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AN OVERVIEW OF TRAM SAFETY IN THE CITY OF ZAGREB

ABSTRACT

About three quarters of total number of traffic accidents in Croatia occur in urban areas. A stable level of safety in public transport is an essential characteristic by which passengers choose which mode of transport to use. To improve results regarding traffic safety, a multidisciplinary approach has a significant role. The aim of this paper is to establish a quantitative and a qualitative analysis of traffic accidents based on several years statistics gathered by „Zagrebački električni tramvaj" (ZET), a public transport operator in Zagreb. Also, based on analysis conducted in this paper, improvements to increase safety of tram transport in the City of Zagreb are suggested. Finally, one of the goals is to encourage further research to improve safety of tram transit network in the City of Zagreb.

Key words: *traffic accident, traffic safety, tram transit, City of Zagreb*

1. INTRODUCTION

Traffic safety is an essential characteristic of every transportation system, especially the public transport as a sustainable passenger transit mode. This is because safety and reliability of public transport should be its top priority, since they result in better performance.

Although traffic safety as a characteristic of a transportation system is highly complex in nature, the most suitable way to describe it, is „a posteriori" – by observing traffic accidents according to their type. Traffic accidents can be analysed in relation to time, number of vehicles or distance, depending upon safety aspect that needs to be pointed out.

About one half of tram transit network in the City of Zagreb is shared by the street network, in which other motorized and non-motorized traffic on the same level occurs. Therefore, traffic safety in the City of Zagreb is continuously influenced by the level of motorization. This is especially true for tram transport.

The goal of this paper is to present methodology for the purpose of analysing traffic accidents in tram transport, based on yearly statistics gathered by offices of public transit operator in the City of Zagreb, "Zagreb Electric Tram" (below: ZET). Statistical monitoring of traffic accidents through long periods of time is a valuable indicator by which traffic accident causes can be recognized, and ultimately actions to eliminate causes of traffic accidents can be taken.

Also, the goal of this paper is to analyse reports of offices of ZET, and to determine causes of traffic accidents in a quantitative and qualitative level. Based on the results, improvements with a purpose of increasing safety in tram transport will be proposed,

encouraging further research in the field of traffic accidents of tram transit network in the City of Zagreb.

2. METHODOLGY

Based on yearly statistical reports of ZET considering level of traffic safety in public passenger transport, the data regarding traffic accidents in tram transit network have been analysed. The research covers the tram transit network in the City of Zagreb over the past ten years. The current state of indicators that influence safety (passenger spaces, vehicle kilometres and the level of motorization) has been analysed based on the collected data. In addition, number of traffic accidents as well as the number of injured people was analysed in an absolute and relative manner, and according to spatial and temporal parameters.

The research performed in this paper used a database provided by Office of supervision and traffic management of ZET, Statistical Yearbook of the City of Zagreb and the Bulletin of road safety of Republic of Croatia.

3. ANALYSIS OF SAFETY IN TRAM TRANSPORT

3.1 SAFETY OF TRAM TRANSPORT IN GENERAL

The tram transit network length of 116.843 m has remained unchanged for the past ten years. The proportion of tram network separated from other traffic (green lanes) is 53%, and the rest of the network (47%) lies directly in the urban street network, in which about 43% is separated from other traffic (yellow lanes). The rest of tram network within urban street network (43%) is shared by other vehicles (white lanes).

Changes of ZET's tram fleet during the past ten years have been accomplished by acquisition of modern low-floor trams which had begun to be used in 2005, and the number of trams has been increasing constantly ever since. This led to the corresponding increase in static capacity (the number of passenger spaces). The inventory number of old vehicles decreased constantly. Therefore, with additional supplies of new low-floor trams further retirements of old trams are expected in the coming years. The renewal of the fleet has significantly increased static capacity of tram fleet in terms of total number of passenger spaces.

However, transport demand, which is characterized by yearly number of passenger trips, is considerably reduced because it has been in continuous decline since 2007. The largest reason for those changes is the increase in passenger car usage which changed the modal split of trips as well as it reduced attractiveness of tram transit (as a consequence of constant decline of operational speed in the network).

By analysing level of motorization in the City of Zagreb (Table 1), an upward trend until 2008 can be noticed, followed by a slight downward trend.

Table 1 - An overview of average number of trams, passenger spaces, vehicle kilometres crossed and level of motorization in Zagreb during the period from 2001 to 2011

	2002.	**2003.**	**2004.**	**2005.**	**2006.**	**2007.**	**2008.**	**2009.**	**2010.**	**2011.**
Motor cars	255	255	255	261	270	273	288	296	**297**	289
Motor trailers	**158**	157	156	149	133	122	114	91	82	77
Passenger spaces	48.804	48.775	48.661	49.282	51.444	53.751	57.620	58.474	58.645	**57.089**
Kilometres travelled,'000	22.727	**22.532**	22.342	22.200	21.010	18.699	17.683	16.776	15.596	14.847
Passengers carried, '000	175.289	180.230	173.298	174.878	176.352	**216.895**	204.543	189.529	177.609	166.772
Level of motorization, vehicles per 1.000 citizens	406	430	450	469	490	508	**525**	516	506	497

Source: [1], [7], [8]

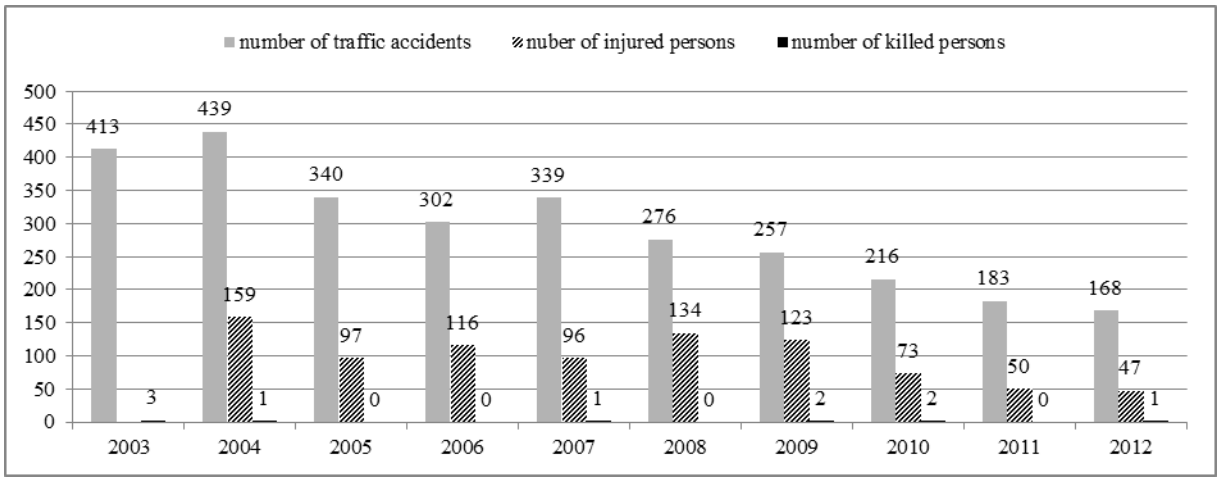

Figure 1 - Absolute number of traffic accidents in tram transit network during the period from 2003 to 2012
Source: [4], data processed by authors

By observing absolute number of traffic accidents in tram transit network for the period from 2003 to 2012 (Figure 1) it can be observed that there is a reduction trend in the number of traffic accidents and people injured in them. Deviations from linearity are considerable in 2007 and 2008, which indicate a possible relation to maximum level of motorization in those periods. The diagram also indicates absence of relation when comparing number of people killed in accidents to number of injured people – such relations require more detailed analysis based on more precise data.

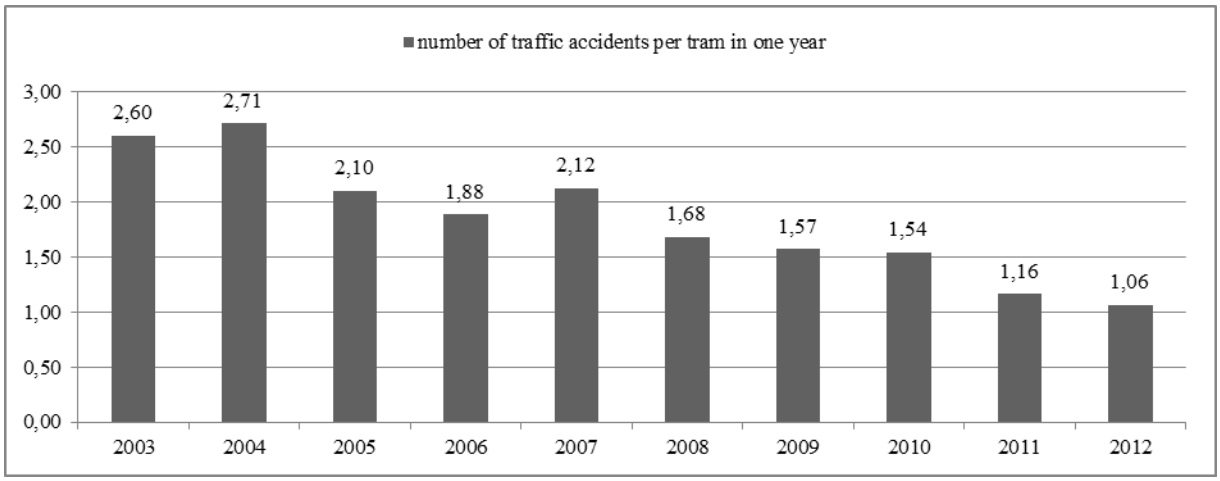

Figure 2 - An overview of relative number of traffic accidents per tram in one year
Source: [4], data processed by authors

Indicators that describe level of safety in tram transit network in higher detail are average number of traffic accidents during a day and average annual number of traffic accidents per one transport unit (one vehicle). Average annual number of traffic accidents per one tram is shown in Figure 2. In tram transit network observed in this paper vehicles cross a total of 34.000 km on a daily basis, and average number of accidents that occur per vehicle every year is 1,06.

By analysing absolute number of traffic accidents according to their type in 2012, accidents with the largest share are collisions of trams with motor vehicles (40%), followed by allisions of trams with motor vehicles (35%) and passengers' fallings inside a tram (11%). Accidents that appear more frequently but less than 10% are tram-pedestrian impacts (6%).

Such values are a natural consequence of traffic flow structure in the road network used by trams in which the number of passenger cars has the biggest share as well as extended pedestrian flows at intersections and in pedestrian zones.

The relative number of traffic accidents (relative to 100.000 km crossed by vehicles) is a quantitative indicator of traffic accidents, and in such manner it describes traffic safety more accurately (Figure 3).[1]

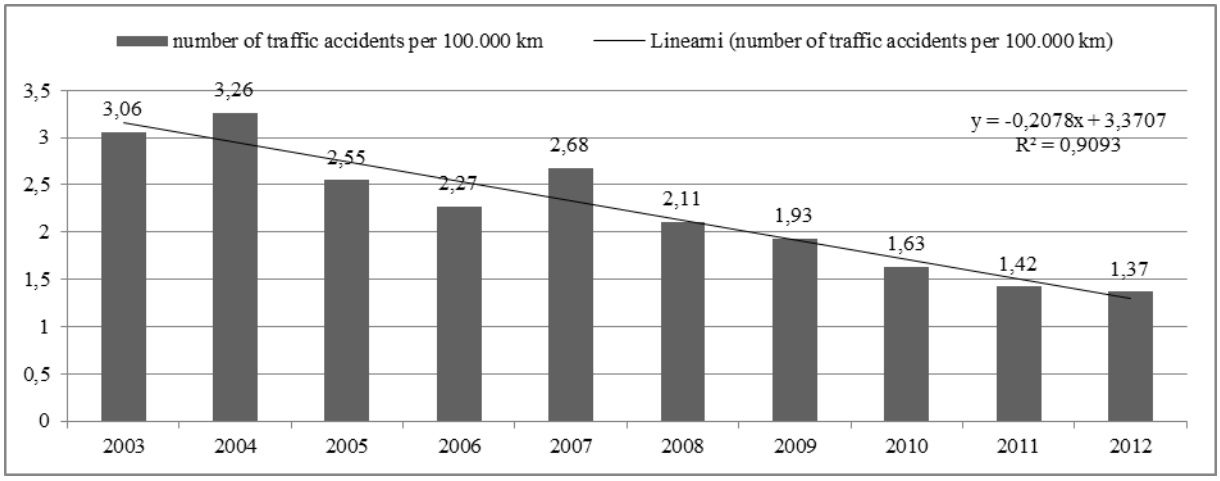

Figure 3. Relative number of traffic accidents per 100.000 kilometres crossed by vehicles for the past ten years
Source: [4], data processed by authors

When compared with Figure 2, Figure 3 shows that changes of absolute and relative number of traffic accidents occur in a similar manner. After conducting the linear regression of relative number of traffic accidents for the period from 2003 to 2012, a significant downward trend (by 0,21 per 100.000 km) can be noticed, with a correlation coefficient of 0,91, indicating a strong correlation between compared quantities.

Therefore, the relative number of traffic accidents is subject to similar changes as the level of motorization in Table 1 indicating that the relative number of traffic accidents depends upon level of motorization in the City of Zagreb. This confirms the following relations: traffic flow intensity is dependent on level of motorization and relative number of traffic accidents is dependent on traffic flow intensity.

3.2 ANALYSIS OF TRAFFIC ACCIDENTS ACCORDING TO SPECIFIC TIME PERIODS

Analysis of traffic accidents according to specific time periods considers the influence of time variable on traffic accidents. The data gathered from ZET were processed for analysis of traffic accidents according to months in a year, days in a week and two-hour intervals during a day. Although the data obtained from ZET had the absolute number of traffic accidents only, time intervals with the similar number of vehicle kilometres can serve for comparison.

In analysis according to months in a year a relatively smallest proportion of traffic accidents occurred in months during the summer (Figure 4). In those months proportion of traffic accidents is smallest because the urban street network recorded smallest traffic volumes of both private cars and trams (which operate under summer timetable). Autumn and winter moths generally recorded highest traffic volumes (of pedestrians, trams and other

[1] The relative number of traffic accidents is the absolute number of traffic accidents divided by the total number of vehicle kilometers crossed, measured in accidents per 100.000 km

motor vehicles) in the city, and as a consequence, the highest proportion of traffic accidents. During the year 2012 the highest proportion of traffic accidents was recorded in November and December, mostly due to negative weather conditions.

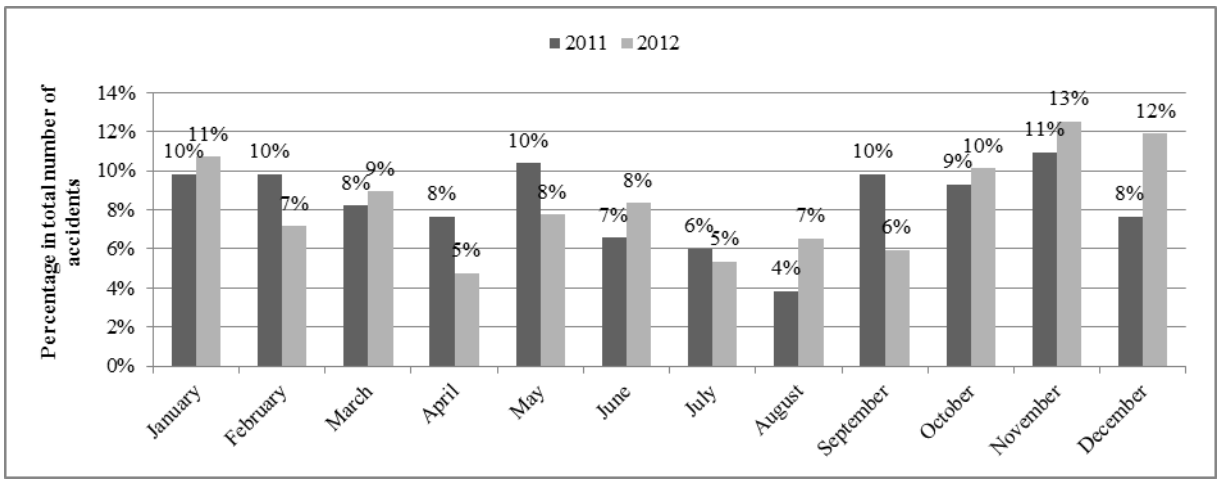

Figure 4 - Percentage of absolute number of traffic accidents, months during a year
Source: [4], data processed by authors

By looking at percentage of traffic accidents by days in a week (Figure 5), relation to traffic volume during workdays and weekends can be observed. Like in most traffic-based systems, the highest percentage of traffic accidents is recorded on Mondays and Fridays. On Mondays, Wednesdays and Fridays deviations from average percentage of traffic accidents during workdays are highest.

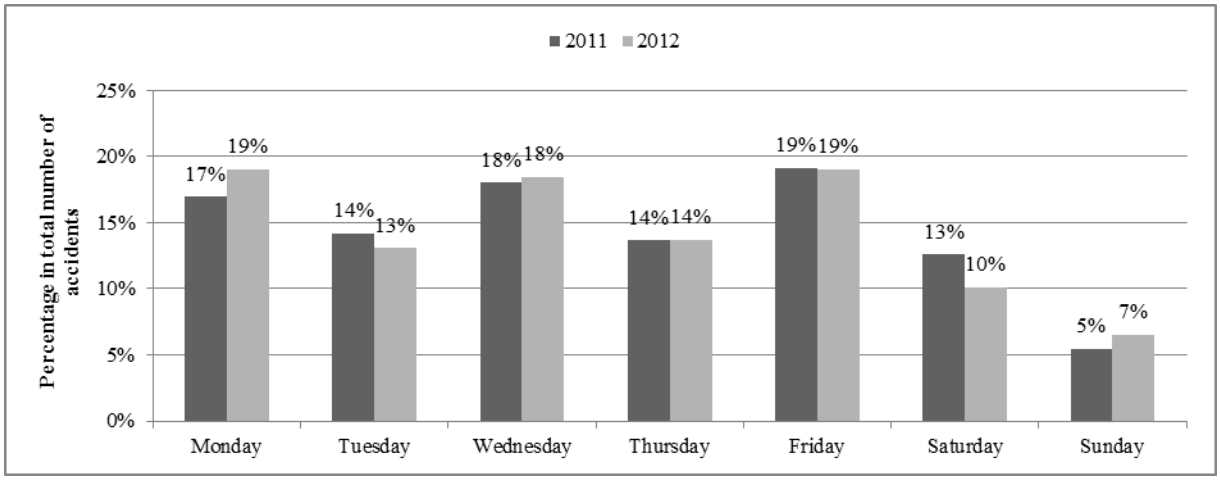

Figure 5 - Percentage of absolute number of traffic accidents, days during a week
Source: [4], data processed by authors

According to reports of ZET, significant oscillations in the number of traffic accidents during a day can be noticed on the urban street network of the City of Zagreb (Figure 6). The highest number of traffic accidents occurs in the morning off-peak hours (08:00 – 12:00) and in the afternoon peak hours (14:00 – 18:00). This kind of traffic accident distribution during a day suggests further and more detailed analysis, because the time periods stated above (especially the morning off-peak hours) don't produce the highest volumes (tram, motor vehicle, passenger, pedestrian).

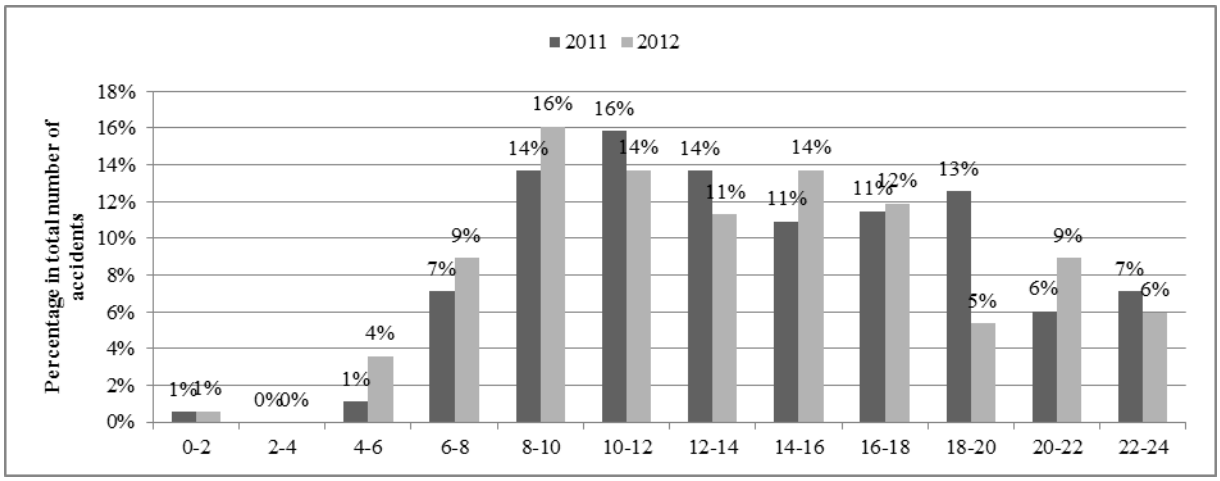

Figure 6 - Percentage of absolute number of traffic accidents, two-hour time intervals during a day
Source: [4], data processed by authors

3.3 SPATIAL ANALYSIS OF TRAFFIC ACCIDENTS

The spatial analysis of traffic accidents includes an overview of places on road network with the highest frequency of traffic accidents and the specific tram transit lines on which traffic accidents occur more frequently. Spatial analysis was conducted for 2012, and the places of interest were road sections, intersections and squares in which 3 or more traffic accidents occurred. The data is shown in Figure 7.

The streets with the highest absolute number of traffic accidents for the observed time period were Ilica and Branimirova street (an average value of 9 accidents per year), followed by Maksimirska street (8), Savska street (6) and Ozaljska street (5 accidents per year). Years of monitoring indicate that the most critical streets in terms of safety are therefore Ilica, Branimirova, Maksimirska and Savska. The safety in tram transport on the mentioned streets is compromised due to high frequencies of tram vehicles, passenger cars and extremely intensive pedestrian flows. Also, the influence of the type of separation is critical – on the mentioned streets tram transit flows are separated by yellow lanes only partially, and compliance to separation of yellow lanes remains questionable.

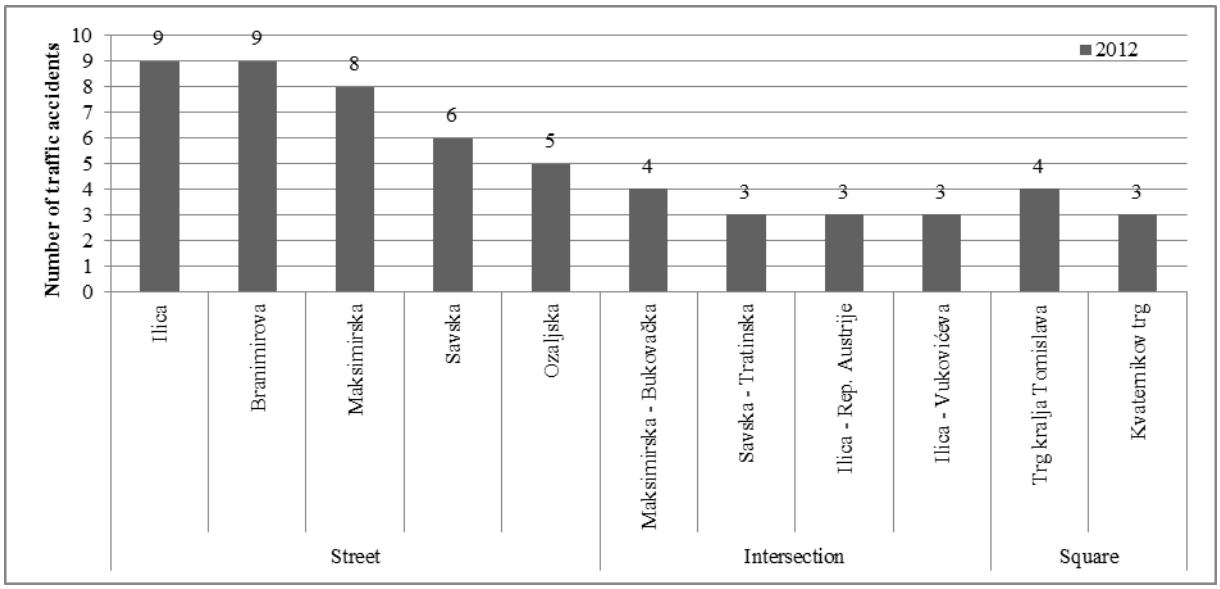

Figure 7 - Absolute number of traffic accidents through various places
Source: [4], data processed by authors

The intersection with the highest number of traffic accidents is Maksimirska-Bukovačka, indicating the need for micro-analysis of the intersection in order to identify the causes of traffic accidents.

Squares with the highest number of traffic accidents are The Square of King Tomislav and The Square of Eugen Kvaternik, which indicates the need for micro-analysis of tram stops.

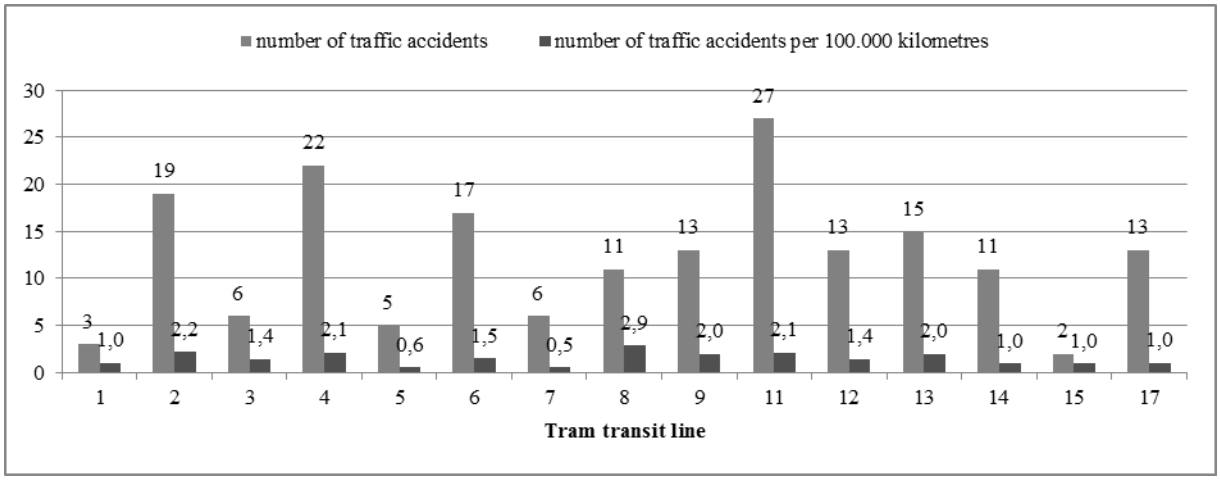

Figure 8 - Absolute and relative number of traffic accidents on each tram transit line, 2012
Source: [4], data processed by authors

Analysis of traffic accidents on each tram transit line in 2012 (Figure 8) shows spatial characteristics on each of those lines. The biggest absolute number of traffic accidents occurs on line 11 (Črnomerec – Dubec), with 27 accidents in a year. However, when observing the relative number of traffic accidents, the most extreme tram transit line is 8 (Mihaljevac – Zapruđe), recording 2,9 accidents every 100.000 km.

The analysis confirmed that 73% of total number of traffic accidents occurs on roads in which tram transit network isn't separated from other traffic. By analysing traffic accidents that took place on yellow lanes, their percentage turned out to be 20% of total number of traffic accidents. If the number of traffic accidents relative to type of separation is divided by total length of tram transit network, probability of traffic accident occurrence becomes 11,5 times greater on non-separated tram tracks (white lanes, yellow lanes) compared to separated tracks (green lanes). If the number of traffic accidents on non-separated tram tracks relative to type of lane (yellow, white) is divided by total length of tram transit network, probability of traffic accident occurrence becomes 2 times greater on white lanes compared to yellow lanes. The results are shown in Figure 9.

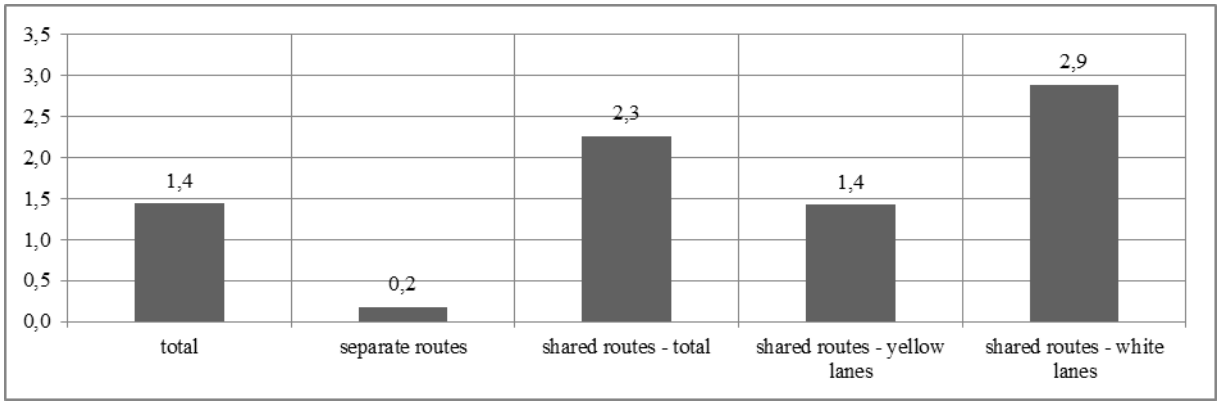

Figure 9 - Number of traffic accidents per km of tram transit network, 2012
Source: [4], data processed by authors

4. DISCUSSION

Analysis of traffic accidents statistics from ZET based on their absolute and relative values had shown a downward trend of their occurrence. Such a decrease in number of traffic accidents is partially caused by decreases in level of motorization but also by decreases in utilized work in tram transit network (Table 1). Number of fatalities fluctuates in the observed period, and without more detailed indicators relations between causes and consequences of traffic accidents can't be established.

When observing traffic accidents according to months in a year, summer months record the lowest number, and winter months record the highest number of traffic accidents. Relative number of traffic accidents (relative to 100.000 km) is proportional to total traffic volume during a day, resulting in the biggest shares of traffic accidents on workdays and lowest on weekends (with peaks on Mondays and Fridays). Frequency of traffic accidents during a day is approximately constant, which is a result of minor fluctuations of traffic flows, with maximum deviation in the morning off-peak hours. Such a distribution of traffic accidents during a day would require further analysis, giving the circumstance that in the mentioned periods (especially 08:00 – 12:00) the volume of motor vehicles, passengers, pedestrians and trams is less intense compared to the morning peak hours. The analysis also confirmed that about three quarters of traffic accidents occur on roadways in which trams are not separated from other traffic. Therefore, it has been proposed to update the existing reports of ZET with the relevant data that describe spatial and temporal characteristics more accurately, and to present the number of traffic accidents as relative and related to driver's business hours at the time of a traffic accident.

The analysis shows that the separation of tram transit network in the City of Zagreb has a positive influence on the level of safety in tram transport. Therefore, it is believed that in addition to physical separation, separation with assistance of horizontal and vertical traffic signalization should be implemented more often (yellow lanes), to assure higher level of safety in tram transport, which was proven by halving the number of traffic accidents on yellow lanes compared to white lanes.

It is also believed that a research about compliance to yellow lane separation should be conducted, in order to relate number of traffic accidents to irregularities on yellow lanes.

One of the limiting factors during the safety level research in tram transit network was the limitation of more detailed data and lack of methodology for its collection and processing. This resulted in insufficiently precise analysis based on derived quantities.

To solve this problem, establishment of geographical database of traffic accidents, which would be an extension of current infrastructure of spatial data (ZG Geoportal)[2] is proposed. Such a traffic accident database could enable systematic and methodical approach when processing the collected data. Entering and processing of data and data analysis would be supported by offices in the City of Zagreb and Zagreb Holding in charge for such operations. The information should be available for general public. Organizational structure (displayed as a block-diagram) proposed in this paper is shown in Figure 10.

[2] ZG Geoportal (Zagreb's infrastructure of spatial data), https://geoportal.zagreb.hr/OGeoportalu.aspx

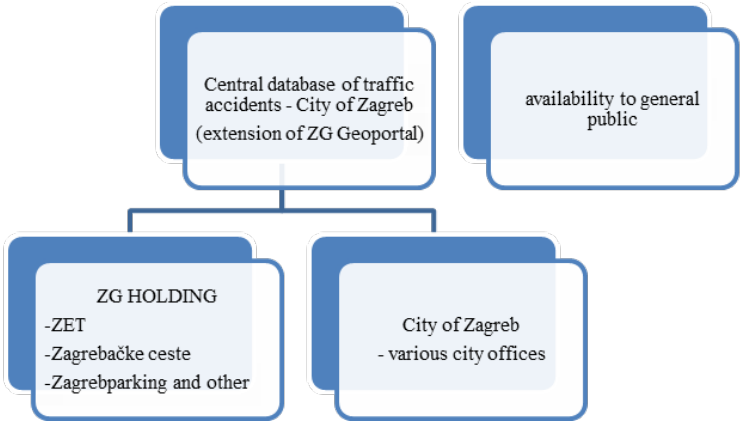

Figure 10 - Proposed GIS database of traffic accidents in the City of Zagreb

5. CONCLUSIONS

A successful effort to improve traffic safety in tram transport should be based on efficient organization at local level. For this purpose it is necessary to synchronize and integrate data related to traffic safety on local scale, and in the end, on regional and national scale (with making data available to general public). For the purpose of traffic accidents analysis in tram transit network in the City of Zagreb, it is necessary to create a traffic accident database based on precise data in GIS (Geographic Information System). Implementation of this strategy would enable a multidisciplinary research that would have the ability to detect causes and eliminate consequences of traffic accidents. Even more detailed study of traffic accident causes accompanied by proposed database would be a sound basis for the detection of traffic accident causality and determination of preconditions to improve safety management in tram traffic in a sense manner, and eventually, in the whole public transport system.

For this purpose, it is necessary to initiate educative and preventive as well as promotional activities which would inform, train and encourage desirable behaviour of general public as a public transport participant.

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