UDC 625.12:625.745.2
DOI: 10.15587/1729-4061.2024.300168

# DEVISING A METHOD FOR IMPROVING PEDESTRIAN TRAFFIC SAFETY WHEN CROSSING RAILROAD TRACKS BY IMPLEMENTING AN INFORMATION SYSTEM WITH A FIXED WARNING TIME

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***The object of research is pedestrian safety when crossing railroad tracks at pedestrian crossings. A method for improving the safety of pedestrian traffic when crossing railroad tracks within the area approaching the railroad pedestrian crossing has been developed, by introducing an information system for warning pedestrians about train movement with a fixed warning time.***

***Experimental measurements of the speed of the rolling stock were carried out in the area approaching the pedestrian crossing over the railroad track. With the mixed movement of trains, it was found that the lowest speed of the train was 67.46 km/h, and the highest was the passenger train – 131.9 km/h. At the same time, the speed of freight trains ranged from 74 to 79 km/h. Such data are needed to determine the speed of the rolling stock on the approach to the crossing or transition, which will allow the light and sound signal to be turned on in time when the movement of a pedestrian across the track will be dangerous.***

***The methodology for calculating the length of the approach section to the pedestrian crossing, depending on the speed of the rolling stock, has been given. It was established that the speed of the rolling stock has a significant effect on the length of the approach section. At the lowest measured speed of the train – 67.46 km/h, the length of the approach section was 317.46 m, and when the passenger train was moving at a speed of 131.9 km/h – 620.68 m.***

***For a single-track section of the railroad, a fixed time has been established for warning pedestrians about the approach of a train to the crossing. It is a constant value that is included in the warning information system on a single-track section, and after it, a complex light and sound alarm with an information board is activated, which will warn the pedestrian about the movement of the train. The method for improving the safety of pedestrian traffic with a fixed time of the pedestrian's anticipation of the train movement could be used at crossings with pedestrian traffic, as a supplement to the crossing signaling subsystem in railroad transport. It can also be used at equipped pedestrian crossings over railroad tracks in urbanized areas. The advantage of introducing such a method is a fixed time to warn the pedestrian, in each specific case of the train approaching the crossing***

***Keywords: traffic safety, pedestrian crossings, information system, railroad track, rolling stock, fixed warning time***

*Received date 15.01.2024*
*Accepted date 28.03.2024*
*Published date 30.04.2024*

***How to Cite:*** *Kovalchuk, V., Lesiv, Y. (2024). Devising a method for improving pedestrian traffic safety when crossing railroad tracks by implementing an information system with a fixed warning time. Eastern-European Journal of Enterprise Technologies, 2 (3 (128)), 50–59. https://doi.org/10.15587/1729-4061.2024.300168*

## 1. Introduction

Railroad infrastructure is a significant barrier to pedestrian traffic and often cuts off or complicates established pedestrian connections in populated areas. However, in many cases, pedestrian connections in urbanized spaces have dense locations and intense pedestrian traffic. When crossing the railroad infrastructure, the pedestrian loses his/her priority, although the current requirements for street infrastructure planning prioritize pedestrian traffic over other types of movement. As a result, in the presence of a railroad, a pedestrian with the principles of behavior on the streets and in the spaces of populated areas demonstrates dangerous behavior and crosses the railroad track in unspecified places.

According to the analysis of the state of traffic safety and accidents on land transport in Ukraine for 2023 [1], traffic accidents at railroad crossings have serious or fatal consequences (Fig. 1).

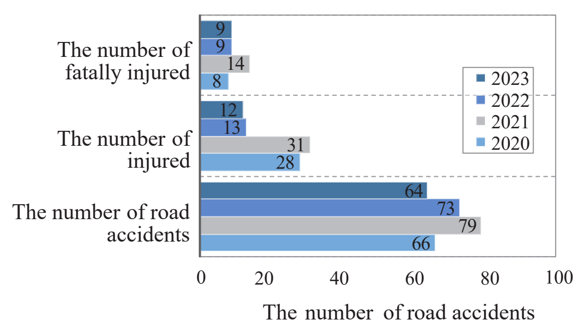


Fig. 1. The number of traffic accidents at railroad crossings for 2020–2023 [1]

It follows from the histogram of the distribution of traffic accidents at railroad crossings for 2020–2023 (Fig. 1) that as a result of road accidents, a significant part of them has consequences in the form of injuries. There are also cases of death of road users.

It should be noted that the task to ensure the safety of pedestrians when crossing railroad tracks is predetermined by various factors. In addition to the geometric and planning parameters of the crossing and the behavioral characteristics of pedestrians, a significant role is played by the speed characteristics of the train when it approaches the railroad crossing. This is due to the fact that when using the existing warning system with a fixed section of the approach of the train to the crossing, there is a drawback in the part of the different duration of the warning time to the pedestrian about the approach of the train to the crossing. This, in turn, affects the patient waiting time of the pedestrian and prompts him/her to violate the safe crossing of the railroad track.

One should note that the issues of functioning of railroad crossings with motor vehicles are mostly studied, rather than the safety of pedestrians when crossing railroad tracks. Therefore, devising methods for improving the safety of pedestrians at railroad crossings is an important and urgent task of scientific research.

The development of a method for improving the safety of pedestrians when crossing railroad tracks is of practical importance in terms of finding effective measures to inform pedestrians about the approach of rolling stock. The number of traffic accidents at railroad crossings (Fig. 1) indicates that the use of guardrails operating on the principle of a fixed distance is not a reliable system for ensuring the safety of pedestrian traffic.

## 2. Literature review and problem statement

Analyzing the issues related to safe railroad crossing by pedestrians, researchers study various aspects of their functioning, technical and operational characteristics of pedestrian crossings, diagnosing violations of safe railroad crossing by pedestrians, etc. However, due attention is not paid to improving the safety of pedestrians when crossing railroad tracks, taking into account the speed characteristics of the train.

In work [2], based on real-time studies of the movement of pedestrians and cyclists across the railroad track, it was established that one of the important reasons for violations of the safety of pedestrians and cyclists is the speed of the train and the duration of the crossing. It was also established that the geometric parameters of the pedestrian crossing have a smaller influence compared to the speed characteristics of the train. However, the work does not provide methods for improving the safety of pedestrians when crossing railroad tracks with a fixed time of warning the pedestrian about the movement of the train before the crossing.

In [3], the patterns of pedestrian behavior at railroad crossings of various types, taking into account geographical differences, were established. At the same time, work [4] established that in order to devise measures to increase the safety of pedestrian traffic across railroad tracks, it is necessary to have reliable primary information that is the cause of accidents on railroads since the causes of violations can be various factors. For example, in [5], a sociological survey showed that 25 % of participants deliberately violated the safety rules of a safe transition due to a long time of waiting for a train to pass. In addition, work [6] established that the common causes of distraction when crossing railroad tracks are talking or looking at the phone screen while driving. However, [3–6] report no studies on improving the safety of pedestrian traffic at the crossing of railroad tracks, taking into account the speed parameters of the train approaching the crossing.

Paper [7] analyzes the risks related to the safety of pedestrians crossing tracks and considers issues related to the nature of decision-making by pedestrians. The application of the modern theory of behavioral and cognitive psychology of pedestrians can be useful for future research in the field of improving traffic safety [8]. In addition, work [9] analyzed the patterns of behavior of schoolboys who regularly cross the railroad, and the influence on the behavior of additional traffic safety training and penalties for violations. Observations of the behavior of pedestrians at railroad crossings [10] showed that road users are mainly distracted by mobile devices. Since technical progress, in particular the use of mobile phones, is developing rapidly, it is necessary to constantly monitor information and conduct research into the behavior of pedestrians at railroad crossings and modernize signaling systems and passive traffic safety devices under modern conditions.

Based on our review of the literature [2–10], it was found that existing methods for improving the safety of pedestrians do not take into account the actual speed of trains when approaching a pedestrian crossing. This does not allow determining the length of the approach section with a fixed time to warn the pedestrian about the approach of the train to the crossing.

Study [11] uses a multilevel approach to identify factors associated with the occurrence and severity of train-pedestrian collisions. These factors include high population density and a significant number of railroad stations in normal train traffic. However, the presence of high-speed trains did not have a significant impact on reducing pedestrian safety. In addition, the study found that guardrail regulations were very effective in reducing pedestrian accidents.

There are a number of works that study various methods of improving the safety of pedestrians at railroad track crossings. In [12], research results show that adding sound devices to crossings controlled by gates with flashing beacons leads to a smaller decrease in the probability of traffic accidents. However, the cited studies do not take into account the influence of the speed of rolling stock on the safety of pedestrian traffic. Also, in work [13], it was established by the experimental studies that most of the participants of the experiment paid attention to the sound signaling warning of the train movement. Only studies of the reaction of pedestrians to the perception of a sound signal are given, without conducting studies on the influence of the speed characteristics of the train on improving the safety of pedestrian traffic.

Work [14] reports the results of studies into the influence of signs (their shape, color) on the perception of pedestrians when crossing railroad tracks. The data show that signs that convey actions with emotional motivation are more effective compared to informational signs. This is especially true in situations involving railroad crossings where there is a high degree of risk of being hit by a train.

Studies into the effect of streetlights on attracting the attention of pedestrians at a railroad crossing [10] showed a positive effect on attracting the attention of pedestrians who are distracted at railroad crossings. When they are used at railroad crossings, one can expect an increase in the safety of pedestrian traffic.

An important factor in improving the safety of pedestrian traffic in urbanized spaces is determining the location of pedestrian crossings across railroad tracks. They should be minimized in terms of pedestrian use, but on the other hand, priority should be given to routes with the greatest pedestrian demand [15].

Work [16] deals with the issue of ensuring traffic safety and functioning of railroad crossings, as well as the technical aspects of detecting trains on approaching sections. At the same time, paper [17] established that an effective way to increase safety at railroad crossings is the use of two closing barriers. However, in these works, the results of research and development of methods for improving the safety of pedestrians at the crossing of railroad tracks are not given.

In addition, the studies cited in [18] show that the construction of underground or overpasses over railroad tracks is in most cases not financially or technologically justified, especially in large cities.

Our literature analysis [2–18] reveals that the issues of the functioning of railroad crossings and passive methods of improving the safety of pedestrians when crossing railroad tracks are mostly studied.

However, even in most works [2–13], it is noted that there are not enough studies into the functioning of pedestrian crossings over the railroad, 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 [3–5, 7]. This, in turn, limits the development of adequate and effective measures to increase the safety of pedestrians when crossing railroad tracks.

In addition to the behavior of pedestrians, important factors affecting the safety of pedestrians when crossing railroad tracks are the characteristics of train movement, namely train speed. A significant role is also played by the length of time a pedestrian patiently waits for a crossing train to pass, the technical characteristics of the crossing, including the duration of the warning signal and the duration of traffic blocking, as well as the gender and age of pedestrians [6].

The task to devise methods for improving pedestrian traffic safety, taking into account the actual speed of trains when approaching a pedestrian crossing, remains unresolved. In addition, there are no regularities of changes in the length of the train approach section, in the case of using the method for improving the safety of pedestrian traffic with a fixed time of warning the pedestrian about the train movement, depending on its speed.

It should also be noted that when passenger and freight trains run at different speeds on the railroad, there is a need to devise a method to ensure the safety of pedestrians across the railroad tracks, taking into account the fixed time of warning the pedestrian about the train movement before the crossing. This is due to the fact that such a method would make it possible to take into account the speed parameters of train movement and timely warn pedestrians about the approach of the train to the crossing.

## 3. The aim and objectives of the study

The purpose of our work is to devise a method for improving the safety of pedestrians when crossing railroad tracks by introducing a warning information system with a fixed warning time, which will make it possible to detect trains on the approaching section in time, determine a fixed time for pedestrians to be warned about the movement of a train, and will inform pedestrians about the danger of crossing railroad tracks. This will make it possible to increase the safety of pedestrian traffic when crossing railroad tracks.

To achieve this goal, the following tasks were set:

– to propose a procedure for determining the speed of rolling stock of railroad transport using inertial technologies;

– to carry out real-time experimental studies into the speed of movement of rolling stock in the area approaching the pedestrian crossing across the railroad track;

– to devise a methodology for calculating the length of the approach section to the pedestrian crossing with a fixed warning time depending on the speed of the rolling stock.

## 4. The study materials and methods

### 4. 1. The object and hypothesis of the study

The object of our research is the safety of pedestrian traffic when crossing railroad tracks at pedestrian crossings with the introduction of an information system with a fixed time warning of pedestrians about the movement of a train.

The main hypothesis of the research assumes that the method for improving the safety of pedestrian traffic involves establishing a fixed time of warning the pedestrian about the movement of the train to the pedestrian crossing. Further, depending on the actual speed of the train, the length of the section approaching the pedestrian crossing is determined, upon entering which the pedestrian is warned about the train movement with a fixed time. This allows early activation of integrated light and sound signaling at the crossing, as a result of which the pedestrian will receive a warning about the approach of the train to the crossing with a fixed notification time. This, in turn, will lead to an increase in the safety of pedestrian traffic when crossing railroad tracks.

### 4. 2. Description of the experimental site for measuring the actual speed of train movement

To carry out experimental measurements of the speed of movement of railroad rolling stock when approaching a railroad crossing, a section of the railroad, located in a straight line, was selected (Fig. 2). The section of the track consists of reinforced concrete sleepers and rails of the P65 type. Crushed ballast.

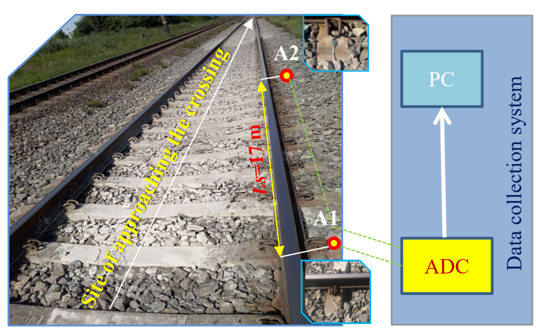


Fig. 2. Experimental site for measuring the speed of rolling stock: A1, A2 – inertial acceleration sensors

The speed of movement of rolling stock was measured using a personal computer (PC), an analog-to-digital converter (ADC), and inertial acceleration sensors A1 and A2 (Fig. 2).

Inertial acceleration sensors were rigidly fixed on the surface of reinforced concrete sleepers. The distance between the sensors was 17.0 m. When the train was moving, accelerations with a frequency of 1000 Hz were recorded, the measured data of which were stored in the computer memory.

When processing acceleration records, digital filtering of the signal was used according to the procedure described in [19–23].

## 5. Results of research on improving the safety of pedestrian traffic at railroad track crossings

**5. 1. Procedure for determining the speed of rolling stock of railroad transport using inertial technologies**

Experimental determinations of the speed of movement of passenger and freight trains, when approaching a railroad crossing, were carried out using modern methods of engineering technologies. They are based on the process of measuring accelerations on the ends of the sleepers of the railroad track, during the movement of railroad rolling stock, with the help of high-frequency inertial analog acceleration sensors. The scheme for determining the speed of railroad rolling stock when approaching a railroad crossing is shown in Fig. 3.

Accelerations are recorded when the rolling stock passes two inertial sensors. An example of recording acceleration plots to determine the speed of rolling stock is shown in Fig. 4.

In Fig. 4, the value of the maximum value of accelerations $a_{1max}$ on the first sensor from the first wheelset corresponds to time $t_1$, and the value of maximum accelerations $a_{2max}$ on the second sensor, also of the first wheelset, corresponds to time $t_2$. As a result, the formula for determining the speed of rolling stock is as follows:

$$v = \frac{L_s}{t_2 - t_1}, \quad (1)$$

where $L_s$ is the distance between inertial acceleration sensors.

So, to determine the speed of the rolling stock of the railroad, it is enough to have only two initial extrema of the acceleration values and only from the first wheelset.

To perform recording and processing of analog acceleration signals, a setup is used, the scheme of which is shown in Fig. 5.

The setup works as follows: when the train hits the first sensor A1, and then the second sensor A2 (or vice versa), the acceleration signals are recorded with the help of an analog-to-digital converter (ADC) and stored in the memory of a personal computer (PC). After that, with the help of a special program, signals are processed, and information is transferred to the information board about the movement of the train; it will be highlighted on the «Train» information board.

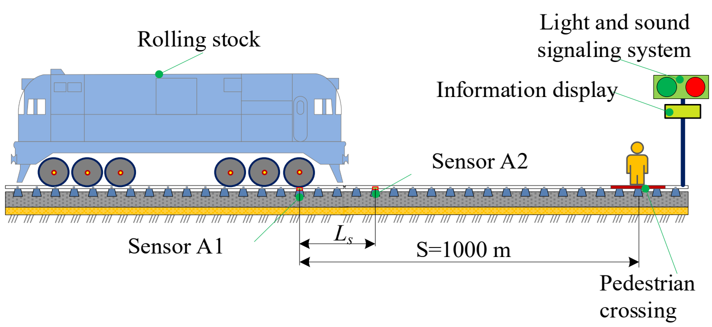


Fig. 3. Scheme for determining the speed of railroad rolling stock when approaching a railroad crossing: $L_S$ – distance between inertial acceleration sensors; $S$ – distance from the inertial sensor to the railroad crossing

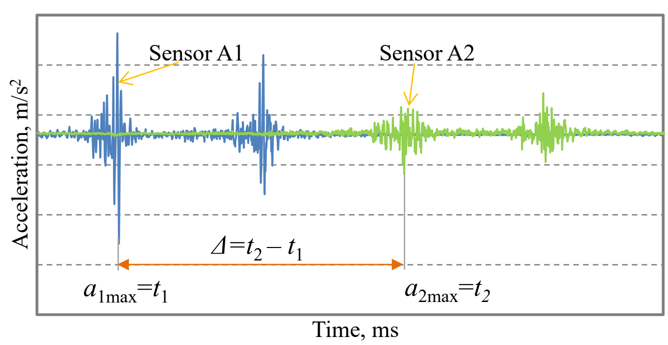


Fig. 4. Plot for determining the speed of rolling stock based on measured acceleration values

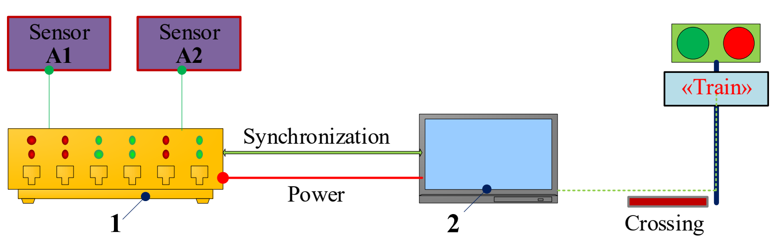


Fig. 5. Setup for determining the speed of train movement: A1, A2 – accelerometers: 1 – analog-digital converter; 2 – personal computer

Depending on the speed of movement, the arrival time of the train at the pedestrian crossing is determined and the light and sound alarm is activated at the moment when the movement of a pedestrian across the track will be dangerous. It should be noted that the time required to cross tracks by a pedestrian depends on the number of tracks and the age and physiological capabilities of the pedestrian.

**5. 2. Results of real-time experimental measurements of the speed of trains in the area approaching the pedestrian crossing**

During experimental tests, acceleration values were recorded during the passage of railroad rolling stock. Recordings were made by two sensors, which were located at a distance of 17.0 m from each other. In addition, one sensor was located on a technically sound section of the railroad, and the second on a section of the railroad that had a loosened ground.

The results of records of accelerations that occur during the passage of a freight train are shown in Fig. 6, passenger train – in Fig. 7, handcar – in Fig. 8, locomotive ChME3 – in Fig. 9, and a freight train with heavy equipment – in Fig. 10.

Fig. 6 demonstrates that the maximum value of the accelerations during the passage of the first wheelset over sensor A1 is 12.16 m/s$^2$ at the time of 612 ms. Next, the first wheelset passes another sensor A2 at a time of 1386 ms and causes a maximum acceleration of 8.51 m/s$^2$.

The records of the acceleration plot (Fig. 7) demonstrate that during the passage of the passenger train, the maximum value of acceleration during the passage of the first wheelset over sensor A1 is 11.71 m/s$^2$ at the time of 251 ms. Next, the first wheelset passes another sensor A2 at a time of 715 ms and causes a maximum acceleration of 9.01 m/s$^2$.

The records of the handcar accelerations (Fig. 8) demonstrate that the maximum value of the accelerations on sensor A1 is 10.68 m/s$^2$ at the time of 256 ms, and on the second sensor A2 is 10.08 m/s$^2$ at the time of 1163 ms.

The records of the accelerations of the shunting locomotive ChME 3 (Fig. 9) demonstrate that the maximum value of the accelerations on sensor A1 is 10.81 m/s$^2$ at the time point of 839 ms, and on the second sensor A2 is 10.04 m/s$^2$ at the time point of 1525 ms.

The records of the accelerations of a freight train with heavy equipment (Fig. 10) demonstrate that the maximum value of the accelerations on sensor A1 is 10.67 m/s$^2$ at the time point of 337 ms; on the second sensor A2, it is 10.28 m/s$^2$ at the time point of 1164 ms.

The results of experimental measurements of the speed of movement of rolling stock are given in Table 1.

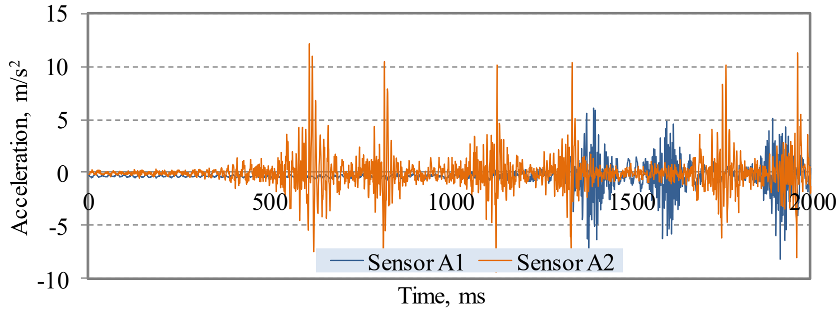


Fig. 6. Recording accelerations when passing a freight train

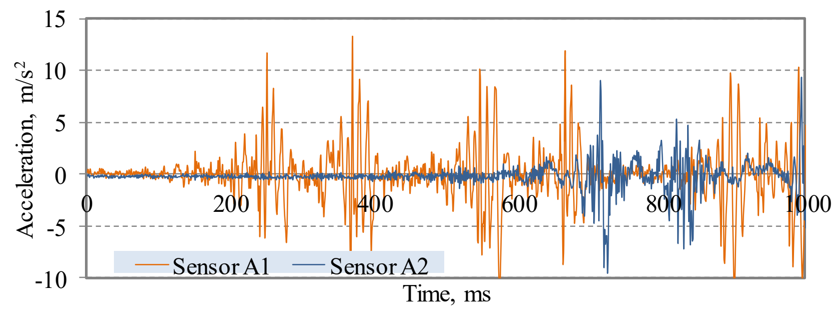


Fig. 7. Recording accelerations when passing a passenger train

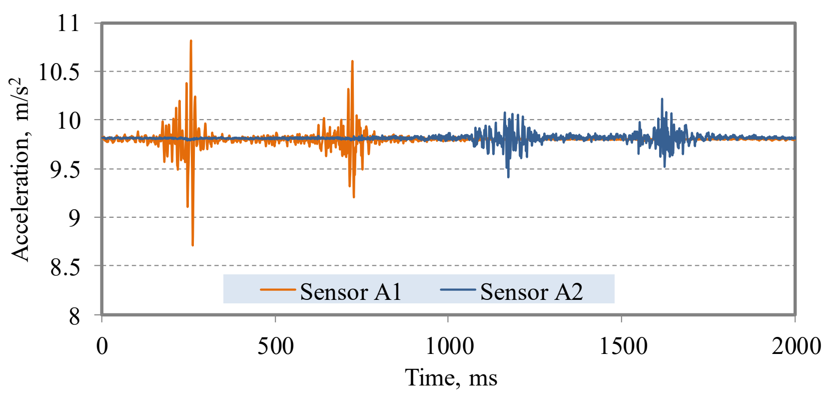


Fig. 8. Recording accelerations when passing a handcar

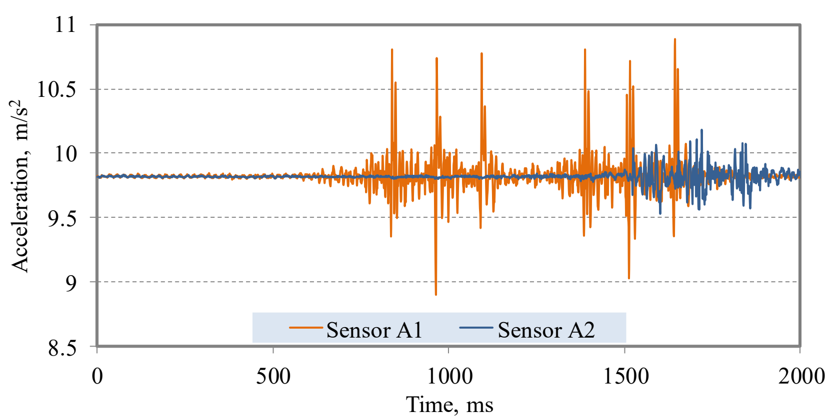


Fig. 9. Recording of accelerations during the passage of the shunting locomotive ChME 3

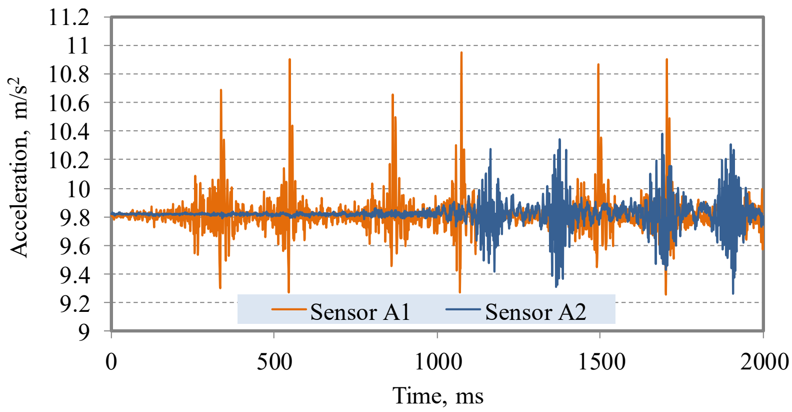


Fig. 10. Recording accelerations when a freight train with heavy equipment passes

Table 1

Results of experimental measurements of rolling stock speed

| Type of rolling stock | Travel time over sensors, ms | | Movement time between sensors A1–A2 | | Distance between sensors $L_s$, m | Speed, $v$ | |
|---|---|---|---|---|---|---|---|
| | A1 | A2 | ms | s | | m/s | km/h |
| Freight train | 612 | 1,386 | 774 | 0.774 | 17 | 21.96 | 79.06 |
| Passenger train | 251 | 715 | 464 | 0.464 | 17 | 36.64 | 131.9 |
| Handcar | 256 | 1,163 | 907 | 0.907 | 17 | 18.74 | 67.46 |
| CME3 shunting locomotive | 839 | 1,525 | 686 | 0.686 | 17 | 24.78 | 89.21 |
| Cargo train with heavy machinery | 337 | 1,164 | 827 | 0.827 | 17 | 20.56 | 74.02 |

From the results of the research, it is clear that the passenger train has the highest speed value of 131.9 km/h, and the train has the lowest speed value of 67.46 km/h. The range of these speed values are indicators that are subsequently taken into account when determining the time of the train's approach to the pedestrian crossing. This directly affects the timeliness of warning pedestrians about the approaching train, using light and sound signals at the crossing.

**5. 3. Methodology for calculating the length of the approach section to the pedestrian crossing with a fixed notification time**

The proposed method for improving the safety of pedestrian traffic when crossing railroad tracks assumes that the light and sound system at the crossing takes into account the speed characteristics of the train and will clearly inform pedestrians about the train's movements and the moments when exiting the track is prohibited. In this system, it is proposed to send a message to the crossing about the approach of the train with a fixed warning time.

The time of the fixed warning to the pedestrian about the approach of the train before the train enters the crossing is determined by the formula:

$$t_{FP} = t_P + t_S + t_{10}, \tag{2}$$

where $t_P$ is the time spent by a pedestrian to safely cross railroad tracks. It depends on the length of the pedestrian crossing $L_P$; $t_{IS}$ is the time for the information system to activate and the warning to be transmitted to the notification systems located at the pedestrian crossing, we take $t_{IS}$=2 s; $t_{10}$ is the guarantee of time for crossing a pedestrian crossing, we assume 10 seconds.

The time spent by a pedestrian to cross the dangerous zone of a pedestrian crossing depends on the length of the pedestrian crossing and the length of the flow of people (a group of people with an interval of 1 m in the flow) is determined by the formula:

$$t_P = \frac{L_P + L_{GP}}{v_P}, \tag{3}$$

where $L_P$ is the length of the pedestrian crossing; $L_{GP}$ is a group of people in the flow; $v_P$ is the estimated speed of pedestrians in a group when crossing railroad tracks. We assume 5 km/h=1.39 m/s.

The length of the pedestrian crossing depends on the number of tracks. The scheme for calculating the length of a pedestrian crossing on a single-track section of the railroad is shown in Fig. 11.

The length of a pedestrian crossing over a single-track section of a railroad track is determined by the formula:

$$L_P = L_{saf} + 1520 + L_{saf} + B, \tag{4}$$

where $L_{saf}$ is the safe distance from the nearest rail to the pedestrian, $L_{saf}$=2000 mm, $B$ is the size of the pedestrian's body, for the 95$^{th}$ percentile it is 342 mm.

As a result, the length of the pedestrian crossing over the single-track section according to formula (4) will be $L_P$=5862 mm. At the same time, the crossing time of a single-track section with a group of people with a length of $L_{GP}$=1.0 m, according to formula (3), will be $t_P$=4.94 s.

Therefore, the fixed time of warning a pedestrian about the approach of a train according to formula (1) will be:

$t_{FP}$=4.94+2+10=16.94 s.

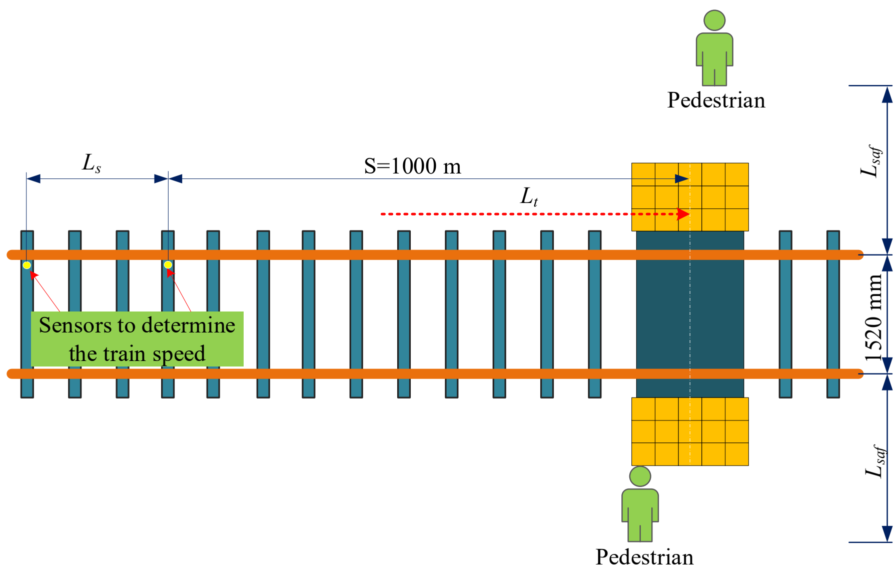


Fig. 11. Scheme for calculating the length of a pedestrian crossing on a single-track section of the railroad: $L_s$ – distance between sensors; $L_{saf}$ is the safe distance from the nearest rail of the track to the pedestrian

Taking into account the fixed time of warning the pedestrian about the train's approach, it is possible to determine the length of the section of the train's approach, during which the light and sound system with the information board will be turned on, which will warn the pedestrian about the train's movement. The length of the approach section at a fixed warning time is determined by the formula:

$$L_t = v_t \cdot t_{FP}, \quad (5)$$

where $v_t$ is the speed of the train on the approach section to the pedestrian crossing.

The calculated results of determining the lengths of the sections of approach to pedestrian crossings on a single-track section, taking into account the speed of movement of the rolling stock, are given in Table 2.

Table 2

Results of determining the lengths of approach sections

| Rolling stock | Speed, m/s | Fixed pedestrian warning time, $t_{FP}$, s | Length of approach area, $L_t$, m |
|---|---|---|---|
| Freight train | 21.96 | 16.94 | 372.00 |
| Passenger train | 36.64 | | 620.68 |
| Handcar | 18.74 | | 317.46 |
| CME3 shunting locomotive | 24.78 | | 419.77 |
| Cargo train with heavy machinery | 20.56 | | 348.29 |

From the results of the calculation of the lengths of the approach sections with a fixed time of warning the pedestrian about the train movement, it follows that the length of the approach section significantly depends on the speed of the train. When the train is moving at a speed of 18.74 m/s, the length of the approach section is 317.46 m, and when the passenger train is moving at a speed of 36.64 m/s, it is 620.68 m.

In addition, with a large length of the approach section, it is necessary to take into account the acceleration of the train. However, the introduced guaranteed margin of time for pedestrian crossing of a pedestrian crossing of 10 s may be sufficient to compensate for the increase in speed in the area approaching the crossing and will allow one to safely overcome the pedestrian crossing.

## 6. Discussion of results of the methodology for improving the safety of pedestrians at railroad track crossings

A critical review of the literature [2–12] revealed that pedestrians are more likely to violate the rules of railroad crossing than to make mistakes. This may be due to the fact that the existing systems for informing the pedestrian about the approach of the train and the regulatory approaches to the design of such systems do not take into account the speed characteristics of the train on the approach and during the movement at the crossing and have different warning times of the train movement. Therefore, the development of methods to increase the safety of pedestrian traffic at the crossing of railroad tracks will ensure the improvement of the quality of life in settlements, which additionally strengthens the relevance of such research.

The proposed method for improving the safety of pedestrian traffic when crossing a railroad track within the limits of pedestrian crossings with a fixed time of pedestrian warning involves the development of an integrated methodology, which aims, first of all, to create conditions for minimizing the number of traffic incidents with pedestrians in populated areas. For this purpose, a fixed time is determined to warn the pedestrian about the approach of the train. Further, according to the established actual speed of train movement, the patterns of change in the length of the section approaching the pedestrian crossing are determined. When the train enters the beginning of the approach section, information is provided to the pedestrian crossing about the approach of the train. This happens by turning on an integrated light and sound alarm system with an information board.

The results of experimental measurements of the speed of rolling stock (Table 1) showed that on this section of the railroad track freight trains move at speeds ranging from 70 to

90 km/h, and passenger trains at more than 130 km/h. Therefore, when planning a system that will ensure the safety of pedestrians crossing the railroad track, it is important to take into account the time of arrival of the train at the pedestrian crossing, which depends on the speed of the train. This will make it possible to timely turn on the blocking alarm at the moment when the movement of a pedestrian across the track will be dangerous. Determining the actual speed of the rolling stock on the approach to the railroad crossing is important as it will enable timely activation of light and sound signaling and lighting on the «Train» information board (Fig. 5). As a result, from a technical point of view, such a system could increase the safety of pedestrians when crossing railroad tracks.

The proposed method for improving the safety of pedestrians at the crossing of railroad tracks, based on a fixed time of warning the pedestrian about the approach of the train, has an advantage over the existing method with a fixed length of the approach section. The use of systems with a fixed length of the approach section has disadvantages regarding the possibility of determining the actual speed of the train approaching the transition [16]. As a result, when passing through a section of track of different types of rolling stock at different speeds, in many cases there will be a long warning about the movement of the train. This has a negative impact on the safety of pedestrian traffic as the patient waiting time for pedestrians plays a role here and can provoke pedestrians to violate traffic rules and cross the track, which threatens their safety.

Implementation of a system with a constant warning time involves constant measurement of train speed in the section approaching the crossing. And the signaling of the crossing takes place in such a way as to ensure the optimal, fixed time of closing the crossing, which will take into account the optimal time of patient waiting for the pedestrian and the speed of the train. Such a system will reduce the time the crosswalk is closed and reduce the likelihood of a pedestrian walking onto the track in dangerously close proximity to a train approaching the crosswalk.

The results of the calculation of the lengths of the approach sections at a fixed time to warn the pedestrian about the train movement showed that the length of the section significantly depends on the speed of the train (Table 2). When the train is moving at a speed of 18.74 m/s, the length of the approach section is 317.46 m, and when the passenger train is moving at a speed of 36.64 m/s, it is 620.68 m. However, this method increases the safety of pedestrians at the crossing railroad tracks, from the point of view of the speed of approaching the rolling stock to the crossing (crossing), the type of rolling stock does not matter.

In addition, with a large length of the approach section, it is necessary to take into account the acceleration of the train. However, the introduction of a guaranteed margin of time for pedestrian crossing of the transition, in the amount of 10 s, may be sufficient to compensate for the increase in speed in the area approaching the transition and will allow one to safely overcome the crossing on foot. However, in each specific case of local conditions, where the crossing is arranged, it is necessary to determine a fixed time for warning pedestrians about the approach of the train to the crossing.

For the practical implementation of the method for improving the safety of pedestrians when crossing railroad tracks, it is also important to understand the number of necessary pedestrian crossings. However, in accordance with DBN B.2.3-19:2018 «Railroads with a gauge of 1520 mm», pedestrian paths should be designed at railroad 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 railroad crossings.

From a practical point of view, the proposed method for improving the safety of pedestrians at the crossing of railroad tracks by using a method with a fixed time of warning pedestrians about the approach of railroad rolling stock can be used at crossings with pedestrian traffic, as a supplement to the subsystem of crossing signaling in railroad transport. In addition, this system could be used in the case of pedestrian crossings over railroad tracks in urbanized areas.

One of the limitations of our research is the measurement of the speed of rolling stock on a straight section of the railroad track, and a fixed warning time is set only for a single-track section of the railroad. The shortcomings of the current research include the limited number of obtained experimental data of measurements of the speed of movement of the rolling stock and, accordingly, the determined lengths of the approach sections with a fixed time to warn pedestrians about the approach of the train. The further development of this scientific research is conducting experiments taking into account the plan and profile of the railroad track under various operating conditions, as well as the speeds of the rolling stock. Also, additional definition of the criteria for the arrangement of pedestrian crossings at that level across the railroad tracks, which would provide an opportunity to increase the safety of pedestrian traffic when crossing the tracks.

## 7. Conclusions

1. A procedure for determining the speed of rolling stock of railroad transport using modern inertial technologies has been devised. It allows one to measure the speed of rolling stock approaching a pedestrian crossing. This is necessary for calculating the length of the section of the approach to the pedestrian crossing and sending a signal to light and sound devices with an information board that warn pedestrians about the movement of rolling stock.

2. The results of experimental research on the speed of rolling stock showed that freight trains move at speeds of between 70 and 90 km/h, and passenger trains at speeds of more than 130 km/h along this section of the railroad track. These speeds are taken into account when a fixed time is determined to warn a pedestrian about the approach of a train, which will lead to an increase in the safety of pedestrian traffic when crossing railroad tracks.

3. A methodology has been developed for calculating the length of the section approaching the pedestrian crossing depending on the speed of the rolling stock, which takes into account the fixed time of warning the pedestrian about the approaching rolling stock. The results of the calculations demonstrated that the speed of the rolling stock has a significant influence on the length of the approach section. When a train is moving at a speed of 18.74 m/s, the length of the approach section is 317.46 m, and when a passenger train is moving at a speed of 36.64 m/s, it is 620.68 m. Therefore, when designing a system for improving traffic safety at pedestrian crossings through railroad tracks, it is necessary to constantly determine the speed of the rolling stock and, based on it, set the length of the section approaching the crossing, taking into account the fixed time of warning

pedestrians about the movement of the train. It should be noted that the fixed warning time depends on the number of tracks, so in each case it must be calculated for the local conditions of the pedestrian crossing.

### Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

### Funding

The study was conducted without financial support.

### Data availability

The manuscript has associated data in the data warehouse.

### Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

### Acknowledgments

The authors are sincerely indebted to the Pidzamchivskaya track of the Lviv Railroad for assistance in conducting experimental measurements of the speed of rolling stock using the designed information system.

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