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Problems of ensuring the safety of pedestrian traffic across railway tracks and ways to solve them

From the analysis of the state of safety on the railways, it was established that a large number of collisions with pedestrians and their injuries occur outside railway crossings, which requires the development of technical means and the development of a safety culture for pedestrians when crossing railway tracks. The work deals with the urgent issues of ensuring the safety of pedestrian traffic when crossing railway tracks. It should be noted that the relevance of this issue today is also important from an economic point of view, since the loss of human life or injury to people has high economic losses for the country. For Ukraine, given the negative trends in population dynamics, preserving people's health and lives is of particular importance. Therefore, the improvement of safety measures for the movement of pedestrians across railway tracks in the conditions of urbanized cities should be considered in the interaction of all authorities and transport enterprises. It has been established that there is zero tolerance for road traffic fatalities in developed nations, so any measures that can improve road safety and prevent injury or death are urgent and require appropriate research and solutions. The proposed system for improving the safety of pedestrians at railway track crossings is primarily intended to create conditions for minimizing the number of traffic incidents involving pedestrians in populated areas.

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Keywords*: safety of pedestrian traffic, urbanized spaces, pedestrian crossing, factors affecting pedestrians, information system.*

Introduction. Railway safety is everyone's responsibility. It is dangerous to take risks at level crossings and crossings, as any incident can lead to work disruptions, vehicle delays, property damage, injuries, and in the worst cases, the death of road users.

Existing studies [1] of the problem of traffic events at pedestrian crossings show that there is a high proportion of pedestrians who deliberately violate the rules of crossing the track. This may be due to various factors, but most studies [2] indicate the need to take into account not so much the geometrical and planning parameters of the pedestrian crossing, but the characteristics of train movement and patterns of pedestrian behavior.

It should be noted that there are practically no studies of pedestrian movement across railways in Ukraine. The issues of improving traffic safety at crossings are mainly considered. At the same time, the problems of crossing railway tracks by pedestrians, especially in the urbanized spaces of large settlements, remain neglected [3]. However, even in the majority of foreign works [4-11], it is noted that there are not enough studies of the functioning of pedestrian crossings over the railway, and the main problem of such studies is the lack of primary information. In particular, a train hitting a pedestrian is

often the result of a deliberate violation or erroneous behavior or assessment of the situation [2-4, 6]. This, in turn, limits the development of adequate and effective measures to increase the safety of pedestrian traffic. Moreover, the impact of educational campaigns on curbing dangerous pedestrian behavior remains unclear [2]. At the same time, the researchers, in works [7-8], come to the conclusion that the study of the transport behavior of pedestrians is important for further research in the field of improving traffic safety.

Research analysis. A number of studies [4-6], mostly foreign ones, have been devoted to the problem of pedestrians crossing railway tracks, since in Ukraine the issues of functioning of railway crossings, not pedestrian crossings, are studied mainly [7-8].

Analyzing the problems of railway crossing by pedestrians, researchers [9-10] study various aspects of their functioning. Part of the research [11-13] focuses mainly on the diagnosis and classification of disorders. In particular, in [4], a detailed analysis of more than 7,000 transport events involving pedestrians on the railway was carried out. As a result, the basic regularities of pedestrian behavior at crossings of various types, taking into account geographical differences, have been established.

In work [5] based on the results of a study of accidents with pedestrians, it is shown that the main problem of such studies is the lack of reliable information, in particular, a train hitting a pedestrian is the result of a deliberate violation or erroneous behavior or assessment of the situation. And this, in turn, limits the development of adequate and effective measures to improve the safety of pedestrian traffic.

The paper [6] investigates the influence of pedestrian distraction during a railway crossing and shows that such factors as talking or looking at the phone screen while driving are extremely common causes of distraction. At the same time, it was also found that the vast majority of violations (disobeying traffic light signals) were observed precisely in attentive pedestrians, which indicates that such behavior was conscious and purposeful. The same thesis that violations at pedestrian crossings are a conscious behavior is confirmed by the results of research given in the work [9]. According to which, almost 25% of the respondents of the sociological research admitted that they deliberately violated the safety rules, while this was a violation not before, but after the passage of the train.

The work [10] is devoted to the study of the nature of decision-making by pedestrians crossing the railway and the analysis of risks related to the safety of pedestrian traffic.

There are a number of scientific works devoted to the study of mainly technical and operational characteristics of pedestrian crossings. In particular, in work [11], on the basis of real-time studies of the movement of pedestrians and cyclists across the railway, it was found that the train characteristics (speed of the train and duration of passage of the crossing train), technical characteristics of the crossing (duration of the warning signal and duration of traffic blocking) have the main influence on the probability of violation), as well as individual characteristics of pedestrians (gender, age). At the same time, the geometric parameters of the transition have a smaller influence, compared to the characteristics of the train and the individual characteristics of pedestrians.

A number of studies [12, 13] are aimed specifically at studying possible measures that should increase traffic safety during railway crossings. For example, the work [12] analyzed the patterns of behavior of schoolboys who regularly cross the railway, and the impact on behavior of additional training on traffic safety and penalties for violations.

In work [13], based on the analysis of transport accidents on the railway, various strategies that were proposed to prevent accidents with pedestrians on the railway are discussed, and it is also shown that the application of the modern theory of behavioral and cognitive of psychology may be useful for future research in the field of transport safety.

So, as can be seen from the analysis of scientific works [4-13], the problem of improving the safety of pedestrians crossing railway tracks has not been sufficiently studied, therefore the development of recommendations for improving the safety of pedestrians when crossing railway tracks is an urgent scientific task.

The purpose and tasks of the research. The purpose of the study is to improve traffic safety at pedestrian crossings over the railway by developing recommended measures to improve pedestrian traffic safety.

To achieve the specified goal, the following studies should be performed:

- to conduct an analysis of the state of safety on the railways of Ukraine and foreign countries;
- to conduct an analysis of the problems of ensuring the safety of pedestrian traffic when crossing railway tracks;
- to offer recommendations for improving the safety of pedestrian traffic when crossing railroad tracks;
- to develop a comprehensive information system for improving the safety of pedestrians crossing railway tracks.

Research materials and methods. As of 2023 (a 9-month report) in the regional branches of JSC "Ukrzaliznytsia" (at stations, tracks, territories of subdivisions) as a result of the collision of railway rolling stock, falling from it or other types of impact, 202 persons outside the railway transport industry received injuries of varying degrees of severity. including 128 with a fatal outcome, of which 16 people were electrocuted, including 6 fatally. During the same period in 2022 (Fig. 1), 177 people were injured, including 109 fatally injured, 15 of them were electrocuted, including 3 fatally [14].

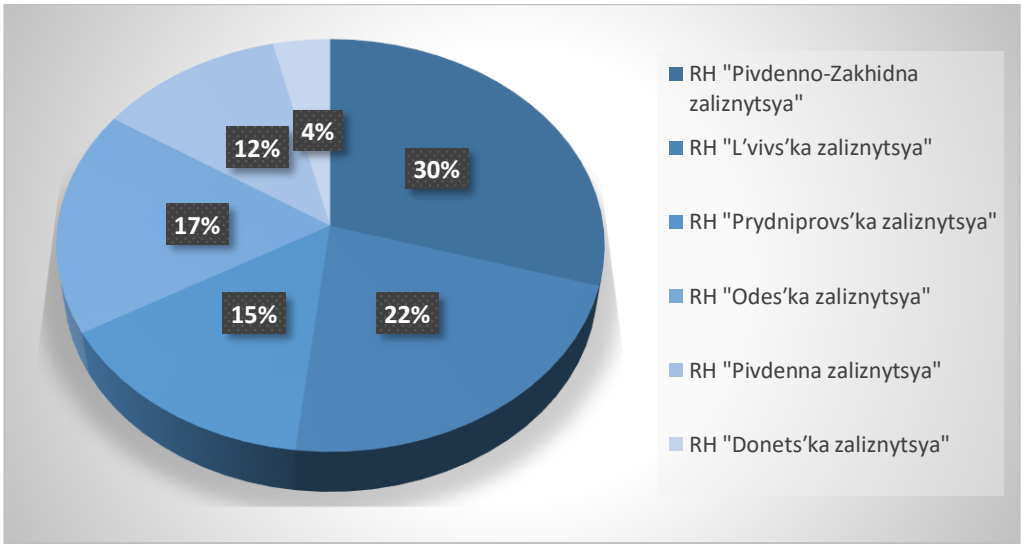

Fig. 1. **Chart of injured persons with fatal outcome in regional branches of JSC "Ukrzaliznytsia" in 2022**

In particular, 43 citizens were injured in the regional branch of "Lviv Railway" compared to 40 in 2022 (+3), of which 26 were fatal compared to 24 in 2022 (+2);

In addition, as of September 28, 2023, 13 children under the age of 16 were injured at railway infrastructure facilities, 7 of them fatally, including 10 children injured by electric shock, 4 of them fatally. During the same period in 2022, 6 children under the age of 16 were injured, 2 of them fatally, including 4 children injured due to electric shock, 1 of them fatal.

The analysis of cases of injury to third parties on railway transport shows that most of the cases occurred as a result of the victims' violation of the Rules for the safety of citizens on railway transport of Ukraine, approved by the order of the Ministry of Transport dated 19.02.1998 No. 54, registered in the Ministry of Justice on 24.03.1998 under No. 193/ 2633, namely: the crossing of railway tracks in unspecified places; walking on railway tracks; boarding and alighting while the train is moving; being in a state of alcohol intoxication on the territory of railway transport facilities.

According to UIC (International Union of Railways), there are more than half a million railway crossings in the world [15]. Monitoring the safety and interoperability of the EU rail system is one of the key tasks of ERA. The agency collects, processes and analyzes various data sets to support recommendations for action to be taken. Constantly monitoring and analyzing safety and interoperability indicators of the EU railway system. A report is then published every two years on a comprehensive

overview of the development of railway safety and interoperability in the European Union (EU). The publication is the publication of a progress report on safety and interoperability in the Single European Railway Area (SERA). This report is based on data available in various EU databases and registers provided by national authorities such as national security agencies (NSAs) and national investigative bodies (NIBs), operators and other actors.

In 2020, the rate of major accidents, fatalities, and serious injuries (FWSI) per million train-kilometers has decreased significantly since 2010 [16]. Despite the decrease in passenger fatalities, taking into account the significant decrease in passenger kilometers (due to the COVID-19 pandemic), the passenger fatality rate increased compared to 2019, showing a slight upward trend since 2017.

The results of the most recent assessment [16] of the achievement of safety targets (annual ERA) show that safety performance remains acceptable at EU level, although possible deterioration of safety performance has been identified in eight cases. Every year, almost 300 road users or pedestrians die in accidents at railway crossings, causing economic damage of 1 billion euros [16]. Of these fatalities, 98% are caused by intentional or unintentional errors by road users, both vehicle drivers and pedestrians. Despite this, society still attributes most fatal accidents at level crossings to the railroad.

The railway community [17] considers this to be a particular problem mainly because it is impossible to predict the actions of individual vehicle drivers and pedestrians at level crossings, despite a number of risk control measures. Actions and misuse of rail infrastructure by members of the public across Europe are disproportionately responsible for more than 25% of all accidents and 29% of all rail fatalities affecting safe rail operations. Obviously, this is an area of significant risk for the railway sector.

However, only 1% of all road deaths in the EU (22,800 in 2019) occur at railway crossings [17]. Thus, the significant risk to the safe operation of the rail network is actually only a minor element of the overall road safety problem.

The level of accidents at level crossings varies significantly among EU member states. The countries with the lowest accident rates have generally developed comprehensive strategies to improve the safety of level crossings, and this has resulted in a small number of level crossings with poor or no protection.[17] Common features of the countries with the highest accident rate are low population density and low volumes of railway traffic. Perhaps these conditions create less incentive for integrated safety management of level crossings.

The accident indicators available at EU level [17] are a damaged track superstructure, faulty rolling stock, including wheelsets, faulty signaling and disregard of danger warning signs (SPADs). Their absolute numbers give an initial idea of their relevance and trends. Between 2016 and 2020, EU Member States reported more than 12,100 accident precursors as defined in the CSI each year. This is expressed as a ratio of approximately 7 warnings to 1 major accident. However, if we do not take into account accidents with l for people caused by rolling stock while driving, the ratio of warnings to accidents increases to 17:1. This highlights the potential of accident warning processing.

Problems of ensuring the safety of pedestrian traffic across railway tracks. Railroads are a significant barrier to pedestrian traffic and often cut or complicate established pedestrian connections in populated areas. The problems of ensuring the safety of pedestrian traffic across railway tracks are shown in fig. 2.

Pedestrians strive to simplify their path (which is especially relevant for low-mobility population groups), so they try to form their routes so that they are the shortest and fastest, and the lack of an organized crossing over the track is often not a reason to abandon the route.

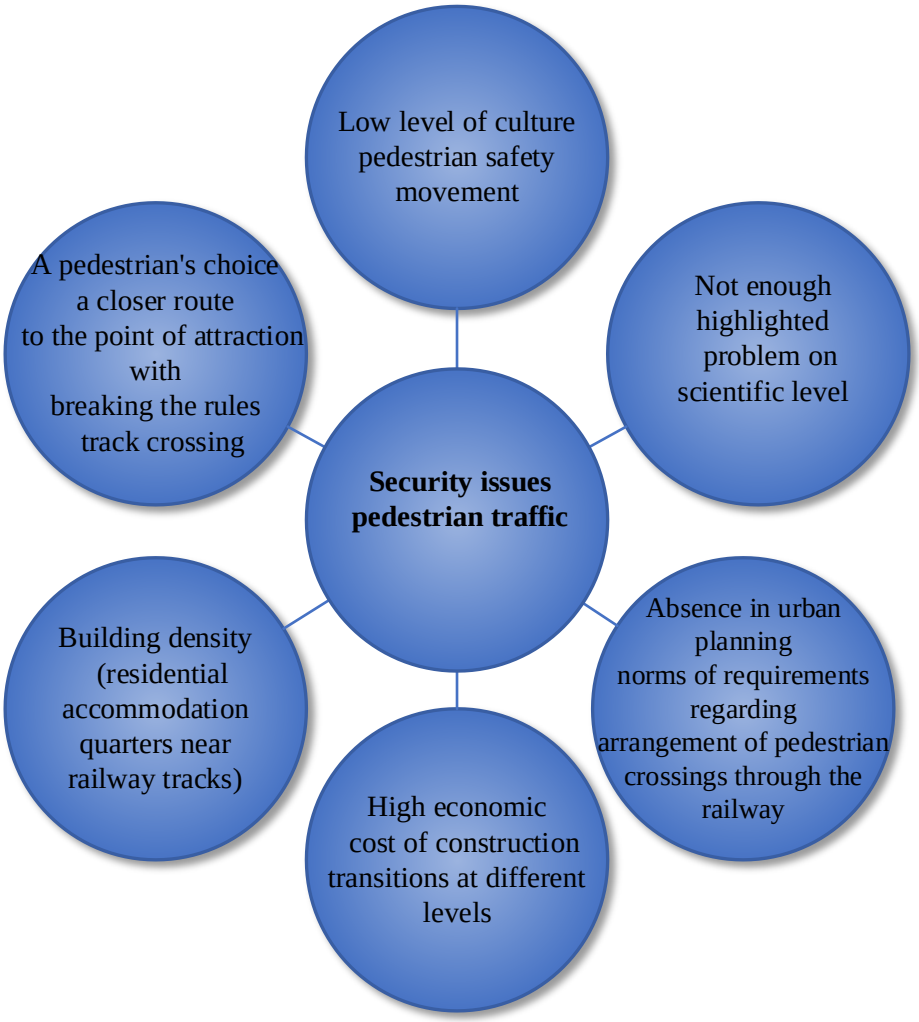

Fig. 2. **Problems of ensuring the safety of pedestrian traffic**

On the other hand, pedestrian connections in urbanized spaces are quite dense, and pedestrian traffic on them is intense. Modern approaches to city planning and street infrastructure prioritize pedestrian traffic over other types of transportation. At the same time, in case of crossing the railway track, the pedestrian loses his priority. But this is inconsistent with the principles of pedestrian behavior on the streets and spaces of populated areas, and pushes pedestrians to dangerous behavior.

In urbanized areas of cities, pedestrians may need to cross railways to reach a public transport stop. The design of these crossings is critical because a pedestrian collision with a train usually results in serious or fatal injuries. So, for example, in fig. 3 shows unauthorized crossings over railway tracks, which are caused by the installation of pedestrian crossings over roads near railway tracks.

As a result, pedestrians do not change their route and go to the center of gravity through railway tracks in unauthorized places. This once again proves that the interaction of all road services is extremely important to ensure the safety of pedestrian traffic.

The existing norms and instructions do not regulate the necessary frequency of the location of pedestrian crossings over the railway in populated areas, nor do they provide for taking into account the actual speed of the train (especially if passenger and freight trains can run at different speeds on the route), properly informing the pedestrian about the direction of approach train or the presence of a train on the opposite track, and also do not take into account the patterns of pedestrian behavior.

At the same time, almost all traffic accidents with pedestrians (at organized crossings or outside them) have serious or fatal consequences.

Fig. 3. **Unauthorized pedestrian crossing over railway tracks**

Even when crossing railways at equipped crossings, there are a number of challenges that provoke pedestrians to consciously or unconsciously violate safety rules. In particular, on long straight sections, pedestrians cannot correctly estimate the speed of the train (since the projection of the train practically does not change when approaching the crossing). However, in case of low speed of traffic, situations of excessively long waiting may arise, when pedestrians may decide to cross the track at the moment of dangerous approach of the train.

Similarly, a pedestrian may not recognize the approach of a high-speed train in time and step onto the track at a dangerous moment. In addition, on single-track sections with limited visibility or in the case of trains moving on the wrong track, existing pedestrian information systems do not indicate the direction of the approaching train in any way, and on double-track sections, when one train is passing, pedestrians cannot see or hear the approach of an oncoming train (at the same time, signaling that continues to work can be perceived as a certain feature of work, and not its activation to inform about the movement of an oncoming train). Therefore, although crossing at a prohibitory signal is not allowed, the pedestrian must make sure of the safety of his maneuver, but modern traffic safety management approaches provide that, in addition to the prohibition, there should also be proper informing of the pedestrian about the danger.

In Germany, ground warning lights are used to improve the safety of pedestrians at urban railway crossings [18] (Fig. 4).

The technology is lights installed in the carriageway, which are an additional technical safety factor when pedestrian's cross railway tracks. They are controlled by the same signal image used for existing light signaling devices (red/dark). However, the conducted studies of the effectiveness of the use of warning ground lights are not high. Since the decrease in the number of people who cross the pedestrian crossing at the red-light circle is not high [19].

According to information on the state of accidents at railway crossings in the United States of America (according to the Federal Railroad Administration (FRA) from 2017 to 2023 [20], the total number of accidents at railway transport in the United States is 61 thousand cases, the number of deaths is 4.9 thousand persons, of which 3,300 are violators of the rules.

Fig. 4. **Ground warning lights**

In the USA, to improve the safety of pedestrians [21], when crossing railroad tracks, hinged sides are used.

In work [21] it is stated that the design of pedestrian crossings over railway tracks is important. Because collisions with pedestrians lead to injury and death of people.

In fig. Figure 5 shows the construction of a pedestrian crossing over the railway track [22], which is used to connect the local residential area with the center of Stonehouse. This crossing uses a red/green light system with constant warning time.

Fig. 5. **Pedestrian crossing over the railway track [17]**

In addition, work [21] states that when arranging pedestrian crossings, it is necessary to provide a minimum of 20 seconds of pedestrian warning time in the case of single-track railways. Crossings over more tracks require additional warning time built into the train detection system. Means that can be used to increase safety at railroad crossings include barrier gates, flashing lights, sound signals, active and passive warnings, fences, level crossings, and the use of penalties in the form of fines.

Also, in work [21] it is recommended to carefully study the location of the pedestrian crossing over the track. This includes an assessment of the number of tracks, the frequency of the location of footpaths across the road, which are located near railway tracks. The location of attractions near the tracks is very important, such as schools, hospitals, kindergartens, shopping centers, etc. At the same time, in cities where there are a large number of people, more effective means of improving the safety of pedestrian traffic should be developed.

In the UK, level crossing closures are believed to be the only way to tackle the risks, and since 2009 the country has closed 1,300 level crossings and invested £200 million in improving safety at thousands of crossings, including building level crossings, installing new barriers and warning systems, new signs,

training people. The result of the activity is the approved strategy for improving safety at railway crossings 2019-2029 [23].

There are 3,000 crossings with active and passive safety devices in Spain. According to the National Agency for Railway Safety (AESF), in the last five years (from 2017 to 2021), 29 people died in 37 major accidents recorded at level crossings, with up to 98% of accidents being the result of human error rather than technical error means or infrastructure [24].

From the given data, it can be concluded that the real situation in the field of traffic safety at railway crossings and transitions constantly requires new approaches and solutions.

Proposed methods of improving the safety of pedestrians crossing railway tracks. In order to increase the safety of pedestrian traffic at railway crossings, it is necessary to use not only standardized automatic traffic signals, which are a cumbersome and expensive complex, but also other technical solutions that can be implemented at pedestrian crossings over railways in urbanized spaces (that is, where the intensity pedestrian traffic and the specific number of crossings per unit of track length are high). The proposed methods of improving the safety of pedestrian traffic at railway track crossings are shown in Fig. 6.

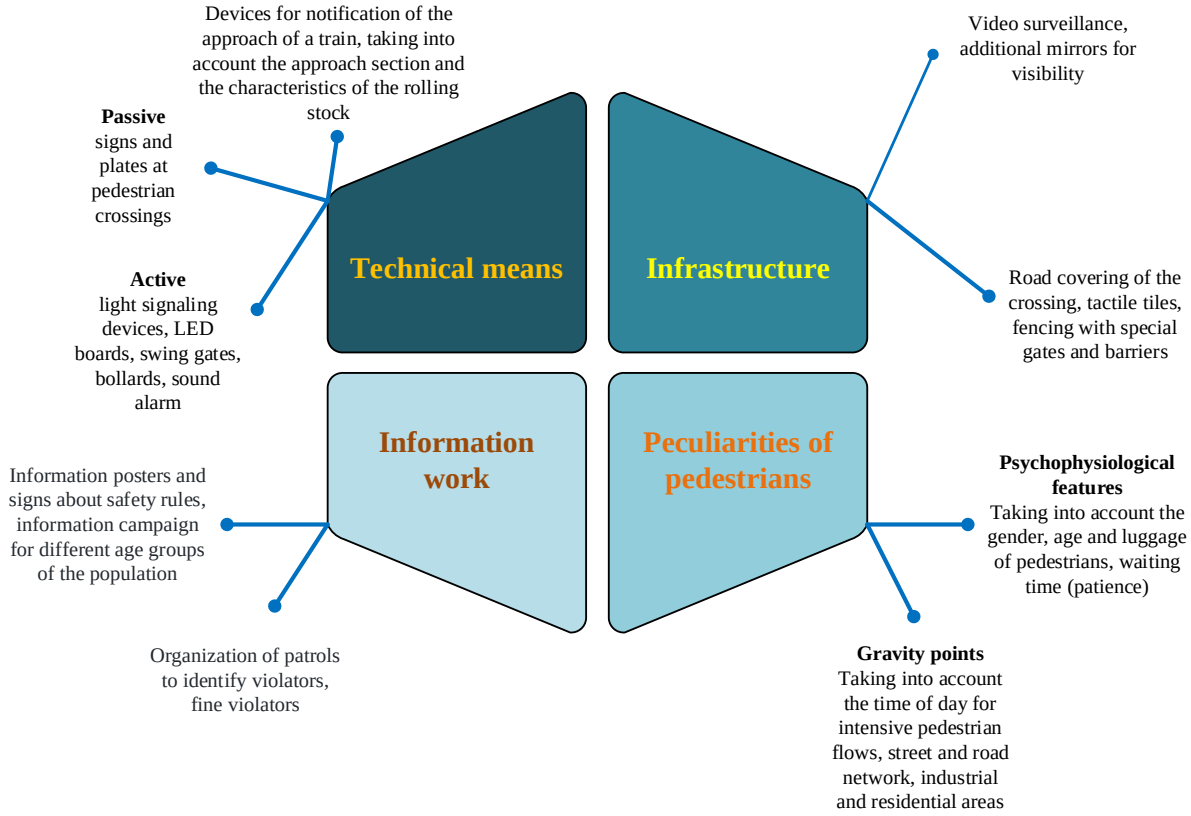

Fig. 6. **Proposed methods of improving the safety of pedestrian traffic when crossing railroad tracks**

Measures to increase the safety of pedestrian traffic include the development of infrastructure through the installation of pedestrian crossings over railway tracks, the use of technical means of warning about train movement, conducting information work for different age groups of the population and fining violators of the rules for crossing the tracks. Psychophysiological characteristics of pedestrians are also a special component of pedestrian safety.

At the same time, an important emphasis is placed not only on the technical provision of crossings, but primarily on the patterns of pedestrian traffic behavior. In particular, pedestrians are less inclined to

unconditionally comply with the requirements of the prohibition of railway crossings, both with regard to the place of crossing and with respect to the acceptable interval to the approaching train.

In addition, measures to improve the safety of pedestrian crossings over railways in populated areas provide an improvement in the quality of life in populated areas, which additionally strengthens the relevance of such research.

At the same time, Ukrainian norms, standards and instructions do not contain requirements for the location and number of pedestrian crossings over the railway, requirements for ensuring the safety of traffic on them, etc. However, the absence of regulations does not mean that there is no need to cross the track (especially if it is due to the planning structure of settlements.

At the same time, the construction of transitions at different levels (bridges, tunnels), which take into account all the requirements for inclusiveness, is expensive. In turn, the installation of an overpass with an information and analytical system to inform pedestrians about the approach of a train will be a much cheaper solution in populated areas for existing or potential pedestrian crossings than the construction of overground or underground crossings.

In the case of taking into account the patterns of pedestrian behavior when crossing railway tracks, it will make it possible to avoid their excessive delays during the railway crossing in the case of trains moving on single-track sections or multi-track sections (when turning off the red lights and turning on the green lights occur after the train leaves the approach section, which is located by moving in relation to the movement of the train), as well as in the case of the actual movement of the train at a speed different from the calculated one.

Information system for improving the safety of pedestrian traffic at railway track crossings. The improvement of systems (Fig. 7) responsible for increasing the safety of pedestrian traffic when crossing railway tracks assumes that the system will take into account the characteristics of train movement, as well as the patterns of pedestrian behavior (speed of movement, length of patient waiting, delay before entering the track, the difference in behavior at regulated and unregulated crossings, etc.), and will clearly inform pedestrians about the direction of train movement and the moments when exiting the track is prohibited. Because the existing technologies used in Ukrzaliznytsia do not have reliable ways of recording the speed of the train's approach, as well as informing about the direction of its movement. Accordingly, the development of an information and analytical system is an urgent task.

The task is solved by the fact that when a train hits an inertial sensor, a rolling stock is detected in the area approaching the pedestrian crossing. Next, a signal is transmitted to the information board installed at the railway crossing about the approach of the train and the blocking alarm is activated. This allows you to warn the pedestrian about the movement of the train to the crossing, to close the pedestrian crossing by means of barrier signaling, which will ultimately lead to an increase in the safety of pedestrian movement across the railway track within the crossing.

It should be noted that pedestrian safety measures depend on the cooperation of infrastructure, technologies, systems and users, so changing one of these factors must take into account its impact on others, so as not to jeopardize safety.

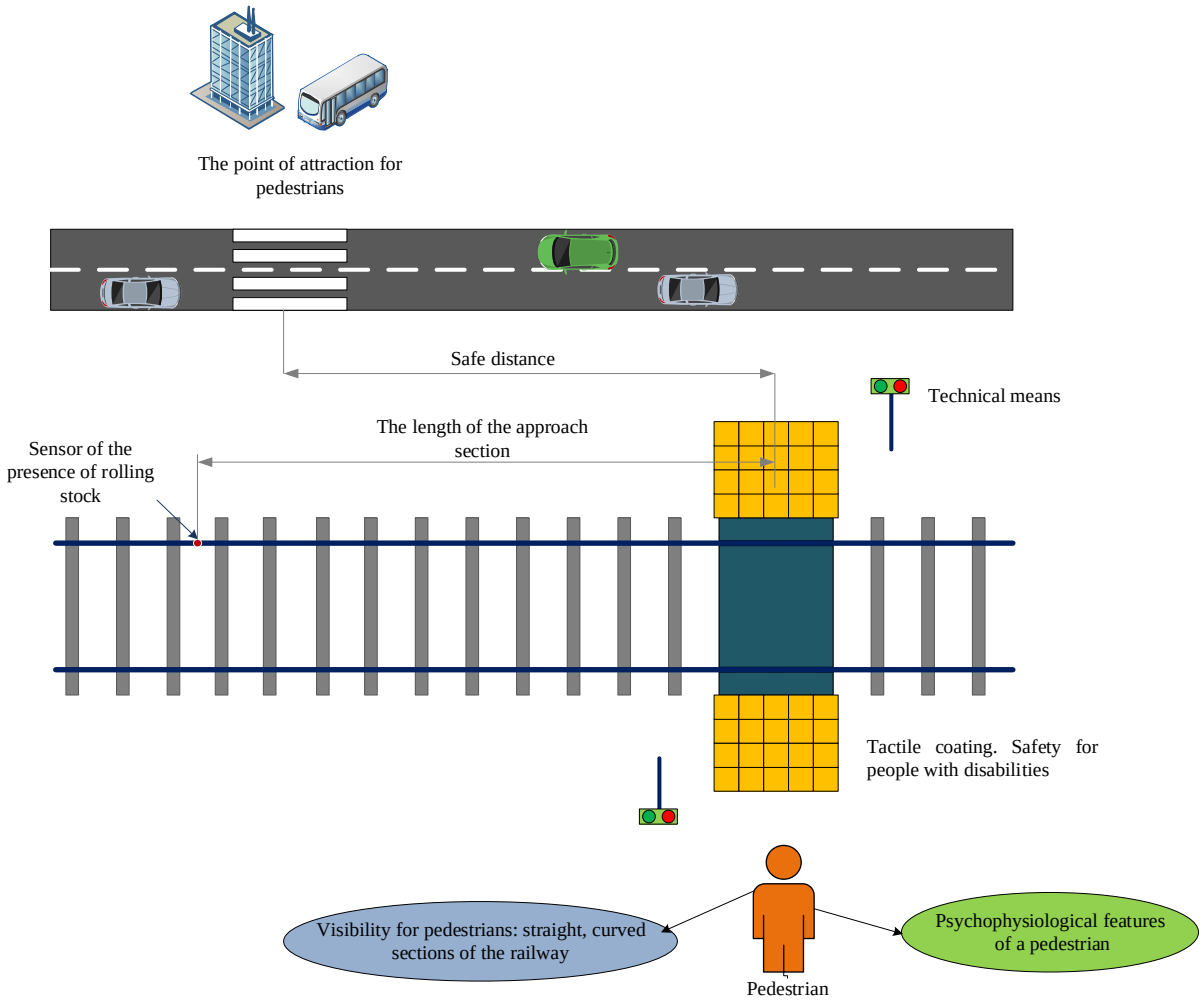

Fig. 7. **Recommended method of safe pedestrian crossing of railway tracks to the gravity point**

In today's world, the process of risk assessment at pedestrian crossings over railway tracks does not keep up with changes in the infrastructure and the increase in traffic flows, the number of pedestrians, and especially in urban areas where changes occur very intensively. Therefore, in our opinion, pedestrian safety measures and recommendations should be reviewed and improved every 10 years.

Conclusions. The following conclusions and recommendations can be made from the conducted research:

1. Based on the analysis of the state of safety on the railways of Ukraine and foreign countries, it was established that in 9 months of 2023, 202 persons not involved in railway transport received injuries of varying degrees of severity in the regional branches of JSC "Ukrzaliznytsia". At the same time, 128 were fatal. Therefore, improving the safety of pedestrian traffic on railways is a very important task.

Addressing safety issues at railway crossings is a complex task that requires the cooperation of various parties, including authorities, railway companies, public organizations and society, by implementing measures that combine technical, organizational and educational approaches. Ensuring the safety of pedestrians is an important aspect of sustainable development and ensuring convenient and safe transport connections.

2. The problems of ensuring the safety of pedestrian traffic when crossing railroad tracks include: the absence of requirements in urban planning regulations regarding the arrangement of pedestrian crossings over railroad tracks, although the density of buildings (location of residential blocks near railroad tracks) only increases every year in large cities. At the same time, the construction of pedestrian crossings at different levels across the track is economically expensive. In addition to infrastructural and

technical means, the problems of increasing safety include the low level of pedestrian culture regarding traffic safety, the pedestrian chooses a route closer to the point of attraction, while violating the rules of safe crossing of tracks.

It should also be noted that in DBN B.2.3-19:2018 "Railways with a gauge of 1520 mm", pedestrian paths should be designed at railway crossings located in populated areas, as well as in case of pedestrian traffic intensity of more than 100 people/hour. At the same time, there are no requirements and/or recommendations in these regulations regarding the arrangement of separate pedestrian crossings that are not part of railway crossings. Therefore, the determination of the criteria for the expediency of the arrangement of ground crossings over the railway additionally emphasizes the relevance of this issue and the large amount of scientific research that needs to be performed.

3. Taking into account all the factors that affect the safety of pedestrian traffic, a number of recommendations are proposed for the safe crossing of railway tracks by pedestrians:

- installation of safe pedestrian crossings near railway stations and centers of gravity, equipped with modern signaling and lighting systems to increase visibility and notify about the approach of a train;
- placement of appropriate road signs and signaling devices that will inform pedestrians about the danger of railway traffic and recommended places for crossing;
- increase or decrease the transition time in accordance with the set signaling by calculating the time and speed of the train approach and its features;
- regular inspection and maintenance of pedestrian crossings to identify and eliminate defects;
- conducting educational campaigns to raise pedestrian awareness of the dangers associated with crossing railroad tracks;
- use of modern technologies, such as motion sensors and monitoring systems, for automatic detection of pedestrians and timely notification of drivers about their presence at crossings.

4. Safety problems of pedestrian movement across railway tracks require various solutions for their solution. An information system has been proposed to increase the safety of pedestrians crossing railway tracks. This system takes into account the characteristics of train movement, as well as patterns of pedestrian behavior (speed of movement, duration of patient waiting, delay before entering the track, difference in behavior at regulated and unregulated crossings, etc.). It also provides for clear information to pedestrians about the direction of train movement and the moments when exiting the track is prohibited.

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Проблеми забезпечення безпеки руху пішоходів через залізничні колії та шляхи їх вирішення

Із аналізу стану безпеки на залізницях встановлено, що велика кількість наїздів на пішоходів та їх травмування відбувається за межами залізничних переїздів, що вимагає розробки технічних засобів та розвитку культури безпеки пішоходів при перетині залізничних колій. У

праці розглядаються актуальні питання забезпечення безпеки руху пішоходів при перетині залізничних колій. Слід зазначити, що актуальність цього питання сьогодні важлива також і з економічної точки зору, оскільки втрата людського життя або травмування людей для країни має високі економічні збитки. Для України, з огляду на негативні тенденції щодо динаміки чисельності населення, збереження здоров'я та життя людей набуває особливого значення. Тому покращення заходів безпеки руху пішоходів через залізничні колії в умовах урбанізованих міст повинні розглядатись в взаємодії усіх органів влади та транспортних підприємств. Встановлено, що у розвинених державах існує нульова толерантність до смертності у транспортних пригодах, тому будь-які заходи, які можуть підвищити безпеку руху та запобігти травмуванню чи смертності, є актуальними та потребують відповідних досліджень та рішень. Запропоновано систему підвищення безпеки руху пішоходів при перетині залізничних колій має на меті в першу чергу створити умови для мінімізації кількості транспортних подій з пішоходами в населених пунктах.

***Ключові слова**: безпека руху пішоходів, урбанізовані простори, пішохідний перехід, фактори впливу на пішохода, інформаційна система.*