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Identification of Solutions for Vulnerable Road Users Safety in Urban Transport Systems: Grounded Theory Research

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Abstract: The share of road vehicles in urban transport systems is a challenge for modern and dynamically developing urban areas in accordance with the concept of sustainable and Smart Cities. Increasingly, there is a need to promote and adapt urban space to the movement of vulnerable road users (VRU). As part of a clear emphasis on the issue of pedestrians and other vulnerable road users, the aim of the article is to define the typology and hierarchy of solutions contributing to the increase in VRU safety in cities. The research process was based on the use of grounded theory. In the adopted research methodology, the use of the Delphi method made it possible to identify the approach of various European cities to the use and implementation of technical, technological and organizational solutions affecting safety. The research made it possible to evaluate individual solutions in VRU safety management and to indicate a list of recommendations for improving security, taking into account the views of international experts. In addition, the results of this study may enrich the current literature, helping to understand the perception of solutions implemented in urban transport systems as a holistic set of interrelated elements supporting pedestrian safety and increasing their role in cities.

Keywords: traffic measurements; transportation safety; sustainable traffic modes; urban transport systems; perceived safety; vulnerable road users; grounded theory research

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1. Introduction

In the EU Member States, the number of road accident victims in the last 10 years has shown a downward trend. In 2019, the death toll decreased by approximately 31% compared to 2009. In the entire EU, in 2019, there were 51 deaths per 1 million inhabitants [1]. It is estimated that road accidents in most countries in the world cost about 3% of the gross domestic product [2]. The WHO report suggests that the price for social mobility, especially in developing countries, is too high because of existing proven measures that can reduce the number of road accidents [3]. Despite the increase in actions for road safety, it is believed that they are not enough in relation to the still large number of road accidents. Pedestrians, cyclists and motorcyclists are most affected by road accidents [4].

Road users like pedestrians, cyclists, motorcyclists and powered two-wheelers are classified as vulnerable road users (VRU). In the ITS Directive of EU, VRUs are defined as: "non-motorized road users, such as pedestrians and cyclists as well as motorcyclists and persons with disabilities or reduced mobility and orientation" [5]. Motorcycles are considered one of the main means of transport contributing to road accidents. Motorcyclists are exposed to road accidents more often than users of other means of transport [6]. The main causes of road accidents involving motorcyclists include but are not limited to speed, acceleration, failure to maintain a safe distance, longitudinal and lateral movement, dangerous maneuvers, and starting traffic before traffic lights turn green [6,7]. There are many solutions that affect the management of driving speed and improve the visibility and alertness of motorcyclists, which in turn is supposed to improve their safety [6]. Compared

to motorcyclists, pedestrians and cyclists are a group of unprotected road users; they are not supported by additional protection and are equipped with technological solutions that reduce the number of road accidents involving them. Therefore, the article focuses exclusively on pedestrians and cyclists as vulnerable road users.

Road accidents have more negative consequences for VRU [8]. In recent years, much attention has been focused on implementing solutions that improve the functioning of urban transport systems. Nevertheless, the generated demand for passenger and freight travel during the COVID-19 pandemic has decreased significantly [9]. Naturally, the restrictions related to the pandemic had a positive impact on the environment and road safety.

There are many solutions to improve pedestrian safety. Nevertheless, it is observed that the measures implemented so far have been mainly aimed at drawing attention to motorized road users [10]. The development of modern cities, based on knowledge and using advanced technologies, makes them Smart Cities, eco-cities, green cities, digital cities, and cities moving towards sustainable development. Many road accidents can be prevented with the available solutions, as many of these accidents can be predicted [11]. Improving road safety requires a holistic approach and includes actions in areas such as policy measures, effective enforcement, the technology used in vehicles and other areas, and actions related to road infrastructure [12].

At the moment, despite many promoted solutions, there is no holistic approach to this issue. Due to the above premises, the literature gap is defined as the lack of a phased approach in the implementation of solutions that improve pedestrian safety. The aim of the study is to determine the solutions contributing to the greatest extent to increasing road safety, with particular emphasis on VRU. As a result of the conducted research, they indicated which solutions play an important role in increasing road safety and should be considered for implementation in urban areas. In Section 2, "Selected solutions for the safety of vulnerable road users", the authors analyzed selected solutions to increase VRU security. In Section 3, "Methodology", the authors presented the research methods used and the research sample. In Section 4, "Results", the authors present the results of their own studies. In Section 5, "Discussion", the authors presented their thoughts on the results of their own research and the general state of knowledge in the studied research area. Section 6 presents the main conclusions.

2. Selected Solutions for the Safety of Vulnerable Road Users

The safety of vulnerable road users is a priority at both local and pan-European levels. Increasingly, cities tend to design more VRU-friendly environments. This direction of development also appears in EU documents, e.g., the White Paper prepared by the European Commission also focuses on the advantages of implementing more comfortable and safe zones for pedestrians and bicycle users. This is due to the growing interest in a sustainable transport system, which is primarily intended to discourage the use of passenger cars [13].

Solutions implemented to increase the safety of vulnerable road users can be broadly divided into technological solutions based on telematic systems, artificial intelligence and big data [11]; solutions for the physical infrastructure of transport [14]; and organizational and institutional solutions [15].

2.1. Solutions Based on Telematic Systems, Artificial Intelligence, Big Data

They include information and communication systems, sensors and advanced mathematical methods, which are the basis for the implementation of Intelligent Transport Systems (ITS) [16]. The purpose of ITS implementation is to complete the safety and combat problems of transport systems by collecting and exchanging data between vehicles, roadside units (RSUs) and traffic management centers [17]. Initially, ITS did not pay special attention to VRU, but it was noted that they are an important element of the transport system. Currently, solutions dedicated to them are being implemented more and more often, e.g., Blind Spot Detection (BSD) [18,19], VRU Beacon System (VBS) [20], Bicycle-to-

Vehicle communication (B2V), Intersection safety (INS), Pedestrian and Cyclist Detection System + Emergency Braking (PCDS + EBR) [21]. BSD is a solution that allows for increased safety by warning drivers about objects in the blind spot. This translates into preventing accidents and reducing their number. The conducted tests show high efficiency both in the daytime and nighttime environments [18,19]. VBS and B2V are systems that allow communication between vehicles and smart devices of tor to warn against potential collisions arising. However, the use of the solution has its limitations, primarily problems related to network overload in congestion conditions, the accuracy of the Global Positioning System (GPS), standardization of messages sent, and prioritization of communication between the vehicle and the VRU in the event of an accident probability [19]. INS is a solution based on vehicle-to-infrastructure and vehicle-to-vehicle (V2X-Vehicle-to-everything [22]) communication. They are based on data collected from both sensor data acquired by in-vehicle and infrastructure-based sensors. Research related to the use of the solution was conducted in Europe [23], the USA [24] and Asia [25]. Unfortunately, the use of INS also encounters problems related to the disruption of communication in congestion conditions [26]. PCDS + EBR is a solution to prevent accidents through earlier identification of objects and autonomous emergency brake in the event of a trip hazard. The tests carried out show the high efficiency of the solution, but there are also significant limitations, e.g., reduced efficiency in night conditions, extended braking time at high speed of the vehicle and unfavorable weather conditions [27].

2.2. Solutions for Physical Transport Infrastructure

Solutions for physical transport infrastructure include, above all, the quality of the surface and the creation of VRU-friendly spaces. Shared space or otherwise also known as shared space, has been defined by the UK Department of Transport as a street or place designed to improve pedestrian traffic and comfort by reducing the dominance of motor vehicles [28]. Based on UK surveys, it was concluded that the intended benefits of shared space could be achieved by reducing vehicle speed in these areas to around 20 mph, equivalent to 32 km/h, and vehicle flow should be low, less than 100 veh./h. The common space is characterized by the lack of safety barriers and the introduction of uncontrolled pedestrian crossings, often with one surface for all road users and little or no separation between the vehicle zone and VRU [13]. In this example, the interaction between the vehicles and the VRUs in terms of their feeling of safety and comfort is of great importance. In the case of too-confident driving, the creation of channels for vehicles is observed, which in turn contributes to the dominance of the common space by this group. The success of implementing such areas is increasing drivers' awareness of the established priorities, increasing the vigilance of vehicle travelers and increasing the trust of vulnerable road users [29].

2.3. Organizational and Institutional Solutions

The last group of solutions is organizational and institutional solutions. These include the implementation of integrated city and transport management, road traffic control, and a traffic management center, implementing the concept of 15 min cities, the smart city concept and actions towards sustainable development [30,31]. Integrated city and transport management are about city development and data-driven policy making. Integrated management is a challenge for decision-makers due to the need to adapt the strategy to those developed at higher levels. Nevertheless, it includes cooperation with the public–private sector and public consultations [32]. Actions taken by designated road traffic control units significantly affect the behavior of road users [31]. Changing the frequency of road traffic control determines, to a greater extent, the adaptation of its participants to the applicable regulations [33]. It should be noted that the effect of these activities is the improvement of road traffic safety. This is due to the fact that human error is the main cause of road accidents [34]. The concept of 15 min cities assumes such space planning where residents can reach all the places necessary for existence within 15 min by bike or on

foot [35]. This assumption requires the reconstruction of infrastructure and the creation of friendly spaces for VRU, which naturally translates into increased security [36]. The concepts of the 15 min city are being gradually implemented in Paris, but other cities in the world are also following suit, seeing the need to change the prioritization of solutions based on the needs of society, thus supporting the development of infrastructure for pedestrians and cyclists. Other cities interested in redesigning public space include Milan and Berlin [37]. Traffic management centers, thanks to data acquisition devices, can track and control traffic in key communication areas, e.g., the Washington State Department of Transportation. The Smart Cities concept assumes a coherent development strategy aimed at providing the best quality of life for residents. This is performed through the implementation of ICT to improve the quality of services and city functions offered. One of the areas of interest in Smart Cities is VRU security. Data collected by ICT is used to understand the nature of traffic flows and use this information to manage the transport system better [38,39]. Internet of Things (IoT) technologies stand out for their potential in managing and developing smart and sustainable cities. The information collected by the IoT enables quick decision making and real-time response to situations [40]. Moving towards sustainable development also contributes to increasing security. VRUs are an important element in the strategy of sustainable transport development in cities [41]. The Sustainable Urban Mobility Plan (SUMP) developed by the European Commission emphasizes the importance of promoting sustainable means of transport, cycling, and walking mobility and creating a safe infrastructure for them [42].

There are many concepts and solutions that affect road safety, with particular emphasis on vulnerable users. Based on the above literature review, it can be concluded that cities use different approaches to managing the urban transport system while striving to be smart and sustainable cities. Different solutions available on the market often inspire cities to implement them, which may affect the level of road safety. It can be noticed that many cities lack a multi-stage approach to reducing the number of road accidents involving pedestrians and cyclists. This translates into the developed research process of the article, in which the authors strive to identify the main factors affecting road safety.

3. Methodology

The adopted research process is based on the use of the grounded theory method to deepen and expand knowledge by reaching new conclusions in the area of road safety. The grounded theory method was developed by B. Glaser and A. Straussi [43]. It allows for generating the theory inductively based on collected data and data coding.

In the research process, a deliberate selection of the sample was selected. The purposeful selection provided initial data, which were then analyzed. Experts were invited to participate in the research, including the management of urban transport systems, and implemented the effects of activities on efficiency, safety and traffic management. The Delphi study was used to collect the data. This method was developed in the 1950s by Norman Dalkey and Olaf Helmer. It was developed to obtain expert consensus [44]. The Delphi study is carried out in rounds; the number of these rounds depends on whether the outliers are adjusted and the achievement of a common position in the questioned areas [45]. The research process is considered complete when (a) there is a strong consensus, (b) there is no progress compared to the previous round and no consensus has been reached. The group of experts in research using the Delphi study does not rely on statistical power but is selected depending on the needs of the research [46]. In the literature, the selection of the number of experts is varied; a sample of 10 to 18 experts [46] or even from 5 to 60 experts is indicated [47].

The authors of the article conducted research using the Delphi method online using a standardized questionnaire. The activities preceding the organization of the questionnaire included visits to public sector units and study visits to European research and scientific centers. Units were located in the Netherlands (Amsterdam, Hague, Rotterdam), Spain (Barcelona), Norway (Oslo), Poland (Częstochowa, Szczecin, Nowy Targ) and Italy (Naples,

Milan). As part of the internships and meetings, overt and uncontrolled observations of the functioning of municipal transport systems and good practices in the field of road safety were carried out, as well as in-depth individual interviews with specialists in the discussed research area. However, only the cities in which the use of good practices in the field of VRU safety was identified during the preliminary research were qualified for the study. Hague, Rotterdam and Milan did not qualify. These studies lasted from June 2018 to February 2021.

In the next step, a questionnaire was developed. As part of the detection of errors, the questionnaire was checked by a randomly selected control group of academic scientists dealing with Intelligent Transport Systems, telematics solutions, city logistics, city planning and road safety management. The control group consisted of 5 people working at the Maritime University of Technology in Szczecin. After introducing corrections in the framework of the conducted pilot studies, the final version of the questionnaire was prepared. In the next step, a group of experts from the cities selected for the study was determined. The questionnaire was sent to 21 experts, 3 from each city. In the next step, the forms were sent to experts with a request to participate in the study (Round 1). The collected experts' answers were then analyzed and allowed for the provision of intermediate results from the conducted research. The second questionnaire (Round 2) contained non-consensus questions. The results from round 1 were presented to the experts in the next round. These studies lasted from April 2021 to January 2022. The individual steps are shown in Figure 1 below.

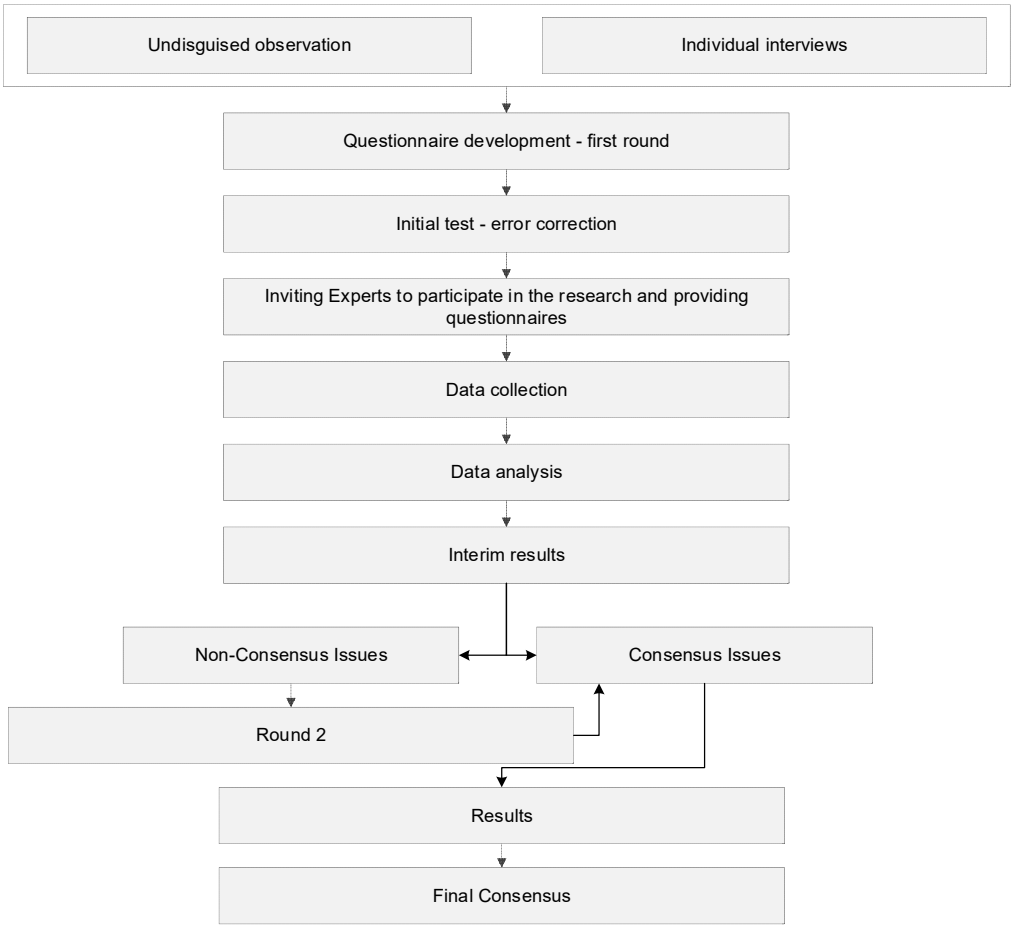

Figure 1. Steps of Delphi method research. Source: Own study based on [45,48].

As a result of the research process, 12 experts from such institutions as Universitat Politècnica de Catalunya (2 experts—professors), Amsterdam University (1 expert—professor), The Institute of Transport Economics in Oslo (1 expert—researcher), University of Naples

Federico II (2 experts—professor and researcher), Maritime University of Szczecin (1 expert—researcher), Czestochowa University of Technology (1 expert—researcher), Provincial Police Headquarters in Szczecin (1 expert—deputy police chief), City Police Headquarters in Czestochowa (deputy head), Road Transport Inspection in Nowy Targ (2 experts—inspectors) confirmed participation in the study. All of them took part in two rounds. The sample size was considered sufficient in light of the literature recommendations.

Based on the collected results from the conducted Delphi study, the transcriptions were divided into fragments, and then the fragments were grouped into codes—open coding. The next step was to group the codes into categories allowing for analyzing more fragments and comparing codes—axial coding. On this basis, the authors defined the main idea and drew conclusions from the inductive analysis.

4. Results

4.1. Collected Data: Delphi Study Results

In the Delphi method, the experts represented cities such as Barcelona (Spain); Amsterdam (the Netherlands); Oslo (Norway); Naples (Italy); Szczecin—the capital of the West Pomeranian Voivodeship in Poland; Czestochowa; and Nowy Targ—poviat cities located in the southern part of Poland. The cities represented by the experts differ in the level of their development, the number of inhabitants, the implementation of solutions affecting road safety and the financing of projects in the area of urban transport systems.

In the first question, the respondents were asked to indicate the factor that should be a priority for city managers. In the first round, 50% of experts indicated the answer to safety, then 17% answered mobility of residents and air pollution. The following answers were 8% each: congestion and other factors. Figure 2 presents the answers to the above question.

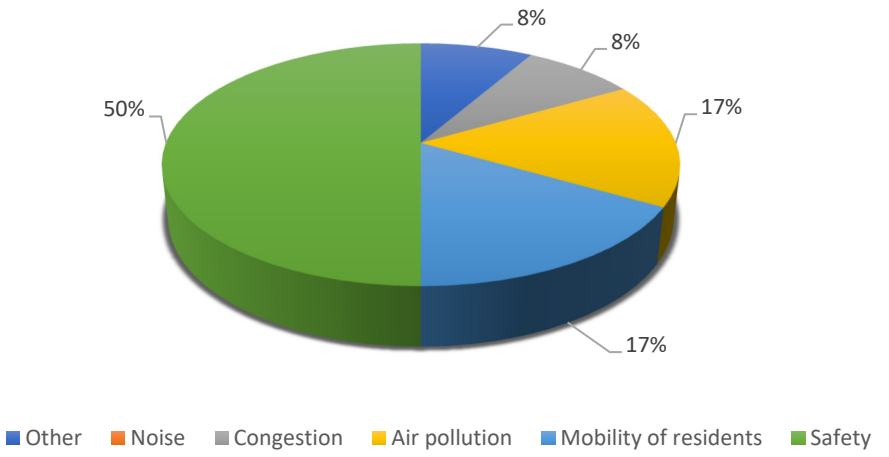

Figure 2. Responses to question 1: Which of the factors should be the priority for the city authorities? Source: own study.

Analysis of the data presented in the graph showed that the activities of local government units should mainly be aimed at ensuring the safety of their citizens. Half of the experts participating in the survey indicated this factor as a priority. Other aspects that city authorities should take into account in their policy are the mobility of residents and the problem of air pollution. One person was in favor of implementing measures to reduce transport congestion, as was the case with another's response to which the factor "fun and live" was assigned. Cities focused on promoting more friendly forms of movement and encouraging residents to walk, cycle or use public transport include in their strategies the reduction in road accidents involving VRUs and the increase in their safety in road traffic and increase in their mobility [48,49]. None of the experts answered noise, although it is proved in the literature that this factor negatively affects the quality and health of society. The increase in the number of residents, which is characteristic of urban areas, corresponds to the increase in the number of vehicles in cities. As a consequence, the increase in road

traffic contributes to the increase and emission of traffic noise [50]. In addition, traffic noise is the main source of noise pollution in cities [51]. The question was a one-choice question; therefore, it can be assumed that the noise was not completely ignored but found its place in other problems indicated by the experts.

The next question was: Are new transport technologies being successively implemented in your city? Fifty-eight percent of experts answered yes, and forty-two percent of experts answered no. The results are presented in the following Figure 3.

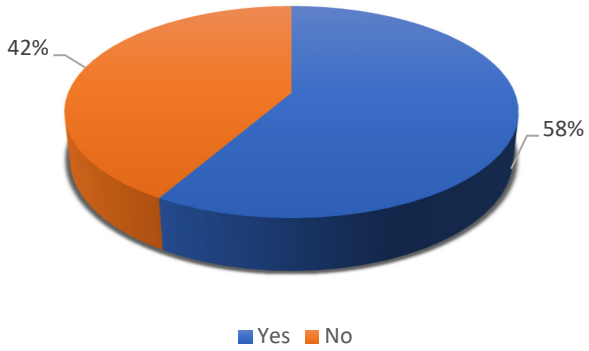

Figure 3. Responses to question 2 in the first round: Are new transport technologies being successively implemented in your city? Source: own study.

Seven experts responded that technological solutions are systematically implemented in the area of transport. These were respondents from Barcelona, Oslo, Szczecin, Nowy Targ and one expert from Czestochowa. On the other hand, five experts replied that such solutions were not implemented in their cities. These cities include Amsterdam, Naples, Rabka Zdroj and Czestochowa. Technological solutions in the area of transport are implemented as a result of identified needs of the city and transport problems [52]. Solutions of this type affect the management of the urban transport system, the organization of transport, vehicle traffic and society, as well as reduce the negative impact on the environment. The next question also concerns the city represented by experts. They were asked to evaluate the development of the city's transport infrastructure over the past five years. The answers are presented in Figure 4.

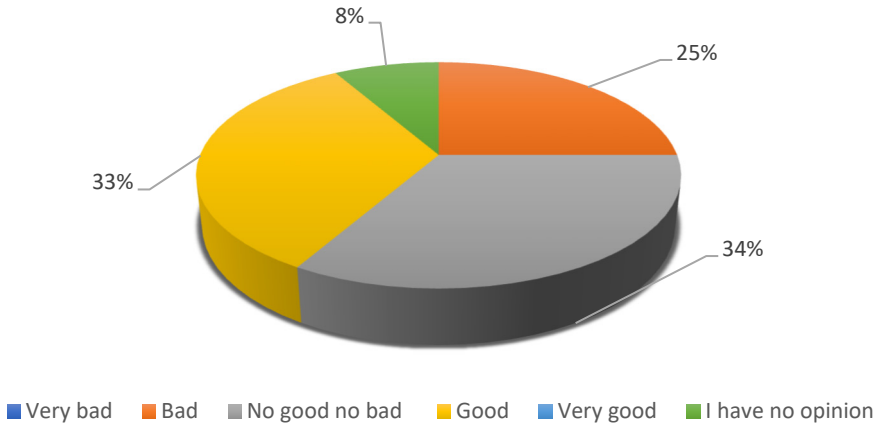

Figure 4. Responses to question 3 in the first round: How do you assess the degree of utilization of the possibilities of developing transport infrastructure in your city in the last 5 years? Source: own study.

Based on the collected data, it can be concluded that the infrastructure investments are being carried out by Oslo. In the case of Naples, Czestochowa and Barcelona, only one of the two experts who participated in the survey expressed a positive opinion on the development of transport infrastructure. The discrepancy is noticed in the responses of the

experts from Czestochowa, where one replied that there was a good degree of utilization of the opportunities for the development of transport infrastructure, and the other responded negatively to the use of these opportunities. It can be noticed that Amsterdam is a city that is gradually implementing the Smart City concept, while in the expert's opinion, the degree of utilization of infrastructure development opportunities has been at a low level in the last five years.

The next question was to give own opinion on the impact of technical conditions on the possibility of implementing telematic solutions supporting the safety of road users. The question was: Do you agree that the technical conditions of the transport infrastructure are the basis for the implementation of transport telematics solutions supporting road safety? Individual responses are presented in Figure 5.

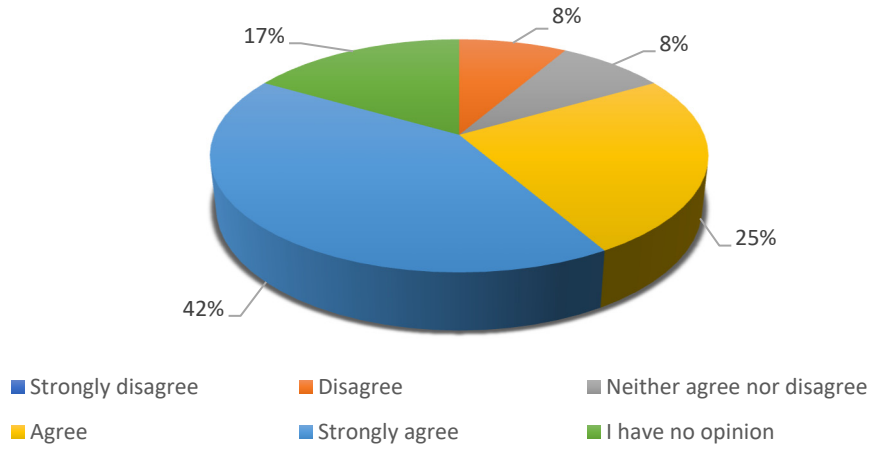

Figure 5. Responses to question 4 in the first round: Do you agree that the technical conditions of the transport infrastructure are the basis for the implementation of transport telematics solutions supporting road safety? Source: own study.

Analysis of the data presented in the graph showed that most of the respondents agreed with the statement presented in the question. "I strongly agree" and "agree" was indicated by eight experts. By taking into account the lack of opinion by two experts, the technical conditions and investing in them may constitute a solid basis for the implementation of technological solutions. In the second round, 11 experts indicated one of the answers confirming the thesis, which constitutes 92% of the total. One of the respondents disagreed with the statement presented in the question. Consequently, investing in telematics systems should be preceded by financial outlays incurred to maintain the transport infrastructure in good condition. This is an important aspect of taking action by city authorities to create a more sustainable and smart city.

The next question asked by the expert concerned which of the indicated measures are most often used by the authorities to improve the safety of the VRU. Individual responses are presented in Figure 6.

Each of the indicated solutions that can be implemented by the authorities is used to reduce road accidents involving vulnerable road users. Nevertheless, based on the collected data, it appears that the most frequently chosen solutions by the authorities are those concerning legal regulations. Legal instruments cover many areas, including traffic management system, road infrastructure, road signs and signals, admission to motor vehicles, road rules, driving time and rest time for professional drivers, and others [53]. Other solutions important from the point of view of building a safe transport system are transport infrastructure solutions. Interestingly, according to the previously presented data, road infrastructure is the basis for implementing technological solutions in the area of transport. This question was repeated in the second round to reach a consensus. The experts' answers were as follows: 10 of them answered that solutions in the field of legal regulations are most often implemented, 1 expert pointed to solutions in the field of

transport infrastructure and 1 expert to telematics solutions. The research results allowed for systematizing the importance of solutions in creating a safer environment for vulnerable road users. For this reason, the main role of implementing and refining organizational and institutional solutions is indicated.

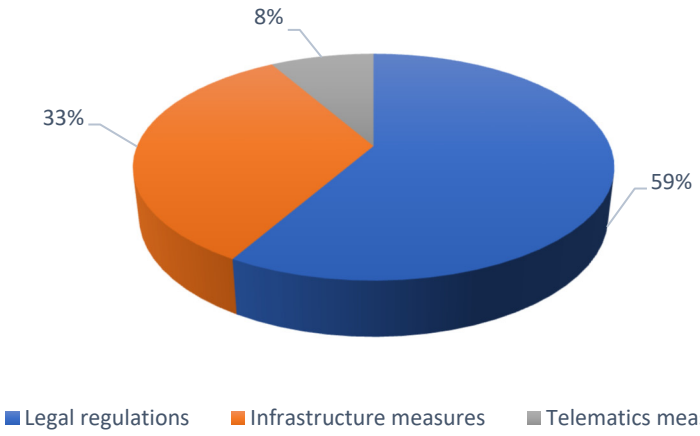

Figure 6. Responses to question 5 in the first round: Which of the measures are most often implemented by the authorities to ensure the safety of vulnerable road users? Source: own study.

In the next question, experts were asked to indicate to what extent they agreed with the statement that driving culture is related to the number of road accidents. The answers to this research question are presented in Figure 7.

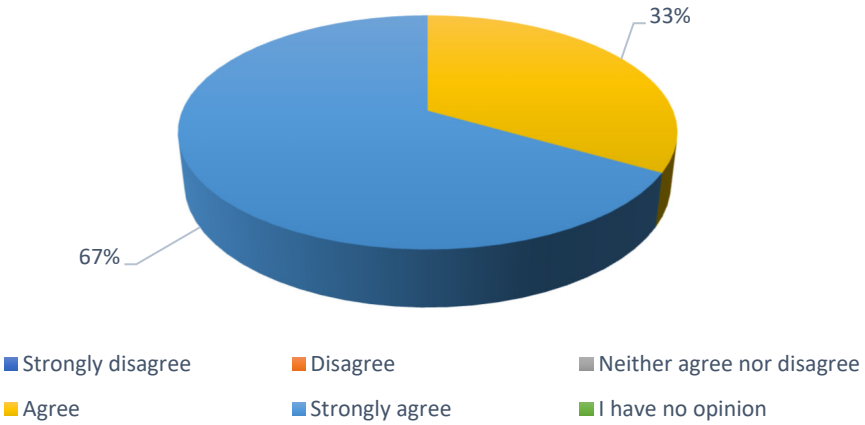

Figure 7. Responses to question 6 in the first round: Do you agree with the statement: The driving culture of drivers influences the number of road accidents in a country? Source: own study.

According to the experts' responses, the driving culture of drivers undoubtedly influences road safety. In the second round, 12 experts indicated the answer: I strongly agree with the statement. In many European cities, authorities deal with a large number of road accidents, despite increasing investments in solutions limiting this problem and increasing citizens' awareness of road safety. Drivers' driving culture may depend on many factors, such as the culture of society in a given area, legal regulations and others. Some behaviors of drivers/traffic participants can be found in a particular cultural environment due to the adaptation of specific occurring conditions [52]. This is an important aspect in the pursuit of the safety of urban transport systems by local authorities due to the limitation of drivers' driving culture in the effective selection and implementation of solutions that improve safety.

Vision Zero aims to minimize road fatalities for vulnerable road users to zero [54]. Therefore, experts were asked if they agreed with the statement that telematics solutions

support the implementation of Vision Zero. The answers to this question are presented in Figure 8.

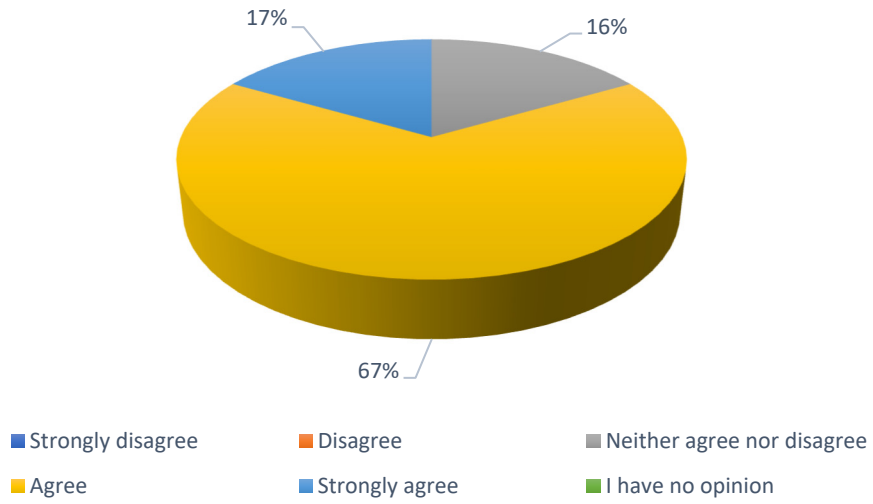

Figure 8. Responses to question 7 in the first round: Do you agree with the statement: Telematics solutions support the implementation of Vision Zero? Source: own study.

According to experts, telematics systems play an important role in the implementation of the Vision Zero concept. In the second round of research, the answers were as follows: 11 experts marked the answer "strongly agree", and 1 expert marked the answer "agree". When returning to the answers to the fourth question, it can be stated that in striving to implement Vision Zero, it is also important to maintain the transport infrastructure in good technical conditions. It is the basis for the implementation of technological transport solutions.

The next question addressed to the experts was to select the aspects affecting road safety. The factors mentioned apply to many areas and different road users. The answers are presented in Figure 9.

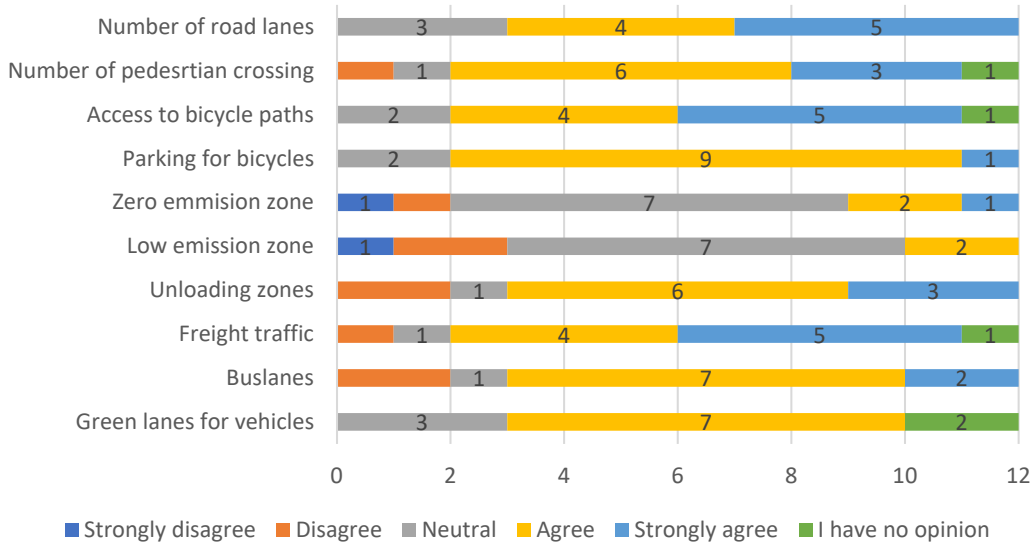

Figure 9. Responses to question 8: Do you agree with the statement: Each of the following aspects affects road safety. Source: own study.

According to experts, road safety is definitely influenced by adapting the infrastructure to the needs of its users. This applies to infrastructural accessibility for cyclists, including paths and car parks dedicated to cyclists, infrastructure available for pedestrians, public

transport and individual transport. In supporting the safety of pedestrians in road traffic, it seems important to design a space that allows easy and quick movement while paying particular attention to the number of available pedestrian crossings adapted in terms of engineering and law. At the same time, a small share of city logistics in influencing road safety was indicated. The more and more frequent introduction of unloading zones, especially in city centers, as "good practice" does not correlate with improving road safety. This is an important aspect in the pursuit of more sustainable urban spaces from the perspective of the negative impact of truck traffic in cities on the environment and its community. This question was also asked in the second round of research. The results are presented in Figure 10. Based on the collected data, it can be concluded that the optics of selected aspects of road safety has not changed. Experts pointed out that, above all, the broadly developed transport infrastructure is important in the pursuit of the security of municipal transport systems. Generally, it can contribute to a smooth flow of road streams. It is also important to adapt the transport network to the public transport traffic. At the same time, a significant role of lighting signaling was indicated, which enables the smooth flow of vehicles through several consecutive intersections creating a green wave. Noticeable development of low- and zero-emission vehicles as well as infrastructure adapted to the needs of their users. According to the literature, low- and zero-emission vehicles in cities mainly contribute to the reduction in traffic noise [51]. This is a significant transport problem faced by city decision-makers. Nevertheless, the role of these vehicles in cities is decreasing in the context of striving to improve road safety, taking into account a number of other solutions.

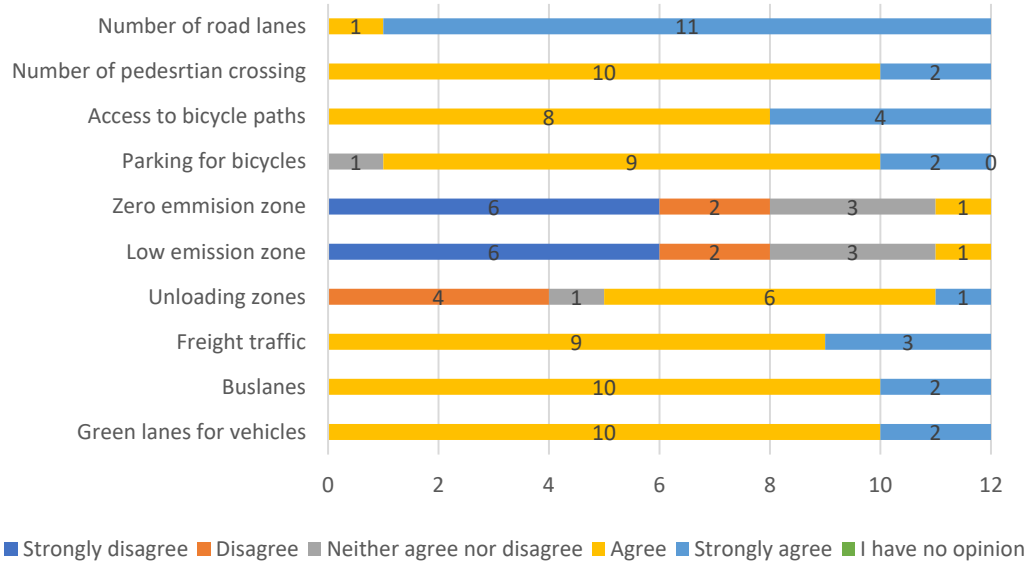

Figure 10. Responses to question 8 in the second round. Source: own study.

In the next question, experts were asked if they agreed with the statement that European cities support pedestrian safety more than other road users. The answers to this question from the first round are presented in Figure 11. In the first round, the experts' opinions were divided. Four experts disagreed with the statement presented in the question by ticking the answers "I strongly disagree" and "disagree". Seven experts agreed with the statement and one said that European cities can focus more on pedestrian safety than on other road users. This question was asked in the second round due to the need to receive a consensus on this matter.

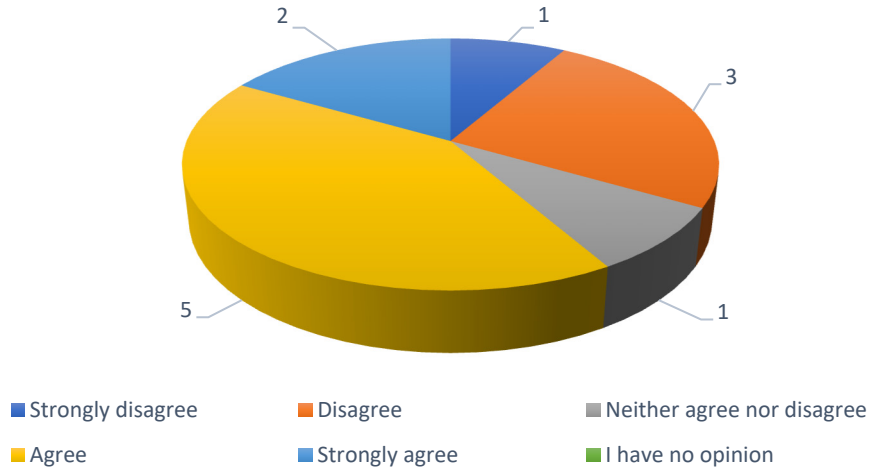

Figure 11. Responses to question 9 in the first round: Do you agree with the statement: Cities support pedestrian safety more than other road users (in the example of European cities). Source: own study.

The answers given in the second round indicate that European cities take into account the safety of pedestrians over other road users in their policies. Two respondents did not agree with the presented statement. Few of the respondents changed their minds during the research, which influenced the number of responses confirming that transport policies take into account the role of pedestrians in transport systems.

4.2. Data Coding

4.2.1. Open Coding

In applying grounded theory to the research process, open coding followed by axial coding was used. Data from the Delphi study were used for open coding. The collected data from the conducted research using the Delphi method were saved using codes. Each piece of data was assigned a code to develop the conceptualization of the data, which is presented in Table 1.

Table 1. Open coding.

No	Question	Answer	Code
1.	Which of the factors should be the priority for the city authorities?	Safety is a priority factor for city authorities.	C1
2.	Are new transport technologies being successively implemented in your city?	Most European cities are successively implementing new transport technologies.	C2
3.	How do You assess the degree of utilization of the possibilities of developing transport infrastructure in the Your city in the last 5 years?	The good technical condition of the transport infrastructure is supported by the authorities of European cities, but not to a sufficient extent.	C3
4.	Do you agree that the technical conditions of the transport infrastructure are the basis for the implementation of transport telematics solutions supporting road safety?	The appropriate condition of the physical infrastructure of transport is the basis for the implementation of telematics solutions.	C4
5.	Which of the measures are most often implemented by the authorities to ensure the safety of vulnerable road users?	To improve VRU security, legal regulations are most often implemented	C5
6.	Do you agree with the statement: The driving culture of drivers influences the number of road accidents in a country?	The safety of road traffic and its individual participants is influenced by the driving culture of drivers	C6
7.	Do you agree with the statement: Telematics solutions support the implementation of Vision Zero?	Telematics solutions play an important role in the implementation of Vision Zero	C7
8.	Do you agree with the statement: Each of the following aspects affects road safety?	In striving for the safety of urban transport systems, the most important is a well-developed transport infrastructure. It is also important to adapt the transport network to the traffic of public transport.	C8
9.	Do you agree with the statement: Cities support pedestrian safety more than other road users (in the example of European cities)?	Pedestrians are an important group of road users whose safety is a priority for city authorities	C9

The answers of the experts were deciphered, and they were defined as one statement reflecting the answers to each of the questions asked. A code was then assigned to each specific statement. These codes were then used to develop axial coding.

4.2.2. Axial Coding

At the next stage, the connections between the codes assigned in the open coding part were examined. On this basis, four main categories were developed (Table 2). The first one concerns the institutional and organizational area to which combined codes such as C1, C5 and C9 were assigned. The next category is technological conditions, to which codes such as C2 and C7 were assigned. In the infrastructure area, there are codes such as C3, C4 and C8. In the fourth category, behavioral conditions were identified, to which code C6 was assigned.

Table 2. Axial coding.

Category of Code	Code
Institutional and organizational	C1; C5; C9
Technological	C2; C7;
Infrastructural	C3; C4; C8
Behavioral conditions	C6;

4.2.3. Selective Coding

In the next stage of the research process, selective coding was used. In this way, the categories extracted from the axial coding were combined. These categories enabled the development of the core category. The individual stages of the applied research process are presented in Figure 12.

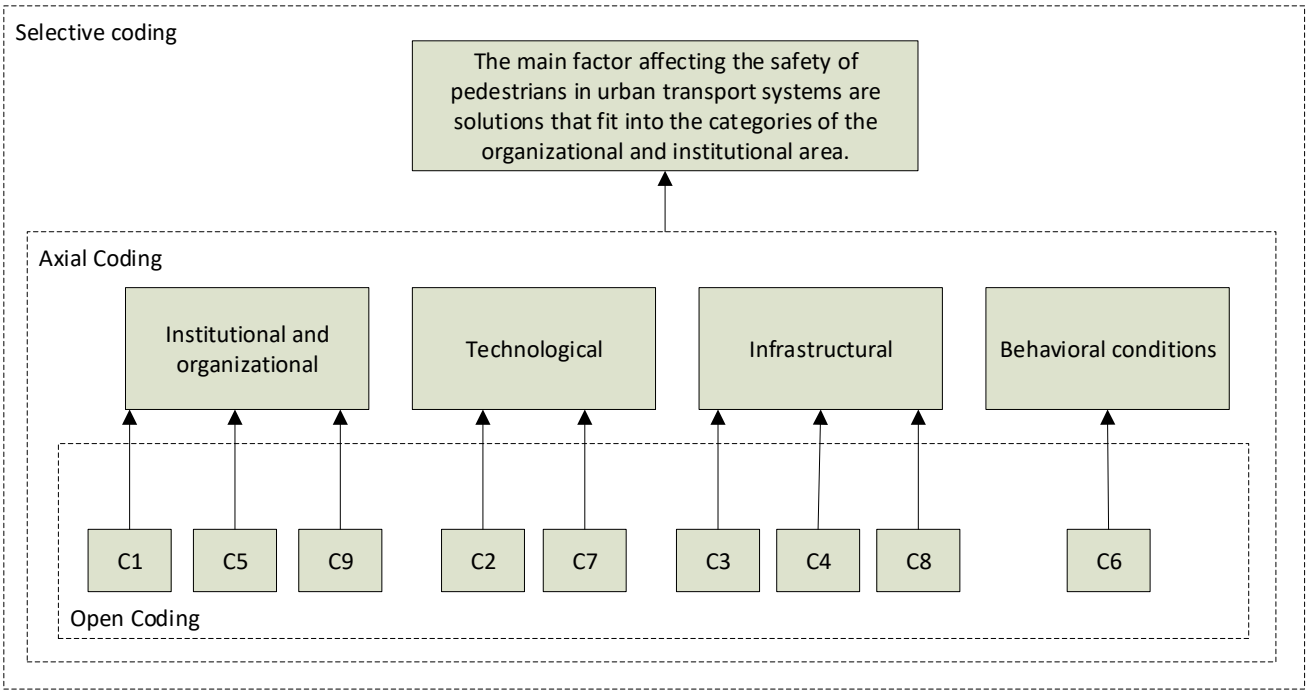

Figure 12. Selective coding.

The collected data were divided into four categories of solutions, which allowed the identification of the most important areas affecting the safety of pedestrians in the urban transport system. As part of selective coding, in which inductive analysis was used, which allowed for concluding that the main factors affecting pedestrian safety are institutional and organizational solutions, followed by infrastructural solutions.

The institutional and organizational factor is mainly influenced by the city authorities. In the absence of cooperation between individual units from the public–private sector, this becomes a limitation in improving the safety of pedestrians in transport networks. An important element for the implementation of solutions in this area is the sharing of data between individual levels of management at the local, regional, national and higher levels. Nevertheless, the institutional and organizational factor has an impact on other categories; it can condition infrastructural and technological development as well as have a positive impact on the behavior of individual road users. Experts who took part in the research using the Delphi method indicated that solutions in the field of implementing technological solutions are often used and implemented in European cities, but they are not sufficient to improve road safety. For this reason, it is necessary to focus on solutions in the areas of institutional and organizational as well as infrastructural.

5. Discussion

In order to strive to ensure road safety and achieve Vision Zero, decision-makers must look at this issue holistically. The analysis of road safety in recent years in individual countries does not give the current picture of the level of safety due to the restrictions on movement introduced by the COVID-19 pandemic. Travel restrictions influenced the dominance of other groups of road users [55]. Until the outbreak of the pandemic, these were motorized vehicles. There was an increase in the share of VRU mobility, which in turn resulted in an increase in VRU accidents [56]. The literature review in the introduction indicates that the reduced number of vehicles in cities related to the spread of the COVID-19 pandemic had a positive impact on reducing transport problems. Nevertheless, experts point out that city authorities should mainly increase road safety as one of the main transport problems in cities. By taking into account the change in the preferred mode of movement in cities, this direction may set new trends in the management of urban transport systems. Experts indicate different orientations of city authorities in relation to particular groups of road users in their efforts to improve the safety of urban transport systems. According to research, it is most often pedestrian safety that is supported by city authorities. Nevertheless, it is worth noting that the research ended in 2021 and did not include post-pandemic observations.

The results of the conducted research indicated the organizational and institutional role in increasing road safety. This factor has a significant impact due to the development of a strategy tailored to the current needs of the city. Due to the dynamics of changes taking place in the environment, the culture of society, human, financial and material resources, and political influences, the institutional structure for road safety management is not universal. Road traffic organization has a direct impact on road user safety management. In the selection of road traffic organization solutions, it is important to apply good practices that have the best effect on the participants of the transport network. In addition, the organization of road traffic management should be coordinated with other areas implemented, such as strategic city development planning, public transport management, maintenance of transport infrastructure, enforcement of road traffic regulations, management of transport projects, supervision of freight transport processes, transport investments and others. The literature indicates that the severity of injuries is influenced by the speed of vehicles [57]. Therefore, there is an increased activity of local authorities implementing limited speed zones [58]. Limiting the speed of vehicles to 30 km/h in an accident with a VRU causes a fatality rate of 10% for pedestrians or cyclists, and at a speed of 50 km/h, the fatality rate of road accidents oscillates between 55% and 90% [59]. The severity of road accidents for pedestrians is influenced by the type of vehicle involved in the accident, and injuries can be more severe in the case of trucks and the health of the drivers [60]. This is due to the greater rigidity of heavy goods vehicles, greater weight than passenger vehicles and a larger impact area in the event of an accident involving a vulnerable road user [61]. In addition, the lack of regulations related to the limitation of transport by long vehicles and their transport in urban areas contributes to the increase in the number of VRU accidents.

Promoting more environmentally friendly forms of transport should take into account the construction of space in the transport policy, reducing the risk of road accidents. Based on the example of research in Oslo, it has been shown that road accidents involving cyclists and trucks have severe consequences [62]. It is worth noting that the experts unanimously point to the important role of the impact of trucks in improving road safety in cities.

As part of the conducted research, another area of interest for decision-makers should be changed in the area of physical transport infrastructure. Road geometry is an important aspect of road safety. According to the data provided by the Road Traffic Office of the Police Headquarters in Poland, in 2020, accidents occurred most often on straight road sections, on bends, slopes and hilltops. Regarding road accidents in Poland, in 2020, the largest number of road accidents occurred on the road, at pedestrian crossings, on bicycle paths, on sidewalks/pedestrian roads, on slopes, at exits from a property/field and in parking lots/customer service yards [63]. The knowledge of the risk of road accidents involving VRU is the basis for making decisions related to the planning of infrastructure development, which consequently reduces the occurrence of accidents and their consequences [62]. According to experts, in the construction of urban space characterized by a high level of safety, it is important to take care of infrastructure solutions for each means of transport. Safety is influenced by the number of lanes, green wave, bus lanes availability, as well as the number of pedestrian crossings and infrastructure facilities for cyclists, including bicycle parking lots.

According to experts in the pursuit of achieving Vision Zero, the implementation of technological solutions is essential. Nevertheless, to implement solutions in this field, it is important to develop transport infrastructure. The technological factor is increasingly often and more widely used in the pursuit of increasing the level of road safety. One of the examples based on the use of technological progress is telematics systems, which are based on the behavior of road users. The complexity of these systems requires the use of devices that enable data acquisition, data processing and communication, and presentation of data to recipients—individuals or administrators. The development of telematics systems is supported by the increasingly widely used ICT solutions. Databases and cloud computing are important elements in urbanizing cities around the world [64]. Large databases increase the analytical potential. The creation of large data sets and possible rapid analysis supports many processes in the field of knowledge management and problem-solving. Therefore, city managers have an analytical tool enabling the collection of data on road traffic hazards, accidents, air pollution, traffic noise emissions and many others. This is possible thanks to the proliferation of IoT devices. However, the implementation of telematics solutions requires the consent and cooperation of many institutions. The potential for implementing technological solutions is very large, while the main limitation of their implementation is financial resources. Most experts pointed to the tertiary role of technological solutions in improving VRU security in urban transport systems. Considering the transport system holistically, it seems important to implement solutions based on telematics systems, solutions enabling data acquisition and big data creation, or increasingly commonly used solutions based on artificial intelligence.

6. Conclusions

When promoting more environmentally friendly forms of transport, it is necessary to select risk factors and the impact of measures reducing their probability. As risk factors are discussed in the reports on road accidents, the aim of the article was to identify the factors that may influence the increase in VRU safety in road traffic.

As part of the research, it was found that a significant problem is adapting policies and organizational solutions to the real transport needs and problems of the city. Changing social behavior during the COVID-19 pandemic has contributed to the achievement of accident reduction goals by many cities and countries. Nevertheless, the return to the road traffic intensity from before that period shows the effectiveness of the previously implemented measures. It is worth noting that more VRUs increase the number of interactions

between the VRU and the drivers. Moreover, the consequences of the incidents with these two traffic groups are more severe for the VRU.

Many cities are switching priorities in their urban transport systems, assigning them to cyclists or pedestrians. Promoting more environmentally friendly forms of travel has become good practice. The creation of an infrastructure appropriate for this contributes to increasing their safety. It is also important to promote the use of this form of travel.

The technological solutions that constitute the basis for building Smart and Sustainable Cities are important from the point of view of the implementation of the Zero Vision. Systems that enable data collection in the context of selecting and implementing various types of solutions tailored to the current needs of the city play an important role in that aspect. Appropriate analysis of this data allows not only to understand the actual state but also to plan changes and identify problems with the possibility of solving them.

The main limitation of the implementation of a coherent strategy for improving road safety is the different visions and goals of changing city managers. In addition, the lack of cooperation between various authorities and existing problems with the flow of data and information, based on which strategic plans can be adapted to the real problems and expectations of the city, may also have a negative impact. As the conducted research shows, it is the institutional and organizational factor that plays the main role in building a safe urban transport system, taking into account its unprotected participants. Therefore, it is important to make decisions affecting the functioning of urban transport systems on the basis of collected data, available information and in cooperation with all city stakeholders in order to identify their needs.

The validation of the research results obtained in the research process carried out using the Delphi method are cities that are based on the phased implementation of solutions indicated in the study by the experts. An example of such a city is Barcelona, where city authorities have set road safety and the reduction in accidents as a priority. More than half of the people in Barcelona travel on foot, and the city authorities refer to the city as "the city of pedestrians" [48]. Studies carried out in Barcelona indicate that shifting at least 40% of passenger vehicle travel to cycling or public transport in Barcelona would significantly reduce the deaths of residents [65]. Another example of the validation of research results is the city of London, which in its "Pedestrian Safety Action Plan", sets out a plan to support safety and improve the efficiency of torrents for vulnerable road users. The strategic plan is so important that the authorities are working to increase the number of people walking, which in turn is to translate into a greater number of pedestrians [49].

Summing up the conducted research, it should be noted that the research and analytical procedure gave the answer to the research question, i.e., identified factors affecting pedestrian safety in urban transport systems, as well as desirable solutions that should be implemented by cities as a priority. As a rule, city authorities change their approach to prioritizing road users with particular emphasis on unprotected user groups, thus implementing several solutions in this regard. According to the authors, the article helped fill the existing scientific and cognitive gaps in the perception of factors and their importance in affecting pedestrian safety.

This study provides insightful findings and contributes to the existing literature, as well as a few points to note. The first concerns the personal views of the research sample and the lack of representation of various city stakeholders. The opinions presented and represented by the experts may inaccurately correspond with the actual state of development of urban transport systems, taking into account vulnerable road users. It seems important to take into account the promotion of the represented city by the experts as the one that should be an example for others through the prism of its management and implementation of a number of different solutions. Based on the research results, the authors intend to continue the research, taking into account the limitations related to the conducted research process, focusing in particular on the development of cities friendly to unprotected road users in the post-pandemic period.

This article presents the first stage of research, aimed at determining the knowledge gap, collecting good practices used in the world and evaluating individual solutions in VRU safety management. The research process will be continued in the future in order to create complete recommendations for local authorities regarding the implementation of good practices aimed at increasing VRU security. Their goal will be to select solutions appropriate to the needs of specific cities and to implement them in the most effective and efficient way in terms of the achieved results.

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