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METHOD FOR IDENTIFYING HAZARDOUS ROAD LOCATIONS AT THE INTERSECTION OF TRAMLINES AND ROAD TRAFFIC

Summary. Passenger transport safety is an important issue. This paper presents a method for the identification of locations at the intersection of tramlines and road traffic, which are characterized by a high level of risk. Furthermore, different aspects of risk have been determined in order to analyse the problem in a complex way. For each aspect of risk, a measure was developed to estimate the level of risk. The application of the proposed method has been presented on the basis of an analysis of documentation of traffic incidents on the tram network. Accordingly, hazardous road locations have been identified.
Keywords: traffic engineering; traffic safety; hazardous road location

1. INTRODUCTION

The level of road traffic safety in Polish cities is still not satisfactory. The level of risk may be characterized in many different ways (e.g., [4,5,12]). The numbers of traffic accidents and the numbers of casualties are most commonly used. Although both these measures are decreasing [16], they are still too high in Poland in comparison to other European countries.

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The value of the traffic fatalities index per 100,000 inhabitants is more than two times higher in Poland than in Great Britain and significantly higher than in Germany or France [8]. That means that the risk of being involved in a traffic accident[3] in Poland is too high and should be reduced.

In the literature associated with traffic safety, there are many different approaches to defining a location that is especially dangerous for users of the transport system. For example, in [14], a hazardous road location is defined as a “location on the road network in which there is a significant concentration of all - or only particular, types of traffic accidents or effects of these accidents”. However, in [9] and [11], a hazardous road location (also called an “accident prone location” or a “crash hotspot”) is any location in which there is a higher than expected number of traffic incidents than in other similar locations, as a result of local risk factors.

The claim that the number of traffic incidents in hazardous road locations is connected with local risk factors seems to be of great significance. Therefore, those incidents that have occurred due to inappropriate features of the location should be of critical importance in the process of identifying accident-prone locations than those incidents caused by reckless or inappropriate ways of driving.

Based on that assumption, one may surmise that the environmental features of a location, resulting from insufficient visibility or non-typical design, should play a key role in modelling road traffic safety. On account of this hypothesis, by using engineering methods, one can influence the number of traffic incidents in analysed locations [9]. In addition, in [14], a claim is made that the influence of the environment of locations is often ignored. Most road traffic incidents occur because of human (i.e., drivers or pedestrians) error, but defects of the location have a big influence on the possibility of such mistakes being made.

Many methods have been developed in order to identify hazardous road locations. In [9] and [18], the most common hotspot identification methods are described. Usually, these methods are associated with the frequency of occurrence of road traffic accidents or with different safety measures. The analysis of the frequency of occurrence is also mentioned in [7] and [11] as one of the easiest methods of determining the risk in particular locations. Other, albeit simpler methods, may be associated with the total number of accidents or the costs of property damage [9].

In [14], different approaches for determining the limit values of safety measures have been described. Those approaches include:

- Determining the limit value arbitrarily
- Accepting a value that is significantly higher than the average value
- Accepting a value of a chosen high quantile

Most methods are developed for road traffic, whereas the safety of tram traffic is often overlooked. This is very alarming because the safety of any operation in a passenger transport system should be the primary standard of its functioning [2]. Traffic incidents involving trams should be treated with great attention, due to the specificity of tram traffic. First of all, a tram is a means of public transport that usually carries more than 50 passengers, all of whom are exposed to danger. Moreover, an incident on the tram network usually affects vehicles that do not take part in the incident itself. One of the most important demands that is addressed in the context of public transport is the certainty of arriving at the destination [13] - an incident on the tram network may make that demand impossible to fulfil.

[3] In this paper, the term “accident” is used to refer to a traffic incident that resulted in casualties, whereas, for those incidents without any fatalities or injured people, the term “collision” is used.

It is also of great importance to perform an analysis of traffic safety in a complex way, as only such an analysis can lead to a significant improvement in the level of safety [3].

Taking the above into consideration, the main purpose of this paper is to develop a method of identification of hazardous road locations at the intersection of road traffic and tramlines, which considers different aspects of risk.

2. DESCRIPTION OF THE PROPOSED METHOD

In different papers, there are various definitions of a hazardous road location. Furthermore, some authors almost treat the terms "hazardous road location" and "blackspot" as synonyms [6,9], whereas others distinguish them [14]. Therefore, there is a need to formulate a definition of a hazardous road location, which can be used in further analysis.

An assumption was made that a hazardous road location at the intersection of tramlines and road traffic should be particularly dangerous, and that different aspects of risk should be taken into consideration. The three most important aspects of risk that were chosen are shown in Fig. 1.

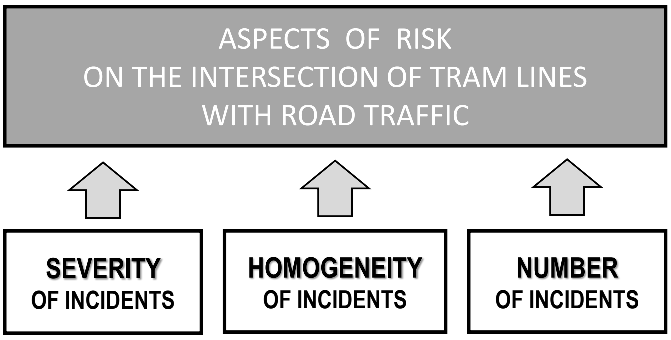

Fig. 1. Aspects of risk included in the proposed method; source: own research

Based on those factors, a definition of a hazardous road location was formulated. According to this definition, a hazardous road location is a location on a transport network in which limit values of measures connected with severity, homogeneity and the number of traffic incidents are exceeded. Therefore, there is a need to develop a complex method for identifying hazardous road locations at the intersection of tramlines and road traffic, which will include all identified aspects of risk [1,17].

2.1. Characteristics of the chosen risk factors

The severity of incidents is usually represented by the number of casualties (people injured or killed as a result of an accident). There are about 3,000 people killed and about 40,000 injured in accidents on Polish roads every year [10]. As Polish law states, a person killed in an accident is a person who died at the scene of an accident or within 30 days of the accident in a hospital [10]. Despite being a tragedy for the family and source of great pain for them, the death of a person in an accident also causes financial loss, on account of all the administrative and medical costs involved, such as the arrival of emergency services or any court proceedings [10]. The cost of one fatality is therefore assessed at about PLN 2 million (PLN 2,052,518in 2015) [10]. If a person was seriously injured, the cost may be even higher (about

PLN 2,323,299in 2015) [10]. Taking all the relevant factors into consideration, the severity of traffic incidents is one aspect that must not be ignored.

The second aspect of risk is the homogeneity of traffic incidents. This is defined as the occurrence of the same types of incidents. If incidents of the same type happen regularly in a particular location, then this location should be considered as being more hazardous than locations with the same number of incidents, but of different types. Such an assumption was made because the repetitiveness of the same types of collisions or accidents may indicate a serious problem with infrastructure, traffic organization or other local faults. If incidents that occur in a particular location are of different types, then one may assume that those incidents occurred randomly and are mostly connected to individual mistakes by road users.

The final aspect of risk is associated with the total number of traffic incidents in an analysed location. Every collision or accident between a tram and another vehicle should be a source of concern, as a large number of incidents in one location, even if they are not of the same type and without any casualties, is still an evidence of high risk in that location.

2.2. Criteria used in the proposed method

To describe the proposed method, a set of numbers of potential hazardous road locations has been determined as:

$$\boldsymbol{I} = \{1, \dots, i, \dots, \bar{I}\} \tag{1}$$

where: i - the number of each potential hazardous road location at the intersection of tramlines and road traffic; and $\bar{I}$ - a total number of all potential locations.

In order to take the aspect of time into consideration, a set containing numbers of individual study years has been determined as:

$$\boldsymbol{T} = \{1, \dots, t, \dots, \bar{T}\} \tag{2}$$

where: t - the number of each year of analysis; and $\bar{T}$ - the total number of years of analysis.

An important issue, which has to be taken into consideration, is the minimal study period. As collisions and accidents between trams and other vehicles are rare, in comparison to those involving only road vehicles, a minimal study period was determined to be three years. Such a period should allow for the avoidance of randomness in the occurrence of incidents.

Moreover, analysed incidents may be divided into categories. A set of the numbers of possible categories of incidents has been determined as:

$$\boldsymbol{K} = \{1, \dots, k, \dots \bar{K}\} \tag{3}$$

where: k - the number of category of incident; and $\bar{K}$ - the total number of categories of incidents adopted in the analysis.

An assumption was made that, in the proposed method for the identification of hazardous road locations at the intersection of tramlines and road traffic, three criteria would be used: one for each previously mentioned aspect of risk. For each criterion, a measure was worked out in order to express the level of risk in the analysed location in terms of numerical values. A limit value for each criterion was also established.

2.2.1. Criterion of the severity of incidents - K1

In order to use the criterion of the severity of incidents, a measure was proposed, which describes the level of risk associated with the analysed aspect in terms of numerical values. The numerical value for criterion K1 in *i* location, i.e., $K1_i$, is calculated using the following formula:

$$K1_i = \sum_{t=1}^{T} Xfa_{i,t} + \sum_{t=1}^{T} Xin_{i,t}, \qquad i \in \boldsymbol{I} \tag{4}$$

where: $Xfa_{i,t}$ - the number of incidents involving fatalities in *i* location in *t* year of analysis; and $Xin_{i,t}$ - the number of incidents with only injured casualties in *i* location in *t* year of analysis.

The criterion of severity is used in order to identify those locations at the intersection of tramlines and road traffic, in which the risk that there will be casualties as a result of an accident is especially high. Taking into consideration the fact that a tram is a means of public transport, which is often used by a considerable number of passengers, a reduction in the number of incidents involving trams, which may result in injuries, should be of very high priority.

However, such incidents are relatively rare; therefore, the limit value for the criterion of severity was assumed arbitrarily. This criterion shall be treated as fulfilled if at least one incident results in casualties in the analysed location; thus, the limit value $K1_{lv}$ of criterion K1 may be assumed as $K1_{lv} = 1$. The decision about whether the criterion of the severity of incidents is fulfilled should be taken on the basis of the following formula:

$$K1_i \geq K1_{\mathrm{lv}}, \qquad i \in \boldsymbol{I} \tag{5}$$

2.2.2. Criterion of the homogeneity of incidents - K2

For the purpose of modelling safety at the intersection of tramlines and road traffic, five categories of incidents were identified. The following categories have been distinguished:

- *k* = 1: a minor collision between two vehicles, which were parallel to each other at the moment of the incident, in which one of the vehicles was not taking part in traffic
- *k* = 2: a minor collision between two vehicles, which were parallel to each other at the moment of the incident, in which both vehicles were taking part in traffic
- *k* = 3: side collision
- *k* = 4: front collision
- *k* = 5: rear collision

Categories 1 and 2 were introduced due to the specificity of tram traffic - its characteristic feature being that trams and road vehicles often run parallel to each other. Incidents covered in these categories have resulted in minor paint damage, usually as a result of contact between mirrors or a mirror and the car body. As the proposed method does not include incidents with pedestrians, no category including such incidents was distinguished.

In order to use the criterion of the homogeneity of incidents, it is necessary to calculate the numerical value of criterion K2 in *i* location for *k* category of the accident, i.e. $K2_{k,i}$. This value is calculated on the basis of the following formula:

$$K2_{k,i} = \sum_{t=1}^{T} y_{k,i,t}, \qquad k \in \boldsymbol{K}, i \in \boldsymbol{I} \tag{6}$$

where: $y_{k,i,t}$ - the number of incidents assigned to the *k* category in *i* location in *t* year of analysis.

The criterion of the homogeneity of incidents is used to identify those locations in which the structure of accidents is homogeneous. The homogeneity of incidents is defined as the regular occurrence of incidents assigned to the same category. Therefore, the limit value of this criterion should be appropriate in eliminating incidents that happen due to random causes, and not because of local risk factors, which influence the behaviour of drivers [19]. In the proposed method, it was assumed that the limit value should be calculated using the total number of years of analysis: $K2_{\mathrm{lv}} = \bar{T}$.

Therefore, the criterion of the homogeneity of incidents shall be considered as fulfilled on the basis of the following formula:

$$K2_{k,i} \geq K2_{\mathrm{lv}}, \qquad k \in \boldsymbol{K}, i \in \boldsymbol{I} \tag{7}$$

2.2.3. Criterion of the number of incidents - K3

The final criterion is calculated on the basis of the total number of incidents in a particular location during the study period. To calculate the numerical value of criterion K3 in *i* location, i.e., $K3_i$, the following formula is proposed:

$$K3_i = \sum_{t=1}^{T} \sum_{k=1}^{K} y_{k,i,t}, \qquad i \in \boldsymbol{I} \tag{8}$$

where: $y_{k,i,t}$ - the number of incidents assigned to the *k* category in *i* location in *t* year of analysis.

The criterion of the number of incidents is used to identify those locations that stand out from other locations because of the total number of incidents. Therefore, there should be a significant difference between locations that satisfy the proposed criterion and those that do not. The limit value should be calculated using the quantile Q_{95} of the number of incidents, which is expressed as: $K3_{\mathrm{lv}} = Q_{95}$.

Therefore, the criterion of the number of incidents is considered as fulfilled when the numerical value of measure $K3_i$ is equal to or exceeds the numerical value of limit value $K3_{\mathrm{lv}}$, as in the following formula:

$$K3_i \geq K3_{\mathrm{lv}}, \qquad i \in \boldsymbol{I} \tag{9}$$

2.4. Groups of traffic safety

In order to rank locations in terms of traffic risk and to determine which locations should be the object of further detailed analysis, once all the measures are calculated, each location should be assigned to one of five groups of traffic safety. The assignment to one of five groups is made according to criteria that are fulfilled in the analysed location.

Criteria that are assumed to be fulfilled for each group are presented in Table 1.

Tab. 1

Groups of traffic safety

Group	Fulfilled criteria
I	K1 and K2 and K3
II	(K1 and K2) or (K1 and K3)
III	K2 and K3
IV	K1 or K2 or K3
V	-

According to Table 1, if, in the analysed location, all criteria are fulfilled, then such a location is considered to be most hazardous. Locations assigned to Group I should be analysed in the first place. If two out of three criteria are fulfilled, then such a location may be assigned to Group II or III. As it is assumed that death and injury as a result of an accident are the most dangerous effects of a traffic incident, if one of the two fulfilled criteria is the criterion of severity, then such a location should be assigned to Group II. Locations assigned to Group I, II or III should be chosen for further analysis.

2.5. Procedure for identifying hazardous road locations according to the proposed method

The procedure is shown in Fig. 2. In order to use the proposed method, it is necessary to collect data about all traffic incidents at the intersection of tramlines and road traffic in the study area in the given period of analysis. The study period should not be shorter than three years.

The collected data should include information about the following:

- Location of an incident (as precisely as possible)
- Date of an incident
- Time of an incident
- Types of vehicles involved
- Number of casualties (fatalities and injured)
- Damages to vehicles
- Causes of an incident
- Responsibility
- Circumstances of an incident

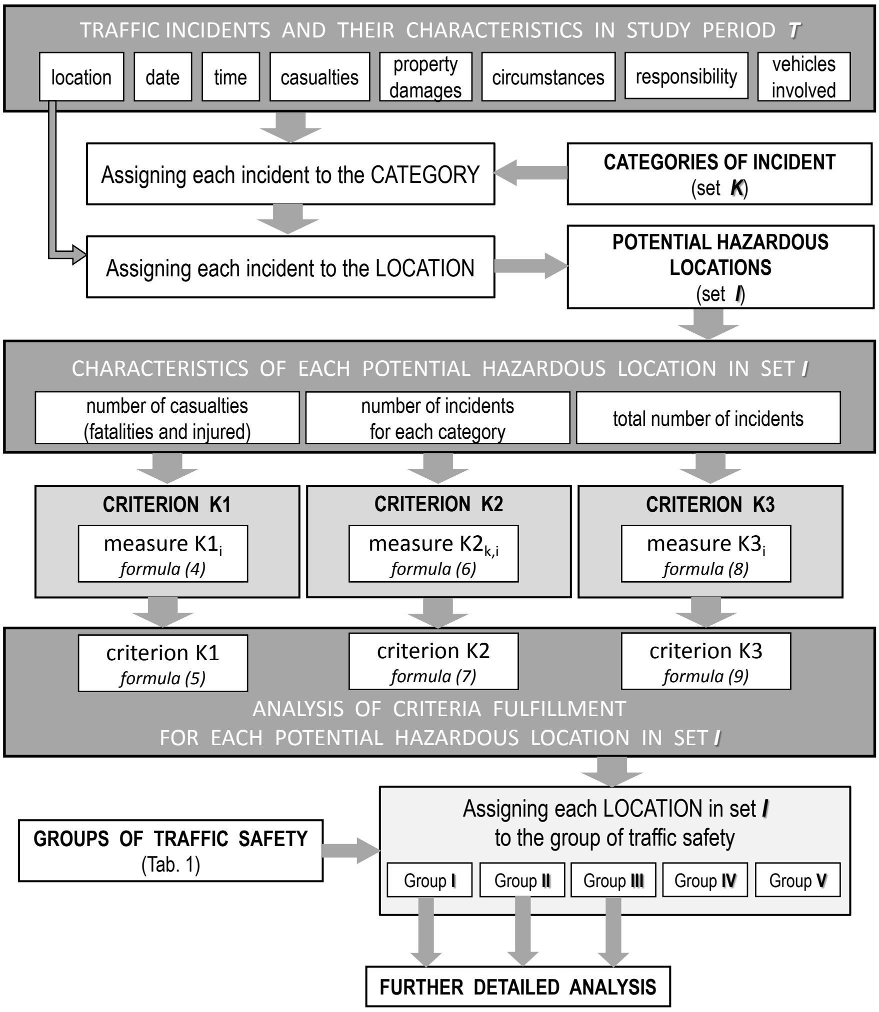

Fig. 2. Scheme for the procedure of the proposed method;
source: own research

Each incident has to be assigned to one of five categories. Subsequently, all locations of an incident should be identified. To each identified location, the following information should be assigned:

- Number of incidents for each category
- Number of casualties (fatalities and injured)
- Total number of incident

The next step is the calculation of the numerical values of measures $K1_i$, $K2_{k,i}$, $K3_i$, according to Formulas (4), (6) and (8). Then, these values are compared with the limit values, using Formulas (5), (7) and (9), in order to check if the analysed criterion is fulfilled. On the basis of fulfilled criteria, all locations are assigned to one of five traffic safety groups. Locations assigned to Groups I, II and III should be subjected to further analysis.

3. ANALYSIS OF DATA FROM TRAMWAJE ŚLĄSKIE S.A.

To present the application of the proposed method, an analysis of the documentation of traffic incidents involving trams, which belong to Tramwaje Śląskie, was conducted. The documentation included information about incidents only with vehicles from Katowice-Zawodzie Tram Depot. Incidents from 2014, 2015 and 2016 have been analysed.

Katowice-Zawodzie Tram Depot is one of four depots currently in operation on the Tramwaje Śląskie S.A. tram network, which consists of [15]:

- 96.2 km of overhead cables
- 102.3 km of tram lines
- 10 traction stations

Currently, almost 100 vehicles are in operation in the analysed depot. They run on 13 tram lines in the cities of the Silesian Agglomeration [15].

3.1. Analysis of documentation

The main sources of information about the incidents were the reports written by tram drivers. They are obligated to prepare such reports after every collision or accident. Such reports include every piece of information that is needed for the proposed method of identifying hazardous road locations. Unfortunately, the location of incidents was not always defined precisely, which led to the necessity of excluding a few incidents from further analysis.

More than 500 occurred during the study period. The incidents that took place at the tram depot, on the tram loops or on sections of the network, which are currently not in operation, were excluded from further analysis. Therefore, 419 traffic incidents were analysed. Out of these 419 incidents, in 391 cases, only vehicles were involved, while, in 28, vehicles and pedestrians were involved. After incidents with an unprecise location were excluded, 370 incidents (in which only vehicles were involved) were chosen for further analysis.

Each incident was assigned to one of five groups of categories of incidents. As it turned out, most incidents were assigned to Group 3, i.e., side collision (over 60%). Group 2 was next, covering minor collisions between two vehicles, which were parallel to each other at the moment of the incident, in which both vehicles were taking part in traffic. The exact numbers are shown in Fig. 3.

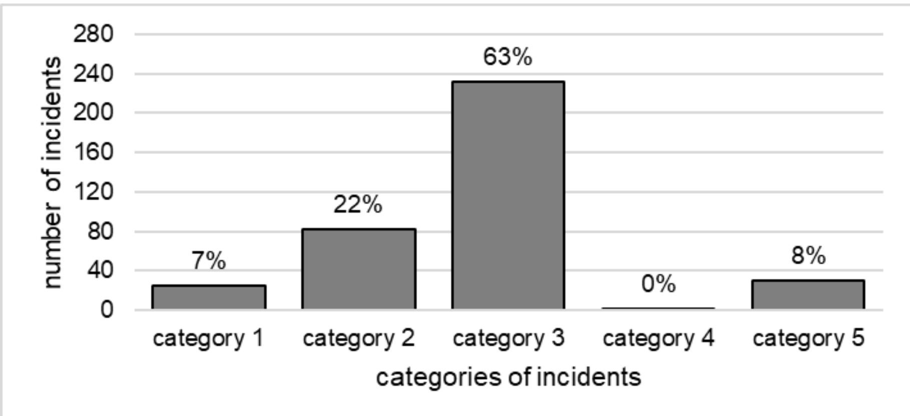

Fig. 3. Accident structure by categories of incidents; source: own research

Once all incidents were assigned to particular locations, it turned out that 370 incidents took place in 176 locations. In 106 locations, only one incident had taken place, while there were five or more incidents in only 16 locations. The structure of the locations in which no more than 10 incidents were recorded is presented in Fig. 4.

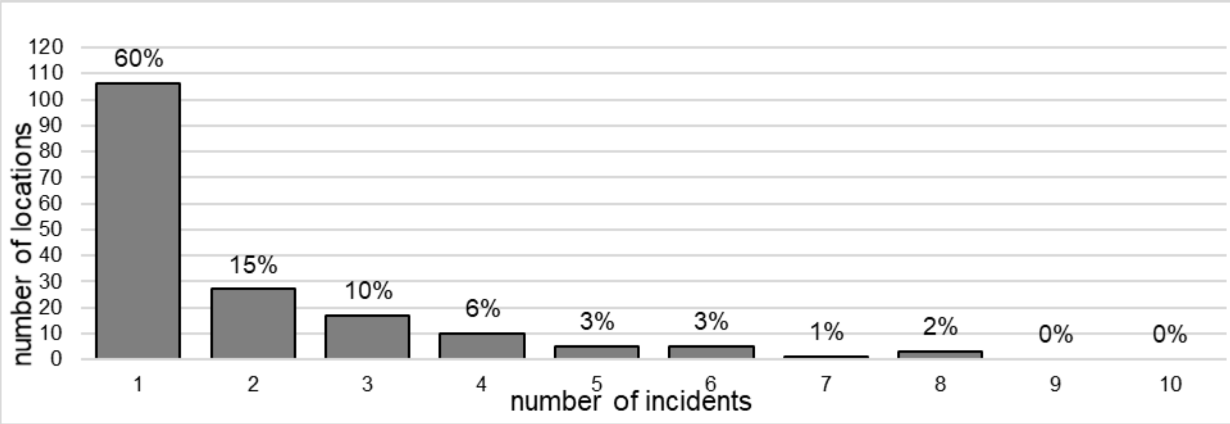

Fig. 4. Location structure by number of incidents; source: own research

3.2. Identifying hazardous road locations

Once all locations were identified, for each location, the values of three measures determined by Formulas (4), (6) and (8) were calculated. For the criterion of homogeneity K2 and the criterion of the number of incidents K3, the limit values ($K1_{\mathrm{lv}}$, $K2_{\mathrm{lv}}$, $K3_{\mathrm{lv}}$) had to be calculated. In the case of the criterion of homogeneity, the limit value was fairly easy to determine; as the study period was three years, the limit value was also 3. In the case of the criterion of the number of incidents, the numerical value of quantile Q_{95} was calculated. Following the appropriate calculation, all limit values were determined to be as follows:

$$K1_{\mathrm{lv}} = 1 \Rightarrow K1_i \geq 1$$

$$K2_{\mathrm{lv}} = 3 \Rightarrow K2_{k,i} \geq 3$$

Once the numerical values of all measures were calculated and compared to their limit values, it turned out that 11 locations, out of 176, at least fulfilled the requirements for Group III. From these 11 locations, only two were assigned to Group II and none to Group I. In Table 3, all hazardous road locations at the intersection of tramlines and road traffic, as identified by the proposed method, are presented.

Tab. 3

Locations identified according to the proposed method

No.	Location	Criterion K1	Criterion K2	Criterion K3
1.	Intersection of Gliwicka Street in Katowice and Gałeczki and Armii Krajowej Streets in	✓	✓	-

No.	Location	Criterion K1	Criterion K2	Criterion K3
	Chorzów			
2.	Entrances to the parking areas for properties 267 and 271 on Gliwicka Street in Katowice	✓	✓	-
3.	Section of road (about 150 m) before Załęże Dwór tram stop	-	✓	✓
4.	Miarki Square in Katowice	-	✓	✓
5.	Intersection of Gliwicka, Grundmanna and Goeppert-Mayer Streets in Katowice	-	✓	✓
6.	Intersection of Starokościelna, Szymanowskiego, Towarowa and Krakowska Streets in Mysłowice	-	✓	✓
7.	Intersection of Chorzowska and Bytomska Streets in Świętochłowice	-	✓	✓
8.	Section of road between Chorzów Batory Train Station and the intersection of Al. Bowid, Armii Krajowej and Inwalidzka Streets in Chorzów	-	✓	✓
9.	Intersection of Gliwicka, Żelazna and Pośpiecha Streets in Katowice	-	✓	✓
10.	General Ziętek Roundabout in Katowice	-	✓	✓
11.	Intersection of Asfaltowa and Chorzowska Streets in Ruda Śląska	-	✓	✓

All locations that were identified as hazardous road locations were objects of further and more detailed analysis, in order to identify reasons, why these locations are of particular risk. They are presented on the fragment of a map of the Silesian Agglomeration (Fig. 5). Red lines represent the current tram network in this agglomeration, which is operated by analysed depot.

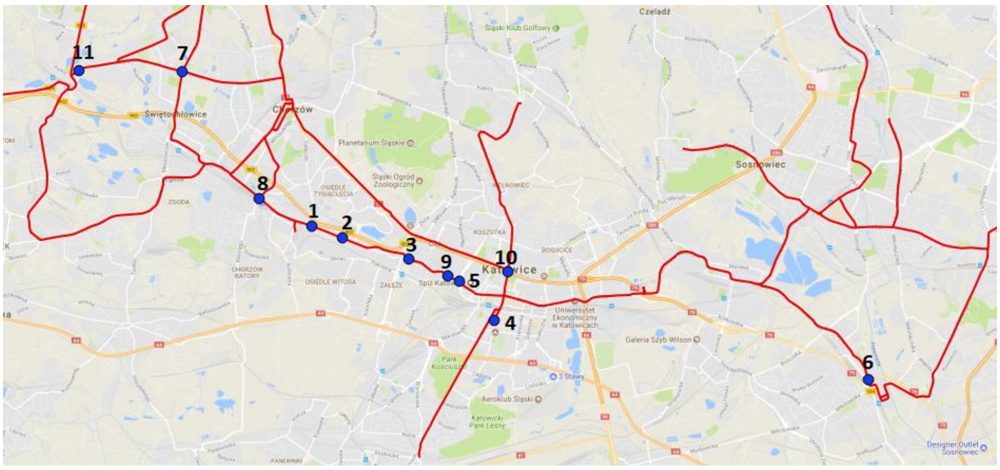

Fig. 5. Hazardous road locations at the intersection of tramlines and road traffic, as identified by the proposed method;
source: own research

4. CONCLUSIONS

The main goal of this paper was to propose a method for the identification of hazardous road locations at the intersection of tramlines and road traffic. The proposed method includes different aspects of risk, thus allowing the problem of safety at the intersections of tramlines and road traffic to be considered from various points of view.

Nevertheless, the safety aspects of tram traffic still need further research. It is still possible to perform a more detailed analysis, i.e., by considering different categories of incidents (the different number of categories as well) or even different criteria, such as the cost of analysed collisions and accidents. That cost may apply not only to property damage, but also to other actions, which must be undertaken when an incident occurs.

An analysis of the documentation concerning incidents on the tram network, as operated by the Katowice-Zawodzie Tram Depot, has been also presented. This allowed us to test the proposed method on actual data. As a result, hazardous road locations at the intersection of tramlines and road traffic have been identified and listed in this paper. In further studies, these locations should be analysed in detail to improve safety. Research should also cover incidents that took place in locations on the tram network operated by other tram depots.

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