for AVs. It is also emphasized that both HD maps and physical road elements (e.g., markings) must be of sufficiently good quality to ensure reliability. Therefore, relying solely on HD maps will probably not be enough, and the road's physical features will still need to be handled properly. That is why the strategy of leaving physical road infrastructure for existing road users and newly emerging technologies is so important [8]. According to other survey research conducted by Tengilimoglu, Carsten, and Wadud, nearly 73% of respondents said that road markings and traffic signs will remain relevant in the era of digital twins. Almost 42% strongly agreed with this statement, and 31% agreed. This shows that physical road infrastructure plays a significant role in the safe and effective operation of ADS technology, a fact that the industry is aware of. Despite this, the infrastructure may not always be able to cope with the integration of vehicles characterized by a high level of automation [30]. In terms of physical infrastructure, investments are likely to be concentrated in areas that benefit both automated and conventional vehicles [17]. It should be assumed that not all countries will be willing or able to adapt their road infrastructure to the needs of CAVs. Therefore, introducing additional road signs may also aid the implementation of automated and connected vehicles in the aspect of road traffic safety. Many experts see expressways as the safest roads for the initial deployment of autonomous and connected vehicles. [31]. The implementation of automated and connected vehicles is expected to reduce road congestion and increase traffic flow [32]. In previous research, the Virginia Department of Transportation team developed a model of AVs and CAVs driver behavior that was evaluated on a test network. The results were as follows: the 100% AVs and 100% CAVs scenarios increased road capacity by 28% and 92%, respectively, over the 100% conventional traffic scenario. Scenarios were created for testing on a basic section of the motorway. In addition, in the case of the heavy-duty vehicle scenario, the implementation of AVs and CAVs showed a significant increase in road capacity on the motorway [33]. On the other hand, one study concluded that low-level automated vehicles will initially have a negative impact on traffic flow and road capacity in mixed traffic. Any improvement in traffic flow will be visible only when the indicators for these vehicles exceed 70% [34].

Research conducted by Tariq in the USA indicates that 41% of respondents (83 technology developers) suggested that significant changes to the road infrastructure will be needed when approximately 25% of vehicles will be AVs. Also, 53% of respondents considered it unnecessary to introduce changes or modifications to road infrastructure during the initial implementation of AVs systems on expressways. According to their answers, respondents tended to favor two scenarios due to the economic implications [35]. The first one aimed for no structural changes on expressways but only the requirement for road markings (signs, surface) to be visible in all weather conditions and easily readable by AVs. Some opinions are even more strongly in favor of the idea that AVs should be able to drive on any road in any weather conditions. It is possible to develop AVs technology that is advanced enough to achieve these goals. Of course, this will increase costs for consumers and, in turn, may harm market penetration. The second scenario favors a separate lane for AVs on expressways. Many European local authorities responsible for road traffic are unprepared for the introduction of AVs on their road networks. The road infrastructure (physical and digital) is intended only for conventional vehicles [36]. It is assumed that changing road infrastructure requires a 30-year planning horizon. The costs associated with adapting the entire infrastructure may prove to be too high, and it is assumed that this adaptation, in the initial phase, will primarily focus on certain road sections. Poor maintenance and differences in road markings can also prevent the effective use of technology in AVs and CAVs [37]. AVs, at the most basic level, must stay within the boundaries of the physical path. Therefore, it is necessary to interpret vertical and horizontal signs located along the road and, consequently, to take actions as part of the driving process. AVs must analyze the geometry of the physical road environment and interpret features of that environment, such as road signs and passive (e.g., lane markings) and active signals (e.g., variable speed limits). AVs cannot drive without roads. Therefore, the regulations constitute a reference for the system of the physical road environment (e.g., road markings) and traffic control [38]. Referring to the above assumptions, a distinction is made to four levels of "cognitive performance," which are divided into [37]: observation, analysis, decision-making, and action-taking. All of these levels are related to road infrastructure. The last three depend on the accuracy of the first level, which is the observation of the road environment. Some manufacturers and technology developers emphasize the development of AVs that can move safely and effectively using existing road infrastructure, including road signs, traffic lights, and variable message signs. This solution significantly reduces the need to introduce important changes to the infrastructure. Considering this approach, which currently seems to be the most probable and common solution for the coming years, it can be noted that the introduction of additional signs on expressways that improve and facilitate travel will be beneficial for the perception systems of vehicles equipped with autonomous systems. The presented signs improve the driving process and increase traffic safety and comfort while facilitating navigation on the road. These signs are useful for people and can also support and facilitate the process of driving a vehicle using autonomous systems. Therefore, the implementation of the presented experimental signs should be assessed positively.

Introducing even minor changes to signs, such as adding a junction number, including junction graphics on directional signs, or introducing countdown markers, which were highly rated during the field test of drivers, allows for increased smoothness and safety of driving. The widespread introduction of the presented markings in Poland and their integration with driving assistance systems, including those related to road sign recognition, represents another step towards improving the physical road infrastructure. Adding the junction number (E20a sign, 88% of drivers are in favor of introducing a junction number) makes it easier for drivers to navigate while traveling, which affects the smoothness of driving, reduces potential congestion, and increases comfort and safety on the road. Introducing a plate with the junction number on subsequent signs before the junction was considered useful by less than 70% of drivers. Despite the low positive assessment of this solution, it is still an important element that can be used by vehicle support systems. Thanks to this solution, together with the introduction of countdown markers (over 90% positive ratings in the survey) on expressways, drivers and support systems will be notified in advance of the need to exit the road, which will allow for a safe and smooth maneuver.

5. CONCLUSIONS

Currently, according to an approach from the site of the state administration, the physical road infrastructure should not be subordinated to AVs, and autonomous cars should adapt to the existing infrastructure. It can be assumed that there will always also be a need to design road infrastructure for conventional vehicles. This affects the idea that public transport and road infrastructure must be adapted to the needs of all users. Most AVs developers who were interviewed for the ITF report stated that their vehicles would have to operate on existing roads, and they did not expect a separate road space to be prepared for AVs. Far too little attention is paid to how to prepare AVs in the implementation phase to operate on physical roads using current technology. It seems important to systematically introduce coherence and uniformity of various elements of the road environment (road signs, road markings, and other road elements). AVs are designed to read the environment of existing roads, and the information used by these vehicles is collected in a way similar to the information obtained by the driver of a conventional vehicle. For this purpose, AVs use on-board sensors (cameras, lidars, radars) to assess the road environment and recognize road signs, signals, and other elements of the road environment. Of course, there are some differences between human vision and sensor perception. For example, AVs may use infrared cameras or radar to see in the dark (38). Knowledge of vehicle assistance systems is an important factor in familiarizing drivers with these systems. Therefore, knowledge about them should also be part of driver training and psychoeducation (39).

Reducing the human factor in the vehicle control process may have a positive impact on the level of road traffic safety. If the estimated market share of vehicles equipped with these systems is approximately 20% in 2030, the reduction in the number of accidents will be 15% [40]. The results are similar or slightly worse than other simulation studies carried out in England aimed at determining a similar relationship (a 25% market share of vehicles with driver assistance systems translated to 12–47% fewer accidents) [41]. One solution may be to implement new signs that are understandable to both drivers and driving support systems, especially in the form of graphics and not in descriptive form. The introduction of experimental markings is perceived positively by drivers as facilitating and supporting the driving process. The described experimental markings are new in Poland. Therefore, additional signs may help in the implementation phase of vehicles equipped with road environment perception systems. At the same time, not all drivers want to give up driving, so signage must be appropriate for both AVs and conventional vehicles. This is confirmed by the drivers participating in the survey regarding adding the junction number to the sign. On average, 88% of responses were positive, and drivers stated that the signage “can be helpful” in making decisions. The results demonstrate the effectiveness of this solution and its potential positive impact on driving assistance systems. Introducing a plate with the junction number on subsequent signs before the junction was considered important by 67% of drivers on average. The issue of introducing countdown markers received the highest percentage of positive votes during the study. Ninety-two percent of drivers consider these signs helpful.

Physical road infrastructure is necessary for the proper functioning of traffic and is a crucial technical element of infrastructure, as confirmed by this research. This article is important in the context of implementing new road signs and increasingly advanced vehicle driving support systems, ultimately implementing vehicles with increasingly higher levels of automation. If the introduction of additional signs including the junction number is helpful to drivers, these signs will have an even more positive impact on the correct functioning of driver assistance systems. It seems necessary to systematically introduce facilitations for systems supporting vehicle driving, ultimately for AVs, which may be facilitated by additional graphic symbols, such as the experimental signs presented in the article.

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