Pedestrian safety assessment in the area of tram stops

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Abstract. The problems of conflicts between pedestrians and vehicles in the area of tram stops are of great importance. The choice of pedestrian behavior is greatly influenced by the location of transport infrastructure facilities in the city. This paper presents the results of a field study, which made it possible to identify the main disadvantages of design solutions in the area of tram stops and operating conditions. Investigation of the shortcomings of design solutions in the area of tram stops made it possible to identify the causal relationship of pedestrian behavior. The fundamental relationship between the causal relationships of the behavior of pedestrians in the area of tram stops formed the basis of the safety assessment model. To connect the safety of tram stops and the behavior of pedestrians, we propose a model for assessing the level of safety of tram stops. The model of the safety level of tram stops is based on the values of causal factors, the contribution index and the degree of hazard, which can be obtained as a result of field observations. The resulting model assumes the distribution of tram stops by safety level, which will make it possible to prioritize quality improvement.

Keywords. Tram stop, pedestrian, carriageway, model, safety.

1 Introduction

Modern metropolises are known for the trend of increasing public transport role. This is especially true for the central districts of cities, where excessive car traffic degrades urban spaces and worsens the living conditions of the population. The main reason for this is the significant and often growing number of trips within the city center that cannot be satisfied by road transport [1]. At the same time, the development of new roads contributes to the formation of even greater congestion and, as a result, takes up space from pedestrians.

Typical for large cities passenger demand can be optimally met by the tram system. Considering tram as one of the types of public transport, it can be noted that it has the highest carrying capacity among street types of transport and provides a high-quality service attractive to passengers [2-3]. Having recognized the priority of tram development in cities, it is necessary to develop and implement measures to increase its competitiveness in all areas [4].

Many countries are introducing new tram networks or expanding existing ones to reduce congestion and improve urban environments. However, the existence of the tram network is

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associated with issues related to the safety of vehicle operation, nodal infrastructure and safety of its operation in mixed traffic conditions [5].

The Russian cities with tram traffic are concerned about the attractiveness of this type of transport: St. Petersburg [6], Yekaterinburg [7], Magnitogorsk [8], Ulyanovsk [9], etc. The quality of public transport depends not only on route tracing, spacing and vehicle reliability or comfort.

A trip by public transport begins not with boarding a vehicle, but with arriving at a stop where passengers should feel comfortable and safe. Therefore, the quality of the stops themselves, their location, organization and equipment are the basis for the quality of public transport [10]. The most important problems observed in urban centers are conflicts between pedestrians moving from (or in) the direction of a tram stop and vehicles [11]. A key role in this is played by the diversity of pedestrian behavior as a result of ignorance of the traffic rules and the braking capabilities of both trams and cars.

The safety of transit passengers and pedestrians has been analyzed using spatial and statistical approaches [12, 13]. Worldwide studies (e.g. [14]) show that tram stops in a mixed transport environment are characterized by different levels of safety, accessibility and performance. At the same time, a study conducted in Wroclaw (Poland) in 2017 shows that passengers rate the safety of travel on trams much higher than on buses [15]. The stopping area is an important element affecting the safety of the tram system. This is the place where passenger flows in urban public transport change. Stops are sources and targets of pedestrian traffic. For this reason, collisions and accidents of passengers with other road users most often occur in stopping zones [16].

In the studies, the authors identified hazards that relate to the safety of tram systems, especially at tram stops. The impact on these events was due to the fact that trams, cars and pedestrians share the road infrastructure in mixed traffic. For this reason, public transport stops are becoming an important element of the junction infrastructure of tram systems, which directly affects the safety of participants in urban traffic. The priority task of the tram stop is to ensure the safe waiting, boarding and alighting from the tram.

The purpose of the study was to identify the main drawbacks in the design of the tram stop areas, using the example of Kazan in the Russian Federation. To improve the quality of service to the population in the area of tram stops, the causal relationships of existing tram stops and the behavior of pedestrians in the area of stops were identified.

2 Materials and methods

2.1 Disadvantages of tram stop areas design

Kazan, 1988, became one of the first Russian cities where the first electric tram appeared. Today the tram system of Kazan consists of 4 operating routes. Most of the tram lines are laid along the axis of the city's main streets, most of them on a designated track.

The study of the existing tram network in Kazan made it possible to identify the shortcomings associated with the provision of transport services to the population. Tram stops with the following features are especially dangerous for people:

- passengers are boarded and alighted directly from the carriageway (fig. 1);
- there are no pedestrian crossings at tram stops, people have to cross the carriageway (fig. 2);
- a significant distance from the pedestrian crossing to the tram stop.

Fig. 1. Tram stop «Yunusovskaya square», Kazan

Fig. 2. Tram stop «Vladimir Kulagin Street», Kazan.

Human behavior is also an important aspect of safety in the area of tram stops. It can be noted that the behavior of people crossing the carriageway to tram stops is a compromise between safety, legality and mobility. The desire to get to public transport is one of the factors that affects pedestrian mobility, and at the same time can lead them to commit dangerous activities.

Thus, deficiencies in the organization of traffic near tram stops greatly affect pedestrian compliance with traffic rules. In addition, the example of some pedestrians may induce other people to cross the road, not following the traffic rules. This means that poor traffic management at pedestrian crossings leading to tram stops can lead to violations of the law by people walking to the tram.

2.2 Approach to the study of conflict situations between pedestrians and vehicle drivers in the area of tram stops

The number of accidents that have occurred at individual tram stops are relatively rare. But at the same time, emergencies arise in which people who cross the carriageway to tram stops may suffer [17, 18]. Conflict situations between pedestrians walking to a tram stop and vehicles usually arise when pedestrians cross the carriageway.

The basis for ranking dangerous tram stops from the point of view of road safety is an analytical-hierarchical process [19]. This process consists of the following steps:

Stage 1 – determination of safety factors;

Stage 2 – the relative importance of safety factors is determined using the processes of the analytical hierarchy;

Stage 3 – determination of the rating of the safety factor of the state p of the development of the d stage;

Stage 4 – presents a safety hazard index for ranking hazardous locations in terms of road safety.

To identify potential hazards for pedestrians near tram stops, a safety survey was carried out by analyzing the frequency and potential outcomes of hazardous situations (road traffic conflicts).

Methods for studying the behavior of road users should be carried out in the following sequence:

1. The observers identified conflict situations and entered data into the form, moreover a part of the research was carried out using photo and video recording, which allowed to reduce the number of participants in the observations, and ensure the accuracy of the research.

2. Registration of the volume of pedestrian traffic along the entire width of the pedestrian crossing, and the direction of movement from the edge of the carriageway to the tram stop and vice versa.

3. Analysis of the pedestrian's behavior and vehicle drivers to determine conflict situations.

4. Development of measures to increase the attractiveness, comfort and safety of urban transport (trams).

2.3 Revealing the causal relationship of the behavior of pedestrians in the area of tram stops

At the sites of the investigated tram stops, we revealed that the causal behavior of pedestrians is the result of flaws in the design of the tram stop area.

The fundamental relationship between the causal relationships of the behavior of pedestrians in the area of tram stops formed the basis of the safety assessment model. To link the safety of tram stops and the behavior of pedestrians, it is necessary to determine the main factors contributing to the occurrence of conflict situations. We took multiple linear regression as the main model for assessing the safety level of tram stops [20]:

$$W = 10 \left(1 - \sum_{i=1}^n x_i \beta_i \right), \quad (1)$$

where W – tram stop safety level;

x_i – variable representing the presence ($x_i = 1$) or absence ($x_i = 0$) of a causal factor at a tram stop;

β_i – causal factor weight;

n – number of causal factors.

Further, the weight of the causal factor can be expressed mathematically as:

$$\beta_i = y_{if} \cdot z_f, \quad (2)$$

where y_{if} – contribution index that indicates the relative contribution of the i^{th} causal factor; z_f – degree of hazard.

More than one causal safety factor may exist for one tram stop. The relative contribution of each causal factor to safety development will be different (y_{if}). Likewise, different conditions that shape pedestrian behavior will have different degrees of hazard (z_f). In general, the safety level of a tram stop is a function of three important parameters: the causal factor (x_i), the contribution index (y_{if}) and the degree of hazard (z_f). Therefore, considering all three parameters, the safety level equation can be modified as follows:

$$W = 10 \left(1 - \sum_{i=1}^n \sum_{f=1}^m x_i \cdot y_{if} \cdot z_f \right), \quad (3)$$

where m – total number of unsafe actions respectively.

In accordance with the proposed methodology, the safety level of tram stops is calculated from the values of the causal factor (x_i), the contribution index (y_{if}) and the degree of hazard (z_f), which can be obtained as a result of field observations. The distribution of tram stops by safety level (W) will help prioritize improvement of the quality of tram stops.

3 Results and discussion

Identification of a potential hazard to pedestrians near tram stops on the street network of Kazan was carried out on the basis of field observations. In the study of measuring conflicts, we identified the following types of tram stops: the presence of an island platform at tram stops, the absence of an island platform (passenger exchange occurs on the lane).

In the case of registering the volume of pedestrian traffic at a pedestrian crossing located in front of a tram stop with an island platform, the following types of pedestrian behavior are defined:

1. A pedestrian entering the carriageway when the tram is not at the stop and its approach is not visible (fig. 3a).
2. The pedestrian entering the carriageway when the tram approaches, it is possible to determine with a gradation in distance (fig. 3b).
3. A pedestrian running out onto the carriageway when the tram is at a tram stop (fig. 3c).

Fig. 3. Pedestrian behavior types when crossing the carriageway to a tram stop: a) there is no tram at the stop and its approach is not visible; b) the tram is approaching; c) the tram is at a tram stop.

Observations of tram stops without an island platform are characterized by behavior types 2 and 3 (fig. 3 b, c).

Fig. 4 shows an example of the proportion of passengers crossing the carriageway along one of the analyzed pedestrian crossings in relation to the approaching trams.

Fig. 4. The share of individual behavior of pedestrians in the area of tram stops.

The analysis shows that the behavior of pedestrians depends on the spatial organization of the tram stop. The «Yunusovskaya Square» stop does not have a designated track on the carriageway, and people board the trams from the carriageway (fig. 1), therefore 97.4% of all pedestrians cross the carriageway when the tram is at the stop and 2.6% cross when the tram is just approaching a stop. A completely different situation develops at the stop «Vladimir Kulagina Street» which is equipped with a designated track, while the pedestrian crossing to the stop is at some distance from the stop (fig. 2). At the Vladimir Kulagina Street stop, 1.1% of all pedestrians cross the carriageway when the tram is at the stop, 18.7% of pedestrians enter the carriageway when the tram approaches, 80.2 pedestrians cross the carriageway when the tram is not at the stop and you can't see it coming.

Investigation of hazardous situations allows us to describe the behavior of pedestrians in various situations, which must be checked before their possible spread. We found that the organization of traffic in the area of tram stops has a great influence on the behavior of people: the presence of road markings, a pedestrian crossing, road signs indicating a tram stop, etc.

The recorded behavior of pedestrians and drivers should be accompanied by assessment indicators. It is possible to determine the proportion of certain types of behavior described above and link them to the volume of pedestrian traffic.

Based on field observations and a literature review, we identified important unsafe actions in the area of tram stops:

- exit of pedestrians to the carriageway in front of driving vehicles;
- crossing the carriageway outside pedestrian crossings;
- waiting for the tram outside the tram stop.

The results of the study of the influence of causal factors on the level of pedestrian safety in the area of tram stops are presented in Table. For this, we determined the causal factors influencing the behavior of people (in this work we focused on three factors; for more detail, additional factors can be considered).

Table. Calculation of the safety level of tram stops.

№	Casual factors	Tram stop «Yunusovskaya Square»		Tram stop «Vladimir Kulagin Street»	
		x_i	β_i	x_i	β_i
1	Lack of a stopping platform	1	0.051	0	0
2	Lack of road markings «pedestrian crossing»	1	0.075	0	0
3	Long distance from pedestrian crossing to tram stop	0	0	1	0.021
	Tram stop safety level, W	8.74		9.79	

As a result of the study, it is possible to prioritize stops to improve pedestrian safety conditions: the lower the safety level, the higher the priority for improvement. Thus, we can conclude that first of all, it is necessary to apply measures to improve the safety of pedestrians at the Yunusovskaya Square tram stop ($W = 8.74$), since the safety level of the Vladimir Kulagin Street tram stop is higher ($W = 9.79$).

4 Conclusion

In modern conditions, there is a need for the priority of public transport. The quality of public transport depends not only on route tracing, spacing, and the reliability or comfort of vehicles.

The quality of stops is an integral part of the quality of public transport, directly influencing the attractiveness of public transport in the eyes of its customers – passengers.

Studies have shown that tram stops in mixed transport environments have varying levels of safety, availability and performance.

We carried out the analysis of tram stops in Kazan, which revealed a number of shortcomings in the organization of stops accessibility. The main disadvantages are: passengers are boarded and alighted directly from the carriageway; there are no pedestrian crossings at tram stops, people have to cross the carriageway; a significant distance from the pedestrian crossing to the tram stop.

The identified shortcomings in the organization of traffic near tram stops showed that they strongly affect the compliance with traffic rules by pedestrians.

To identify the potential danger to pedestrians in the area of tram stops, we propose a method for examining the level of safety by analyzing the frequency and potential outcomes of hazardous situations. It is important to determine safety and hazardous situations, as pedestrian behavior is influenced by the location of traffic flows and destinations.

The proposed method can be used to determine the use of infrastructure for pedestrian traffic. It also aims to identify the causes of hazardous pedestrian behavior in the area of tram stops and prioritize tram stops in improving safety conditions.

Based on the analysis, we conclude that the design of tram stops should always be carried out together with the organization of the space as a whole. This is the only way to ensure a high-quality project and its subsequent implementation.

References

1. K. Jamroz, W. Kustra, M. Budzyński, J. Żukowska. *Pedestrian Protection, Speed Enforcement and Road Network Structure the key Action for Implementing Poland's Vision Zero*, Transp. Res. Procedia **14**, 3905-3914 (2016).
2. A.A. Mironchuk, Yu.Yu. Dobrynina. *Issledovanie vliyaniya rasstoyaniya mezhdu ostanovochnymi punktami na skorost dvizheniya tramvaya*, Inzhenernyj vestnik Dona **4**, 39 (2020).
3. A.E. Gorev. *K voprosu ob ekonomicheskoy effektivnosti gorodskogo passazhirskogo transporta*, Transport Rossijskoj Federatsii. Zhurnal o nauke, praktike, ekonomike **3-4**, 34-36 (2012).
4. E.P. Dudkin, V.A. Chernyaeva, S.A. Doronicheva, K.A. Smirnov. *Povyshenie effektivnosti i konkurentosposobnosti tramvaya na rynke passazhirskikh perevozok*, Izvestiya Peterburgskogo universiteta putej soobshcheniya **2**, 230-237 (2017).
5. A.A. Tubis, A. Poskart, M. Rydlewski. *Ocena ryzyka podróžowania wrocławską komunikacją publiczną z uwzględnieniem aspektów bezpieczeństwa i logistyki*, Prace Naukowe Politechniki Warszawskiej. Transport **120**, (2018).
6. Yu.N. Egorova. *Sovershenstvovanie organizatsii tramvajnogho dvizheniya v Sankt-Peterburge*, Vestnik Gosudarstvennoj polyarnoj akademii **2**, 68-69 (2013).
7. E.A. Lapteva, L.V. Bulavina. *Vozmozhnost sovershenstvovaniya tramvajnogho dvizheniya v gorode Ekaterinburge*, Shkola Nauki **11**, 1-4 (2018).
8. M.N. Potemkina, M.V. Gryaznov, T.G. Pashkovskaya, E.A. Timofeev. *Rol tramvajnogho dvizheniya v formirovanii transportnoj sistemy Magnitogorska*, Mir transporta **6**, 310-326 (2019).
9. A.V. Gorshenin. *K voprosu o stanovlenii tramvajnogho dvizheniya v g. Ulyanovske*, Samarskij nauchnyj vestnik **1**, 129-135 (2017).
10. M.T. Sarwar, G. Fountas, C. Bentley, P.C. Anastasopoulos, A. Blatt, J. Pierowicz, K. Majka, R. Limoges. *Preliminary Investigation of the Effectiveness of High-Visibility Crosswalks on Pedestrian Safety Using Crash Surrogates*, Transp. Res. Rec. **2659**, 182-191 (2017).

11. A.A. Kustenکو. *Issledovanie avarijnosti v tramvajnom dvizhenii*, Vestnik Kurganskogo gosudarstvennogo universiteta. Seriya: Tekhnicheskie nauki **2**, 94-97 (2017).
12. B. Mehmetm, A. Ulak, A. Kocatepe, E. Yazici, O. Erman. *A stop safety index to address pedestrian safety around bus stops*, Safety Science, **133**, 105017 (2021).
13. R. Weiner, K. Singa. *Toolkit for the Assessment of Bus Stop Accessibility and Safety American Public Transportation Association*, Journal of Cleaner Production, **294**, 126282 (2021).
14. S.P. Hoogendoorn. *State-of-the-art of vehicular traffic flow modeling*, Delft University of Technology, 283-303 (2001).
15. F. Naznin, G. Currie, D. Logan. *Key challenges in tram/streetcar driving from the tram driver's perspective – A qualitative study*, Transportation Research **F 49** (2017).
16. D. Cliché, S. Reid. *Growing Patronage-Think Tram?* International Conference Series on Competition and Ownership in Land Passenger Transport (2007).
17. A. Ulak, E.E. Kocatepe, M.W. Ozguven. *Horner How far from home do crashes occur? A network-based analysis* Saf. Sci. **118**, 298-308 (2019).
18. M.B. Ulak, E.E. Ozguven, O.A. Vanli, M.A. Dulebenets, L. Spainhour. *Multivariate random parameter Tobit modeling of crashes involving aging drivers, passengers, bicyclists, and pedestrians: Spatiotemporal variations*, Accid. Anal. Prev. **121**, (2018). DOI: 10.1016/j.aap.2018.08.031.
19. A. Agarwal, K. Pradeep, K. Premit, M. Rakesh. *A methodology for ranking road safety hazardous locations using analytical hierarchy process*, Procedia-Social and Behavioral **104**, 1030-1037 (2013).
20. F.C. Munavar, B.U. Kinjal, M. Bhargab, B. Manfred. *Assessing Safety Level of Bus Stops in the Absence of Crash Data*, https://www.researchgate.net/publication/292514461_Assessing_Safety_Level_of_Bus_Stops_in_the_Absence_of_Crash_Data.