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SAFETY AND FUNCTIONALITY ASSESSMENT OF TRAM LOOPS IN WROCŁAW

Ocena bezpieczeństwa i funkcjonalności pętli tramwajowych we Wrocławiu

***Abstract**: The article presents the implementation of the ISFTL method proposed by the authors consisting in an indicator assessment of the safety and functionality of tram loops. Five tram loops located in Wrocław were analyzed. Each of these loops has different characteristics. The components of each assessment are described in detail and further directions for improving the proposed assessment are indicated.*
Keywords: safety, public transport, tram loop

***Streszczenie:** W artykule została przedstawiona implementacja zaproponowanej przez autorów metody ISFTL polegającej na wskaźnikowej ocenie bezpieczeństwa i funkcjonalności pętli tramwajowych. Analizie poddano pięć pętli tramwajowych znajdujących się na terenie Wrocławia. Każda z tych pętli charakteryzuje się innymi cechami. Szczegółowo opisano czynniki składowe każdej oceny oraz wskazano dalsze kierunki doskonalenia zaproponowanej formy oceny.*
***Słowa kluczowe:** bezpieczeństwo, miejski transport zbiorowy, pętla tramwajowa*

1. Introduction

The concept of sustainable development of large cities makes the development of public transport, in particular trams, an increasingly important goal of municipal infrastructure managers. This is mainly due to the properties of tram transport. Trams moving along a separate track, avoid some traffic congestion. The use of trams reduces the emission of pollutants into the environment. The development of this type of transport is therefore an element of improving the quality of life in cities. The safety and functionality of public transport services are key elements in assessing the quality of this transport. Therefore, there is a need for tools and methods that will allow to assess the safety and functionality of tram transport elements. The literature review shows that there are no publications on safety and functionality assessment methods taking into account the specificity of tram loops. For this reason, the aim of this article is to present the assumptions for the method of assessing the safety and functionality of a tram loop and its application in the assessment of transport infrastructure on the example of a case study - the city of Wrocław. The research problem posed by the authors is the construction of a method for evaluating tram loops based on defined criteria. The authors define the hypothesis that there is a very different level of safety and functionality of tram loops. Therefore, it is necessary to develop tools that allow public transport managers to take corrective actions in this regard.

2. Background of the issue

Tram loops are an important element of the public transport network in large cities. Their task is increasingly not only a change of direction trams, but also to act as an interchange junction for public transport and to create a place connecting public and individual transport, e.g. by using Park & Ride car parks. This is due to the growing demand for the development of mobility, which is crucial for ensuring freedom of movement and a good quality of life for residents [2]. The change in the role of the tram loop observed in recent years is an example of the reorientation of the activities of local authorities towards sustainable and intelligent solutions not only in transport, but also in the entire city logistics [8].

Research on the literature in the analyzed area shows that there are publications on the safety and functionality assessment of point infrastructure in the public transport network. The subject of the described research are methods and criteria for assessing interchange nodes [1, 5, 6, 9, 11, 13], tram stops [3, 4, 10, 12, 15], as well as the linear tram infrastructure [2, 7]. The obtained results of the literature research presented in [14] indicate, however, the existence of a research gap in the area of evaluation methods for tram loops.

Tram loops, which play the role of interchange nodes, have a large role in increasing the attractiveness and efficiency of public transport, as shown, among others, by the

research of the team of Professor Olszewski [11]. Therefore, it is important to ensure appropriate standards of their safety and functionality.

Efficient and convenient organization of transfer between transport vehicles is possible by adapting the transport infrastructure to the size of the passenger exchange and the characteristics of the users using the facility. This adaptation is to facilitate the use of the node by passengers and other potential users of the node [1]. The NICHES + [9] project states that passenger-friendly interchanges should ensure short transitions, safety, accessibility for the elderly and disabled, and an attractive public space [9]. Therefore, the requirements that modern tram loops should have are:

- the possibility of using various means of public transport, both for everyday users as well as tourists and people coming to the city for other purposes;
- the possibility to leave your own vehicle in a safe place;
- safe, well-lit and marked and clean place for passenger exchange;
- available and current information, in those places where it is needed for a smooth change of means of transport;
- ensuring accessible urban space (easy access, easy to use);
- ensuring road safety when using the loop.

The potential benefits of such an designed loop as an interchange node are primarily [11]: minimizing congestion, functionality, efficient use of space, increasing passenger satisfaction and, as a result, increasing the number of journeys carried out via public transport. The infrastructure for the Park & Ride system, appropriately included in the node area, additionally eliminates individual transport from the city center [17], which makes it possible to designate traffic calming zones and restrict access to them only through public transport [16].

This article is a continuation of the work presented in [14]. It describes a detailed research approach to the selection of criteria for assessing the functionality and safety of tram loops using the measures developed by the authors. Taking up this topic results from the lack of a methodology for the tram loop assessment, which would be an effective research tool and practical application by public transport operators.

The two main goals of this article are to present the implementation of the method developed by the authors to assess the functionality and safety of tram loops and to verify the assessment method for specific solutions. To achieve these goals, the most important assumptions of the proposed approach to the index assessment of the safety and functionality of tram loops were presented. Then the selected tram loops in Wrocław were characterized and evaluated using the proposed indicators. A comparative analysis was carried out for the obtained results, which allowed to verify the legitimacy of the proposed approach. Finally, the most important conclusions resulting from the research procedure are presented. It should be emphasized that the method used is at the preliminary stage and will be developed by the authors in subsequent stages.

3. Characteristics of the research method

The method proposed in [14] involves the determination of two independent indicators relating to the assessment of safety and functionality of tram loops. The idea of the method is to evaluate each of the loops in the area of 4 different criteria, which for both indicators are presented in fig. 1.

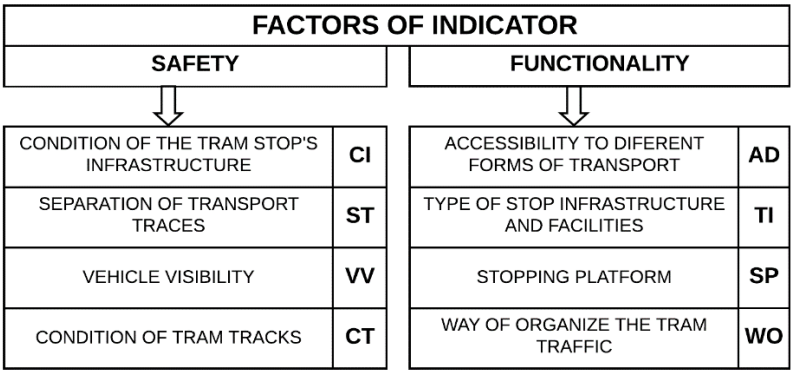

Fig. 1. Components of assessment factors for the ISFTL method, based on [14]

The criteria are evaluated on a five-point scale, which is presented in fig. 2. Detailed information on the factors taken into account when assessing the criteria is presented in [14].

1	2	3	4	5
a complete lack of condition	very low compliance with conditions	partial compliance with conditions	high compliance with conditions	complete compliance with conditions

Fig. 2. Rating scale for individual criteria [14]

The indicator of safety of tram loop $ISTL_i$ is the product of the results obtained by each of the partial criteria and is calculated according to formula 1.

$$ISTL_i = CI_i * ST_i * VV_i * CT_i \tag{1}$$

where:
$ISTL_i$ – the indicator of safety of the tram loop,
CI_i – assessment of the condition of tram stop's infrastructure,
ST_i – assessment of the separation of transport traces,
VV_i – assessment of the vehicle visibility,
CT_i – assessment of the condition of tram tracks,
i – tram loop marking.

The indicator of functionality of tram loop $IFTL_i$ is calculated according to formula 2.

$$IFTL_i = AD_i * TI_i * SP_i * WO_i \quad (2)$$

where:
$IFTL_i$ – the indicator of the functionality of the tram loop,
AD_i – assessment of the accessibility to different forms of transport,
TI_i – assessment of the type of stop infrastructure and facilities,
SP_i – assessment of the stopping platform,
WO_i – assessment of the way to organize the tram traffic,
i – tram loop marking.

Value of the safety indicator (ISTL) and the functionality indicator (IFTL) of tram loops can assume a minimum value of 1 and a maximum of 625. This value results from the maximum point value of the indicator. For easier interpretation of the results, the research method [14] gives the opportunity to present the values of ISTL and IFTL indicators in the form of a percentage, which is calculated on the basis of formula 3.

$$ISTL_{\%i} = \frac{ISTL_i}{625} * 100\ [\%]$$

$$IFTL_{\%i} = \frac{IFTL_i}{625} * 100\ [\%] \quad (3)$$

where:
ISTL – indicator of safety of the tram loop [-],
$ISTL_{\%}$ – percentage indicator of safety of tram loop [%],
IFTL – indicator of the functionality of the tram loop [-],
$IFTL_{\%}$ – percentage indicator of functionality of tram loop [%],
i – tram loop marking.

For the determined percentage values of the ISTL and IFTL indicators, the levels of acceptance of meeting a given evaluation criterion were determined depending on the percentage value of the indicators of safety or functionality of the tram loop. In fig. 3, a diagram with specific acceptance levels is presented.

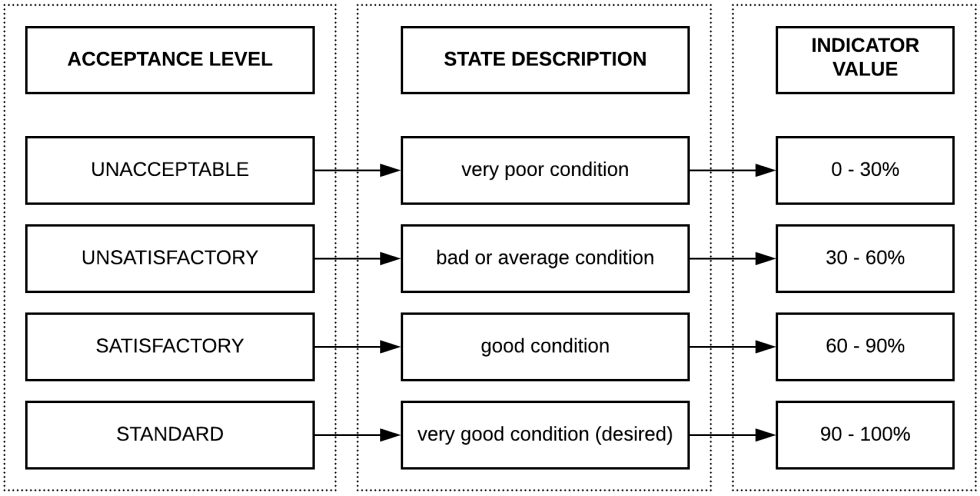

Fig. 3. Acceptance levels for the percentage values of safety and functionality indicators of tram loops

The proposed test procedure related to the evaluation of the safety and functionality of the tram loop involves the following steps:

1. Audit of a tram loop in terms of safety and functionality - using the measurement form.
2. On the basis of the completed forms and identified shortcomings and threats, a specific point value is assigned to each of the factors (CI, ST, VV and CT as well as AD, TI, SP and WO).
3. Calculation of the values of safety and functionality indicators based on the formulas provided.
4. Analysis of the results, determination of the strengths and weaknesses of the tested facility based on the assessment, presentation of recommendations for improving safety and functionality.

4. Characteristics of the assessed tram loops

The aim of the study was to assess tram loops in Wrocław for which safety (ISTL) and functionality (IFTL) indicators of tram loops were determined. The presented approach to the assessment is universal, therefore it should enable the assessment of safety and functionality for different types of tram loops. In order to verify the adopted assumptions of the methodology, five tram loops located in Wrocław (Poland) with different characteristics were selected for analysis. Factors differentiating the tram loops are presented in fig. 4. The presented division of the loop distinguishes 5 main factors determining the most important features of the loop. In the figure, symbols are given next to specific parameters. These symbols will be used later in the article.

The determination of ISTL and IFTL indicators was preceded by the preparation of the characteristics of all tram loops located in Wrocław. However, in the article the presentation of the results was limited only to analyzes concerning the selected 5 loops, which represent various types of tram loops and at the same time constitute the basic research sample. These characteristics were carried out using the field research method through direct observation and available knowledge. The developed form allows to collect the data necessary to conduct a detailed tram loop audit in accordance with the adopted criteria for assessing the safety aspects and functionality of the facility.

The field study was conducted in December 2019. In tab 1. are presenting the most important parameters of the analyzed tram loops taken into account during the analysis and detailed information describing the factors differentiating the tram loops (fig. 4). As an additional parameter - NL - the number of lines served on a given loop as of 31.12.2019 was also given.

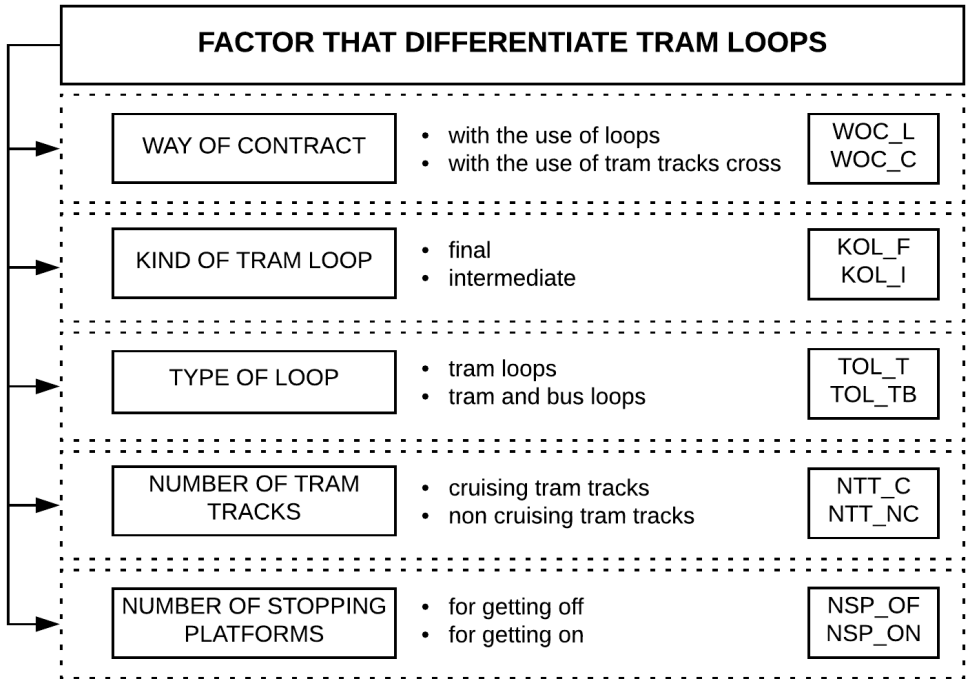

Fig. 4. Factor that differentiates tram loops

Table 1

Parameters of tram loops selected for analysis

No.	Name of tram loop	WOC	KOL	TOL	NTT	NSP	NL
1	KRZYKI	L	I	TB	C-2 NC-0	ON-1* OF-1*	2
2	GAJ	C	F	T	C-0 NC-2	ON-1 OF-1	2
3	OPORÓW	L	F	TB	C-3 NC-0	ON-3 OF-1	3
4	SĘPOLNO	L	F	TB	C-2 NC-0	ON-1 OF-1	3
5	KLECINA	L	F	T	C-2 NC-0	ON-1 OF-1	2

* stop platforms are located about 100 m from the loop

Figure 5 presents diagrams of the analyzed tram loops, respectively: 1 – Krzyki, 2 – Gaj, 3 – Oporów, 4 – Sępolno, 5 – Klecina. In the diagrams, the lines correspond to the axes of tram tracks and the markings in the squares with the letters A and T indicate the locations of the stops.

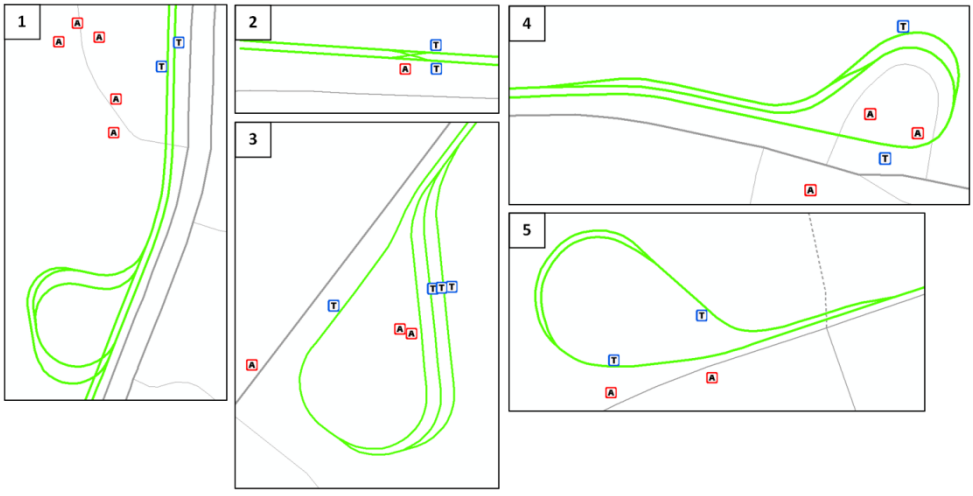

Fig. 5. Diagrams of rated tram loops

5. Results

Knowing the factors taken into account [14] when determining the point value for specific criteria included in individual indicators, a detailed analysis of 5 selected tram loops in Wrocław was carried out. The results are presented in tab. 2, in which the respective columns give the assessment of the parameters taken into account in the assessment process. At this stage of research, the expert method of scoring was adopted.

Table 2

Values of individual parameters taken into account when calculating the safety and functionality indicator of tram loops

Tram loop	SAFETY INDICATOR						FUNCTIONALITY INDICATOR					
	CI	ST	VV	CT	ISTL	%ISTL	AD	TI	SP	WO	IFTL	%IFTL
Krzyki	4	3	5	4	240	38%	4	5	5	5	500	80%
Gaj	5	4	5	5	500	80%	3	5	5	5	375	60%
Oporów	5	4	5	5	500	80%	5	4	4	5	400	64%
Sępolno	2	1	5	2	20	3%	4	3	1	2	24	4%
Klecina	5	5	5	5	625	100%	4	4	5	5	400	64%

The measurements carried out allowed for the conclusion that the Krzyki loop (fig. 6) has a low level of safety compliance. The first aspect is the condition of the pavement surface, which is not adequate. There are individual defects and unevenness. In the case of the separation of transport traces (ST), no pedestrian crossing through the tram track was identified and there was a clear problem in separating pedestrian and cyclist streams. The entire length of the stop leads as a road to the bicycle parking lot which can lead to dangerous situations in the cyclist-pedestrian relationship. The technical condition of the track is assessed as satisfactory. In terms of the functionality of the loop, the evaluation result is satisfactory.

Fig. 6. Tram platform stops located in Krzyki tram loop in Wrocław (Poland)

In the case of the Gaj loop, which is an example of a tram loop where the way of contract is realised with the use of a tram tracks cross. This is the type of place where the tram line ends, which can only be served by tram trains adapter for two-way travel. Changing direction is done here using a cross. The assessment of the functionality of this loop is on the border of the average and good condition. The accessibility to different forms of transport (AD) was rated at this low level. In the immediate vicinity of the loop there is no B&R and the city bike station is located away from the loop and it will be separated by four pedestrian crossings. The level of safety on the loop is assessed as satisfactory.

The Oporów tram loop has 3 tram platforms for people getting on, which do not have any additional markings indicating which line is serves passengers on the selected platform. This loop has only one bus shelter and one table of dynamic passenger information. Both are on one platform. These factors cause that in the assessment of functionality at the type of stop infrastructure and facilities (TI) and stopping platform (SP) parameters for this loop a point value of 4 is assigned. The remaining parameters were rated maximum due to the very high proportion of meeting the requirements. Therefore, the evaluation of the functionality of this loop is good. The safety aspect was assessed at the same level, the only weakness in the case of safety is the lack of adequate separation of transport routes between the different users of the loop.

The Sępolno loop (fig. 7) has the lowest values of ISTL and IFTL indicators. Both in the case of the safety and functionality assessment, the conducted tests showed a very bad condition of both parameters, classifying the loops at the unacceptable level in both areas of the assessment. During the audit carried out at the loop it was observed that the condition of the tram track is in poor condition. The surface of pedestrian and bicycle routes is in very poor technical condition, the pavements are uneven and have cavities. In the loop area, there are no pedestrian crossings and pavements separated from the tram track. There is also a lack of bicycle traffic separation. The Sępolno loop meets all requirements only in terms of accessibility to different forms of transport and visibility of tram trains in the area of the loop. In the case of functional indicator parameters, there is a lack of adaptation of bus platforms and infrastructure. There are no shelters, benches and dynamic passenger information boards on the loop. Platforms are not adapted for the disabled. The platform for passengers who getting on is too short. And the number of platforms for passenger who getting on is not adapted to the number of tram lines which serving loops.

Fig. 7. Tram platform stops located in Sępolno tram loop in Wrocław (Poland)

The Klecina loop (fig. 8.) is an example of a tram loop where the direction change takes place differently than on typical loops. As a standard, tramway traffic on the loop runs counter-clockwise and stops are located on the outside of the tram track. In the case of the Klecina loop, the tram traffic is clockwise and the stops are located inside the loop. The awarded point values depend on the selected parameters for: accessibility to different forms of transport (AD) - no P&R parking, the distance from the city bike station is about 80 m, bus stops located at the street adjacent to the loop at a short distance from the stop; type of stop infrastructure and facilities (TI) - no dynamic passenger information boards, service outlets and the ticket machine is located outside the tram loop.

Fig. 8. Tram platform stop for getting on located in Klecina tram loop in Wrocław (Poland)

Based on the results obtained in accordance with formula (3), shows the ranking of individual loops. Figure 9 presents a graph with the percentages of safety and functionality indicator of the analyzed tram loops.

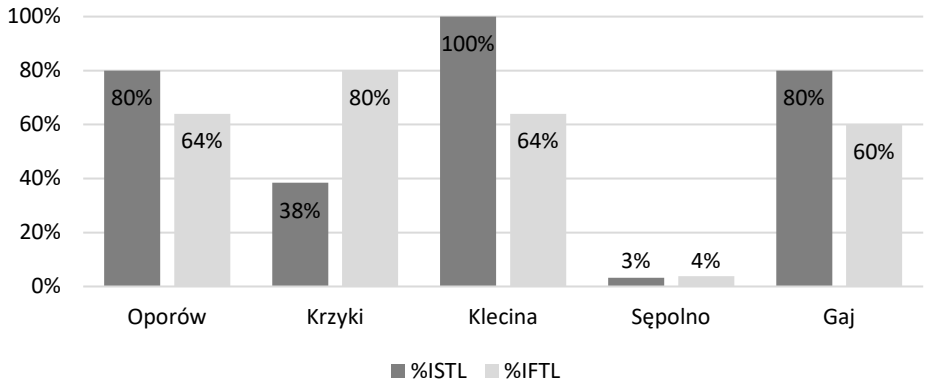

Fig. 9. Percentage values of ISTL and IFTL indicators for selected tram loops in Wroclaw (Poland)

The results indicate that the Sępolno loop is an example where it is necessary to carry out repair and modernization works aimed at improving the safety of users and the functionality of the facility. Analyzes indicate a significant risk of adverse events, including those threatening the health and life of users. One loop that has obtained the maximum indicator value (only in terms of security) is the Klecina loop.

6. Summary

The implementation of the method of assessing the safety and functionality of the streetcar loop makes it possible to state that the proposed tool is universal in nature and is adapted to the specific functioning of tram loops. In addition, the detailed characteristics of the loops prepared with the use of the developed measurement form allow for the analysis of their functioning and indication of areas / elements that reduce the level of its functionality and user safety.

The research carried out on selected loops in Wrocław proves that the hypothesis was correct - there is a variation in the level of safety and functionality of tram loops. It was also shown that for one of the assessed loops corrective actions should be taken as soon as possible.

The proposed approach to loop assessment may support the road safety inspection process for the assessment of the existing tram infrastructure, but can also serve as a tool supporting the safety audit process of new or modernized tramway projects. In this case, a detailed list of evaluation criteria can serve as a model for the created plans and projects.

Further work on the improvement of the research method should be directed to the evaluation of the sensitivity of individual evaluation components and the possibility of introducing weights corresponding to the importance of a given evaluation criterion. Additionally, it is necessary to precisely assign the scores in individual criteria to the requirements for loops. The list of criteria and sub-criteria should also be expanded to increase the accuracy and quality of the assessment. It is also necessary to take into account the criteria of road traffic in the loop area (vehicles, pedestrians). The ISTL and IFTL indicators themselves can be used to carry out inspections and audits of tram loops. In further works, the authors will extend the implementation of the method to tram loops in other cities, including Gdańsk, Warsaw, Kraków, Olsztyn, Elbląg or Wrocław (other loops), which will allow for increasing the research sample and comparing the level of safety and functionality not only within a given city, but also between them. The results of the assessments will be recommendations for appropriate municipal units responsible for public transport. In the longer term, the authors assume the development of the described method to other elements of the transport infrastructure, taking into account the conditions and the selection of dedicated evaluation criteria.

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