

## CARTOGRAPHIC ROAD RISK ANALYSIS AND HIGH-RISK SPOTS ON CROATIAN ROADS

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### ABSTRACT

This paper compares the indicators of spatial development for the road network of Croatia towards chosen countries in Europe and on a county level in Croatia. It also shows the number of traffic accidents per counties and links it with indicators of spatial development. The paper presents the results of the research of spatial distribution of traffic accidents in Croatia by counties. An example of a hazardous site identification on the A6 motorway is provided by the accident data report. All the comparisons and analyzes are presented graphically in the form of charts and cartography-related views in the MapViewer 7 software. The result shows that there are significant differences between counties. It is often the case that similar values relate to counties derived from similar level of development and similar number of population. From the results it is concluded that the number of traffic accidents is more dependent on the population than on road network length in relation to the surface of the county. To invest in remediation of hazardous sites, it is necessary to consider more factors than repeated traffic accidents.

**Keywords:** traffic, density, road accident, safety, road network, map

### INTRODUCTION

Road traffic is the primary and most developed type of traffic in Croatia. Some of the reasons therefor are the importance of tourism, the country's territorial arrangement as well as the position inside Europe's traffic network. Higher incomes and affordability of motorized vehicles in recent years as well as big investments in motorways have led to higher motorization and to the development of road network in Croatia. One of the unwanted consequences of higher motorization is the increase in the number of traffic accidents. Traffic accidents lead to road injuries and, according to the World Health Organization (WHO) [1], road injuries are the most common death cause for adolescents in the world.

As human life comes first it is necessary to reconsider road safety and the factors we use to define hazardous sites on roads. A European-wide program in this domain is the European Road Assessment Programme (EuroRAP). EuroRAP is producing risk maps which show crash statistics on roads and motorways on a national level [2]. Within the EuroRAP program the A3 motorway was analyzed. In this research we analyzed and displayed the spatial distribution of traffic accidents on the A6 motorway from junction Bosiljevo 2 to junction Kikovica. Furthermore, we tried to identify high-risk spots for this

motorway section. Traffic accidents data used in this research was provided by the Croatian Ministry of the Interior (MUP).

## INDICATORS OF ROAD NETWORK DEVELOPMENT

There are several indicators of road network development like the degree of automobilization (number of cars in comparison to population), the degree of motorization (number of motorized vehicles in comparison to population), and the degree of mobilization (average annual number of rides with one vehicle type per person) [3]. We used quantitative attributes of development – spatial and demographical density.

Spatial and demographical density are indicators of road network development for spatial entities like cities, counties, regions or countries. By comparing them to the number of traffic accidents it is possible to define correlation between the length of road network, the population and the number of traffic accidents. To calculate the spatial density of an area we used the length of road network and the corresponding area [4]:

$$G_p = \frac{D \times 100}{P}, \quad (1)$$

where  $D$  is the road network length in kilometers and  $P$  the area in square kilometers. The value indicates how many kilometers of road network are inside 100 square kilometers. Demographical density of an area is calculated using the length of road network and the number of inhabitants in that area [4]:

$$G_d = \frac{D \times 10000}{S}, \quad (2)$$

where  $D$  is the road network length in kilometers and  $S$  the number of inhabitants. The value indicates how many kilometers of road network are per 10000 inhabitants.

In 2015. Croatia had a spatial density of 47,75. Compared to other selected EU countries, Croatia belongs to less developed countries with a spatial density three times smaller than the average (Fig. 1). Croatia had a demographical density of 63,08 in 2015. (considering the last population census from 2011.) which ranked it on the bottom of the table with values twice as low as the average (Fig. 2).

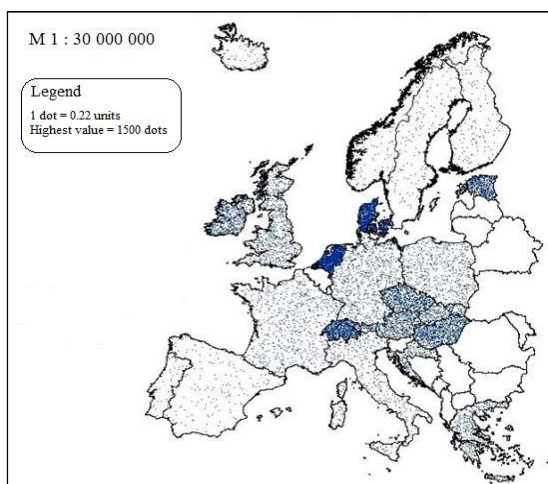


Figure 1. *Spatial density in EU countries*

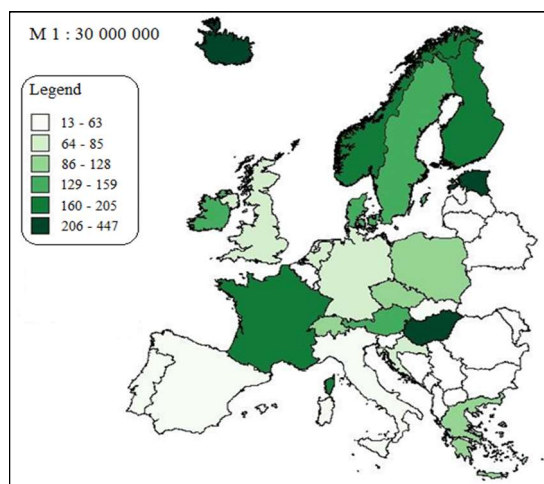


Figure 2. *Demographical density in EU*

Calculation of spatial and demographical density was done on a county level based on data from the 2011 population census and values for length of road network from the Ministry of the sea, transport and infrastructure from 2013 [5]. Varaždin County has the highest spatial density followed by Međimurje and Krapina-Zagorje County (Fig. 3). It is important to note that the city of Zagreb has lower spatial and demographical values, but this is only because 708 km of road network are not classified as public roads since 2012. If we would add those kilometers, the spatial density of Zagreb would be the highest with a value of 121,68. Also, important to add is that data used for creating cartograms of spatial and demographical density refers to public roads so therefore the city of Zagreb must be interpreted with caution (Fig. 3, Fig. 4). All cartographic presentations were created using MapViewer 7 software by Golden Software.

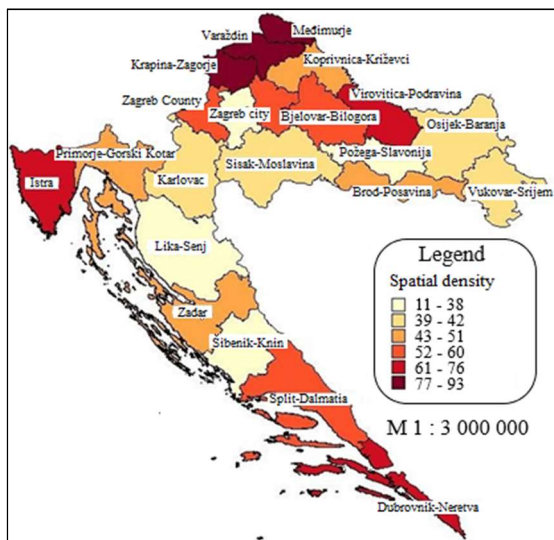


Figure 3. *Spatial density by county*

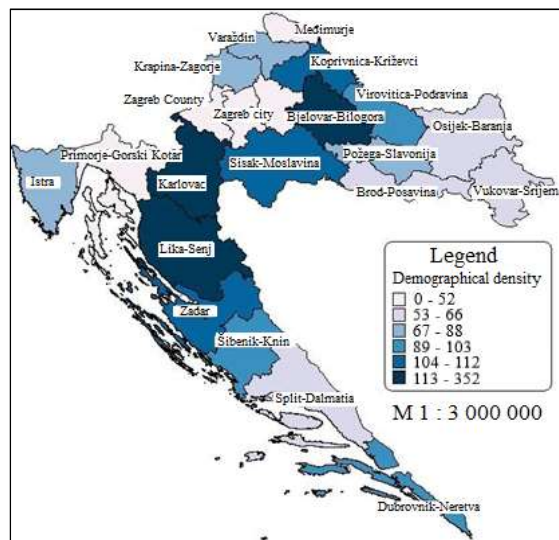


Figure 4. *Demographical density by county*

## TRAFFIC ACCIDENTS IN CROATIA

According to data from the Croatian Ministry of the Interior, most traffic accidents in 2015 occurred in counties with the three biggest cities by population: Zagreb County and the city of Zagreb (both in the same police department), Split-Dalmatia County and Primorje-Rijeka County (Fig. 5, Fig. 6) [6].

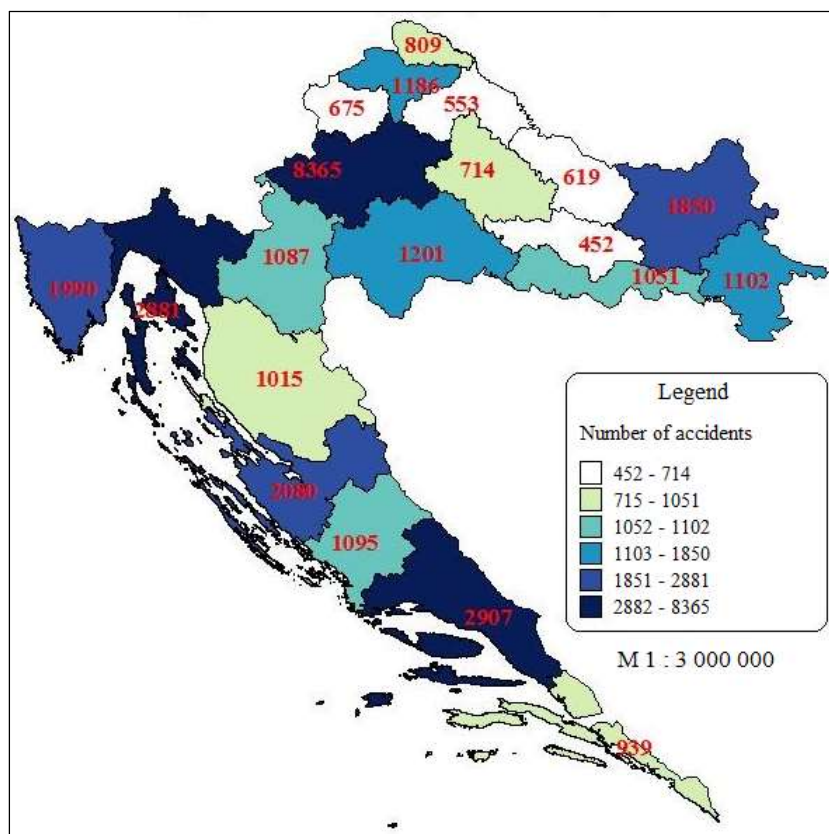


Figure 5. Cartogram of traffic accidents per county in 2015 in Croatia

It is interesting to notice that Požega-Slavonia County has the least number of traffic accidents even though it has the most registered driving licenses (70) per 100 inhabitants [6]. The number of traffic accidents per 1000 inhabitants, drivers and licensed vehicles in this county is also significantly less than the average. In every county there are less traffic accidents per 1000 registered drivers than per 1000 licensed vehicles because there are more registered drivers than licensed vehicles (0,85 licensed vehicles per registered driver).

Table 1. Traffic accidents for counties per inhabitants, drivers and licensed vehicles [6]

County	Number of traffic accidents		
	per 1000 inhabitants	per 1000 drivers	per 1000 licensed vehicles
Zagreb (County and city)	7.6	14.0	17.3
Krapina-Zagorje County	5.1	9.9	11.1
Sisak-Moslavina County	7.0	13.8	17.5
Karlovac County	8.4	15.9	18.1
Varaždin County	6.7	13.0	14.3
Koprivnica-Križevci County	5.4	10.2	10.9
Bjelovar-Bilogora County	6.0	11.5	11.6
Primorje-Gorski Kotar County	9.7	16.0	18.5
Lika-Senj County	19.9	42.8	44.8
Virovitica-Podravina County	6.5	13.0	15.4
Požega-Slavonija County	5.8	8.8	12.2
Brod-Posavina County	6.6	13.1	19.1
Zadar County	12.2	23.6	28.1

Osijek-Baranja County	6.1	12.1	16.4
Šibenik-Knin County	10.0	20.0	22.8
Vukovar-Srijem County	6.1	11.9	18.0
Split-Dalmatia County	6.4	11.9	14.1
Istra County	9.6	14.7	15.3
Dubrovnik-Neretva County	7.7	13.5	15.1
Međimurje County	7.1	12.8	14.9

Lika-Senj County stands out because of the highest rates per 1000 inhabitants, drivers and licensed vehicles (Table 1). This county has also the highest demographical density (Fig. 6) as well as the highest number of licensed vehicles per registered driver (0,96). The assumption can be made that the number of traffic accidents is higher in counties with a higher number of registered drivers, which is confirmed by 8365 accidents in Zagreb County and the city of Zagreb compared to the average of 1629 traffic accidents per county [6]. Although Zagreb leads in the total number of traffic accidents, the number of accidents per inhabitant, per registered driver and per licensed vehicle is lower than the average.

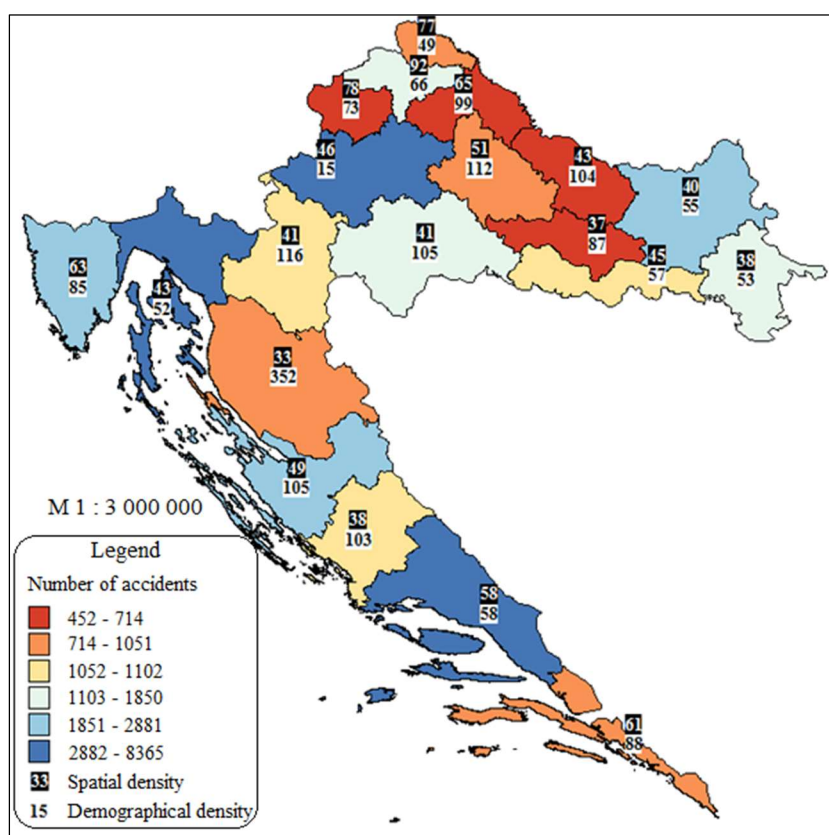


Figure 6. Cartogram of traffic accidents per county with labels showing spatial and demographical density in 2015 in Croatia

## METHODS FOR DEFINING HAZARDOUS SITES ON ROADS

One of the safety aspects of road networks is the identification of hazardous sites. To improve safety on roads it is necessary to identify and remediate spots on roads that are risky or hazardous. The definition of a hazardous spot on a road varies in the international

literature but generally accepted are three definitions: numerical, statistical, based on traffic accident prediction [7].

The accepted methodology for identifying a hazardous site in Croatia defines a hazardous site as part of a road no longer than 300 meters, and a hazardous section as part of a road no longer than 1000 meters, if one of the following requirements is met [7]:

- 12 or more traffic accidents with injured persons occurred on this location in the past three years.
- 15 or more traffic accidents regardless of the consequences were recorded on this location in the past three years.
- 3 or more equivalent traffic accidents occurred on this location in the past three years with the same group of participants, driving in the same direction and on the same conflict surface.

According to these criteria, the identification of a hazardous site depends solely on the number of traffic accidents without the investigation of location characteristics or traffic load. Therefore, it is expected that the number of identified hazardous sites is smaller than it should be. In 2015 a new methodology [7] has been developed by the Faculty of Transport and Traffic sciences in Zagreb, but it has yet to be adopted.

## **IDENTIFICATION OF HIGH-RISK SPOTS ON THE A6 MOTORWAY**

We analyzed a section of the A6 motorway that connects the Croatian inland with the north coast. The section goes through the mountainous region Gorski Kotar and it's not uncommon that part of the motorway is closed in winter because of harsh weather and road conditions. Length of the section is 71,5 km and it has 7 junctions: Bosiljevo 2, Vrbovsko, Ravna gora, Delnice, Vrata, Oštrovica i Kikovica. As per current methodology and traffic accident data, the analyzed motorway section would not have any identified hazardous sites. Therefore, to identify high-risk spots, we took additional data into account such as traffic density, technical characteristics and categorization of road sections, as well as accident location and consequences. This data was gathered from the website of Croatian roads (Hrvatske ceste d.o.o.), from Google Street View and provided by the Croatian Ministry of the Interior. The results of the research are 11 identified high-risk spots along the section (Fig. 7).

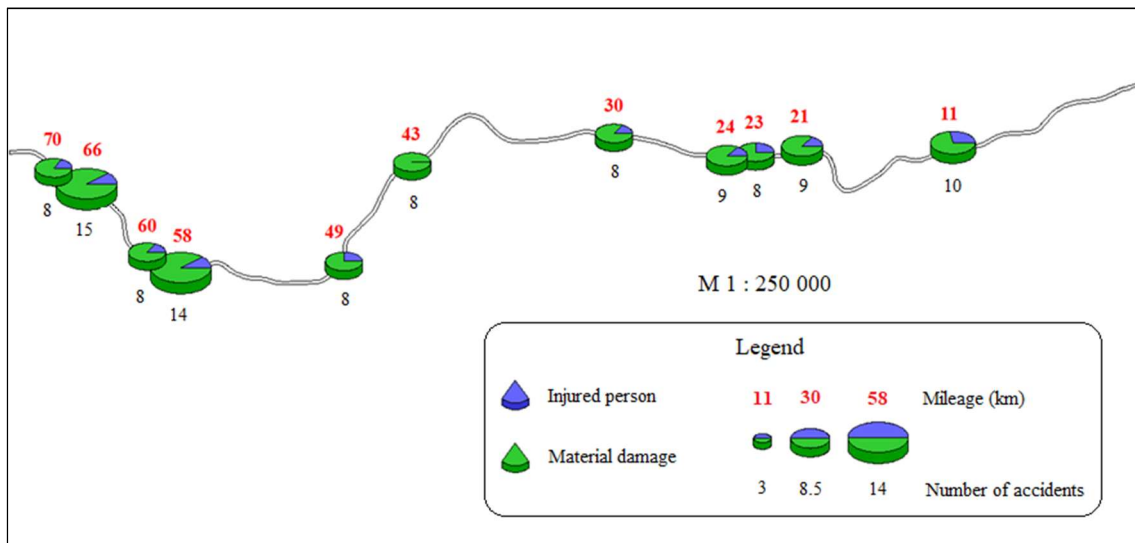


Figure 7. *Spatial distribution of high-risk spots along the analyzed section*

Figure 8 shows an example of the identification of a high-risk spot located on the 66<sup>th</sup> kilometer of the A6 motorway. Some characteristics of this spot are three driving lanes without an emergency lane, no fence between road and environment, speed limit of 100 km/h (too high for frequent strong winds) and a gradient of 4%. On this location 15 accidents occurred between 2012 and 2016 with material damage on vehicle or road.



Figure 8. *Identified high-risk spot on the 66<sup>th</sup> kilometer of the A6 motorway*

## CONCLUSION

This paper shows spatial and demographical density as quantitative indicators of road network development. We have calculated spatial and demographical densities for selected EU countries. Compared to selected EU countries, Croatia has values below average. Furthermore, we have calculated and cartographically represented spatial and demographical densities of counties in Croatia. These values have been linked with the spatial distribution of traffic accidents by county (Fig. 6). Counties with smaller

population and longest road network have higher values for demographical density and show higher correlation with the number of traffic accidents. Higher populated counties, with a higher number of licensed vehicles and drivers, have a smaller demographical density and more traffic accidents. In contrast to demographical density, spatial density has a lower correlation with the number of traffic accidents. We conclude that the number of traffic accidents on a given area depends more on population than on road network length.

With the current method for identifying hazardous sites in Croatia several high-risk spots on roads are not recognized and remediated. By using additional data, we have identified 11 high-risk spots on a section of the A6 motorway. Remediation of hazardous sites on roads with higher traffic load demands that we consider more factors than just repeated traffic accidents.

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