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ROAD AND INTERSECTION ACCIDENTS: LOCALIZATION OF BLACK SPOTS IN OSTRAVA

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Road and intersection accidents: localization of black spots in Ostrava

Traffic accidents are among the most frequently analysed negative aspects of transport, and tend to concentrate in certain locations, or road sections. Tools of spatial analysis applied to localized data on traffic accidents allow a quick location of specific segments and intersections with an above-average incidence of traffic accidents. However, traffic accidents are a specific type of point data mostly due to the limited space in which they occur. For this reason it was necessary to use an adjusted version of the traditional methods for the assessment of their spatial distribution. The paper presents selected approaches for evaluating the spatial distribution of traffic accidents in the Czech Republic for the period 2009 to 2013. Road sections have not been completely analysed, but the network is divided separately for road sections and for intersections. Subsequently, the most problematic road sections and intersections were identified using the City of Ostrava as an example. Traffic accidents are also assessed in relation to the volume of traffic for elimination of causality between the traffic volume and intensity of traffic accidents. The specific segments with increased accident rates without the influence of traffic volume were also identified.

Key words: traffic accident, accident location, black spot, intersection, the city of Ostrava, Czech Republic

INTRODUCTION

Transport of persons and goods continues to grow. The numbers of drivers, cars, trucks and buses are increasing both in the private and public sectors. Between 2009 and 2013, the number of motor vehicles increased by nearly 294,133 (approx. 6.6%) in the Czech Republic (MoT 2013). Along with the increasing number of vehicles there are also an increasing number of roads that serve these vehicles. The Transport Yearbook 2013 issued by the Ministry of Transport (MoT 2013) implies that the estimated number of passengers using individual transport during a year has been oscillating around 2 billion passengers for a long time. This estimate can also be expressed as 0.5 trips by individual transport per person per day. The number of passenger-kilometres is also increasing; it increased by 1.7% (1 billion passenger-km) between 2010 and 2013. Traffic accidents are an integral part of daily mobility resulting in property damage and most importantly major injuries or even deaths of their participants. Despite various efforts to increase the safety of road users there has been a slight increase in the number of registered traffic accidents based on the data provided by the Police of the Czech Republic in 2014 (ŘSDP PP ČR 2014), when there was 84,398 accidents in 2013, which is approximately 9,578 more accidents than in 2009. However, the efforts to improve road safety are evident from the decrease of the number of fatal accidents, with 1,127 fatalities in 2005; 832 fatalities in 2009; and 583 fatalities in 2013 (ŘSDP PP ČR 2014). Nevertheless, this average is still higher than the average in the European Union. In 2010, the number of fatal accidents in the Czech Republic was 76 per million, while it

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was only 55 in the EU but 94 in nearby Slovakia. The global average was 180 fatal accidents in 2010 (WHO 2013).

Traffic accidents are a special case of point data, with spatial aspects that need to be analysed using specific approaches. Traffic accidents do not occur randomly in space but are clustered in specific locations. One of the factors that cause this clustering is the occurrence within a road network. The second factor is the tendency to create clusters within the network (clustering involves many causal factors of social, structural, technical, natural character, etc.). When dealing with the spatial distribution of accidents it is necessary to focus on the fact that most accidents happen in certain sections of the road network. It is reported that 30 – 40% of all accidents happen on 3% of the roads and speeding (in up to 41% cases) greatly affects the occurrence of fatalities (Hrubeš 2010). Other influences include weather conditions, road surface, road conditions, etc. With the availability of detailed data on road accidents it is possible to analyse the incidence and distribution of traffic accidents using local spatial analyses. Thanks to the expansion of the GPS among police units and also among drivers it is becoming more common to be able to obtain exact coordinates of traffic accidents, which greatly simplifies and also specifies their subsequent processing using local spatial methods.

The complex spatial analysis of traffic accidents in the Czech Republic has not been rigorously analysed, and there are very few publications on this topic (see state of the art in the next chapter), although it is very popular in the world. This paper aims to provide analyses of geographical distribution of traffic accidents on the country and city level facing two facts. Firstly, current publications work only with the road network as a whole and analyse an increased concentration of traffic accidents in it. However, it has been proven (i. e. Young et al. 2013) that a very dangerous road network location for the traffic accidents is the intersection. Therefore in this paper, each traffic accident in and near an intersection was separately analysed followed by the analysis of the accidents that happened on the road segments without any influence of the intersection. Secondly, a strong correlation between traffic volume and the incidence of traffic accidents has been confirmed; however, traffic accidents arise not only as a result of a high traffic volume, but also, for example, of the surrounding environment (Kinderyte-Poškiene and Sokolovskij 2008). Additionally, in the last part of this paper, the influence of traffic density was eliminated by standardizing the number of traffic accidents using data on the number of vehicles from the 2010 Traffic Census. Both the traditional methods and the modified methods that are part of the SANET (Spatial Analysis Along Network) extension, which specializes in the study of events occurring at and along the lines (Okabe et al. 2006a and 2006b), were used for the analyses in this paper.

SPATIAL ANALYTICAL METHODS FOR TRAFFIC ACCIDENTS

Spatial analytical methods are a common part of many software applications working with spatial data. However, as already stated, in the accident analyses it is necessary to use modified methods, because of their specific occurrence. Given that the modified methods are based on the conventional methods, it is possible to divide the methods used for evaluation of spatial distribution of accidents into two equal groups – the density and distance methods (O'Sullivan and Unwin 2010). The most common methods used for the assessment of the distribution of traffic accidents are the density methods where the number of accidents per unit area or the length of road network in the given area of an administrative unit is assessed. Standardization based on the population size, or preferably on the number of vehicles is also often used. Concrete examples are the accident and mortality rates standardized by the size of population or number vehicles (Erdogan 2009). Analyses aggregated to higher territorial units, however, are strongly influenced by the MAUP (Modifiable Areal Unit Problem), where the resulting accident rate strongly depends on the division into territorial units and where if another division is used the results may differ significantly (Wong 2009). Another issue when using aggregate data on traffic accidents is also the ecological fallacy that it is more important when the data are more clustered in space, which, in the case of traffic accidents, is quite crucial. Also, in order to target actions to increase road safety and thus to reduce the accident rate, it is not possible to work with data aggregated into territorial units. To eliminate these issues, it is necessary to analyse the data at a lower level, ideally to work directly with individual accident records with specified geographical coordinates.

In the case of point data defining traffic accidents the main objective of the methods is to identify locations with an abnormally high occurrence of the accidents, which are often given names such as crash concentrated, high hazard, hazardous, dangerous, hot spot or black spot sites, while areas with potentially hazardous features are described as grey spots (Geurts and Wets 2003). In terms of density methods, accidents are most commonly processed using the kernel density estimation on the line (Silverman 1986, Erdogan et al. 2008, Okabe et al. 2009 and Okabe and Sugihara 2012). In addition, this method is very often accompanied by other methods of spatial statistics, such as the K-means clustering method (Anderson 2009), and the Moran's I for measuring the local spatial autocorrelation (Flahaut et al. 2003 and Xie and Yan 2013). In the Czech Republic, the resulting applications are derived from available data. Data on accidents at the level of higher administrative units (LAU 1) are freely available in the Public Database of the Czech Statistical Office and in the yearbooks of the Czech Republic Traffic Police (ŘSDP PP ČR 2014). However, they cannot be used to determine precise location of traffic accidents on the road network. Specific occurrences of road accidents are not readily available and this fact corresponds to relatively little interest in the scientific community in the mapping and spatial analysis of traffic accidents. An exception is the work focused on the evaluation of clustering distribution of traffic accidents and the identification of hazardous locations in the South Moravian region using kernel density estimation (Bíl et al. 2013). The authors have extended the classical kernel density estimation method with evaluation of the strength and stability of individual clusters using the data of the Police of the Czech Republic.

The second group of analyses includes distance methods that work with the relative distances of individual accidents. This represents a significant change compared to conventional distance methods since it does not use the Euclidean distance, but examines the road distance to surrounding accidents. Depending on the type of method it uses either distance to the closest accident or to all accidents. These methods are less common in particular due to the unavailability of data and also due to the increasing computational complexity of some of these methods. The K function is frequently used for the analyses of traffic accidents (Ripley 1976), which again is modified from the planar version to the network version (Okabe and

Yamada 2001 and Yamada and Thill 2004). However, there are also indicators localizing clusters of accidents using road distances between accidents where the so-called dangerousness index is used (Steenberghen et al. 2010). Its statistical significance is tested the same way as in most of the above presented examples using the Monte Carlo simulation.

Several web-based applications focus on traffic accidents in the Czech Republic on a large scale. The application called "Accident spots" works with data starting from 2008 and displays using points of the occurrence of accidents, and evaluates individual accident locations. These are created annually by evaluating records of traffic accidents on the basis of the following criteria (InfoBESI 2015): 1) at least three accidents with personal consequences during one year, 2) at least three accidents with personal consequences of the identical type in three years, and 3) at least five accidents of the identical type in one year (Dopravni Info 2015). The second application called "Statistical evaluation of accidents in the map" can only display traffic accident locations using points and additionally can filter traffic accidents according to many parameters (alcohol, health impacts, road number, etc.) based on the Police data (JDVM 2015). The most advanced application is called "Where do we crash" („Kde bouráme") using the KDE+ method (Bíl et al. 2013) and displaying clusters of accidents across the entire Czech road network (highways and regional roads).

DATA SOURCE

The data source used in this paper is the National Traffic Information Centre (NTIC), which is the central technical, technological, operational and organizational facility of the Unified Traffic Information System for the Czech Republic. This facility provides for the collection, processing, evaluation, authorization and authentication of traffic information and traffic data and was founded on November 1, 2005. The processed traffic accidents are recorded for the period from September 1, 2009 through September 30, 2013, and contain a total of 385,506 records from all over the country. Only motorways, highways and roads of the first, second and third class throughout the Czech Republic in the administration of the Roads and Motorway Directorate have been analysed. The records of traffic accidents themselves do not include any other specific information, with the exception of time and spatial location (GPS coordinates).

To compare the completeness of this data source, aggregated numbers on the level of districts (LAU1) and regions (NUTS3) were compared with the data from the Czech Statistical Office, which are supplied by the Police of the Czech Republic. Thus this concerns the traffic accidents required by law to involve the police, meaning those with material damage over 100 thousand CZK (approx. 3,653 EUR), damage to property of third parties, and of course the accidents resulting in injury or death. The total sum of traffic accidents as supplied by the police data is lower by approximately 16,000 records resulting in the NTIC data containing more records. The traffic accident application mentioned above also contains about 65,000 fewer accidents for the tracked period. Differences compared to official police statistics are not constant in the regions. The map below (Fig. 1) shows the ratio of number of accidents based on the Police data and the NTIC data in total for 2010, 2011 and 2012. The green hues indicate the areas where the Police recorded more accidents, whereas the purple defines the areas with more NTIC records. It is apparent that the regions with a higher number of accidents recorded by the NTIC prevail. The biggest difference in the number of accidents is in the Rokycany district (347%). Conversely, the biggest difference in favour of the Police records is in the Most district. One explanation for such differences is probably the inconsistence in delimitation of the territories for which the data are reported by the traffic police and the territories used by the Czech Statistical Office. The difference may also be caused by other sources of information on accidents than the Police records that use the NTIC. However, the data used are localized to a specific place where the accident was reported, are recorded by a state institution and may thus be regarded as correct.

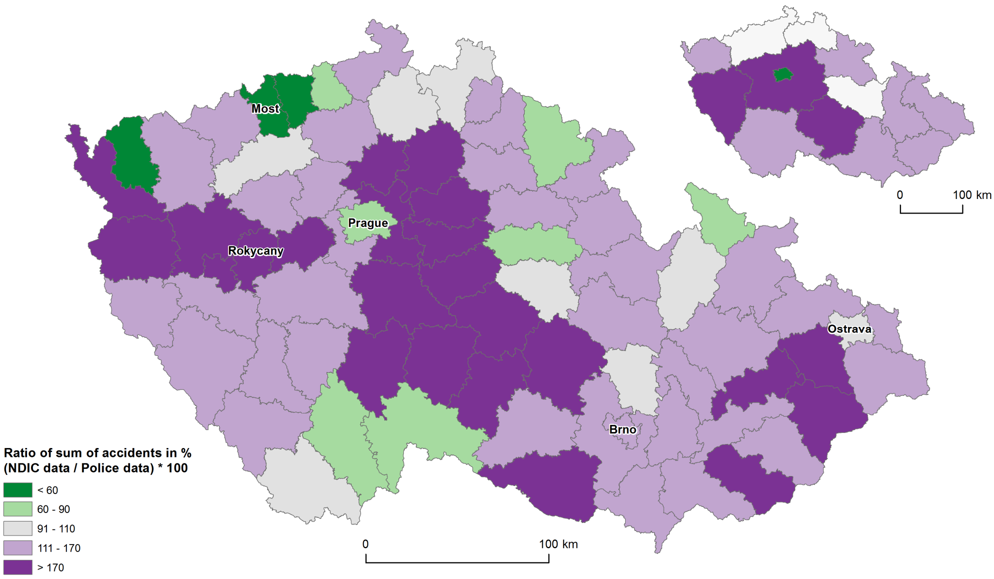

Fig. 1. The ratio of reported accidents in respective regions of the Czech Republic (the sum for the period 2010–2012)

ROAD SEGMENTS WITH HIGH ACCIDENT DENSITY

Critical sections of the road network (black spots) include segments of roads and intersections. As noted above, one innovation is the analysis of accidents on road segments separately without the influence of intersections, into which 14% of all accidents are concentrated. If the accidents caused at intersections were not removed from the analysis, short segments of roads with high rates of traffic accidents would emerge. An accident is considered an intersection accident if it occurs within 50 metres from crossing of the road axes (in the case of the more complicated intersection each level crossing was calculated separately – see Fig. 7 – A). This distance was selected according to the sizes of intersections and according to the occurrence of traffic accidents in the proximity of intersections. A total of 205,816 accidents or 54% of the total located outside the defined zone of intersection influence, account for this part of the analysis.

Division of roads into segments was left to the official division by the Roads and Motorway Directorate (RMD). However, the local lower class roads were not included in the analysis on the national level because these roads are not administered by the RMD. Therefore 125,739 accidents (32.6%) were excluded from the analysis. The following procedure was selected for the correct assignment of an accident to a given road segment. For each line or segment representing the road, a buffer zone of seven metres on either side around the specified segment was created. Any point representing the traffic accident that was located within a buffer zone, was assigned to a given road segment. This ensures that a given segment has been assigned the accidents arising directly on the road, on the shoulder, or inaccurately localized accidents due to low precision of GPS. A buffer zone could not be larger, because then a false assignment of accidents from one segment to another would occur. The resulting value of seven metres was chosen as optimal based on testing both the larger and smaller distances. It was necessary to automatically assign a fixed distance to accidents, especially due to a total of nearly 38,000 road segments (more than 55,000 km).

To assess the segments with high accident density, the data collected for an entire reporting period were selected. All accidents have been assigned to the specified segments and standardized using length of the road segment. The resulting distribution of the relative frequencies of accidents per kilometre of road is considerably left-skewed. On average, during the reporting period of four years there were 3.4 accidents per one kilometre segment of road. Although the maximum value was 321 accidents in the Czech Republic, in the case of segment kilometre-194 of D1 highway, only 38 road segments had more than 100 accidents per one km. The number of segments with a frequency of up to five accidents was more than 30,000, which is a clear indicator of the low accident rate on secondary roads and a high concentration of accidents for the long-term period. 99% of road segments were formed by the segments with a frequency of up to 40 accidents, and 95% of up to 16 accidents. Most of the ten segments with the greatest intensity of traffic accidents are situated on the D1 highway (between Prague and Brno) and R1 expressway (around Prague). These are the segments with the greatest traffic volume of all. This relationship is confirmed by the total intensity of accidents per kilometre of road shown in Fig. 2. The highest intensities are particularly concentrated in the outskirts of large cities and on the busiest roads. High density of traffic accidents is generally not a problem compared to road segments with high individual risk of accident (number of accidents per number of vehicles).

Thanks to the detailed nature of the processed data it is also possible to focus on individual cities and Ostrava has been selected as an example (Fig. 3). In Ostrava, four of the five most critical street segments belong to road I/11 with 118 accidents per km and for most with a frequency above 60 accidents per km of road segment. This road, however, is also among those with the most intense traffic in the entire city (more than 32 thousand vehicles per day on average). These street segments with high accident density relate to high traffic volumes but there are sections of the same road with much smaller accidents per km of road. Therefore, the traffic volume is not the only factor increasing accident risk. This road has two lanes in each direction (except part 4) and there are several intersections (these are filtered out from this analysis). But these critical segments have lower speed limits (50 kph), several traffic lights, and pedestrian crossings. And these disturbances in traffic flow probably have the most significant influence on the resulting traffic accident density. Also the second main road in the west-east direction (II/479) contains three from the ten most problematic segments with even 110 accidents per km and with an average frequency of 67 accidents per km. These three segments are located in the city centre.

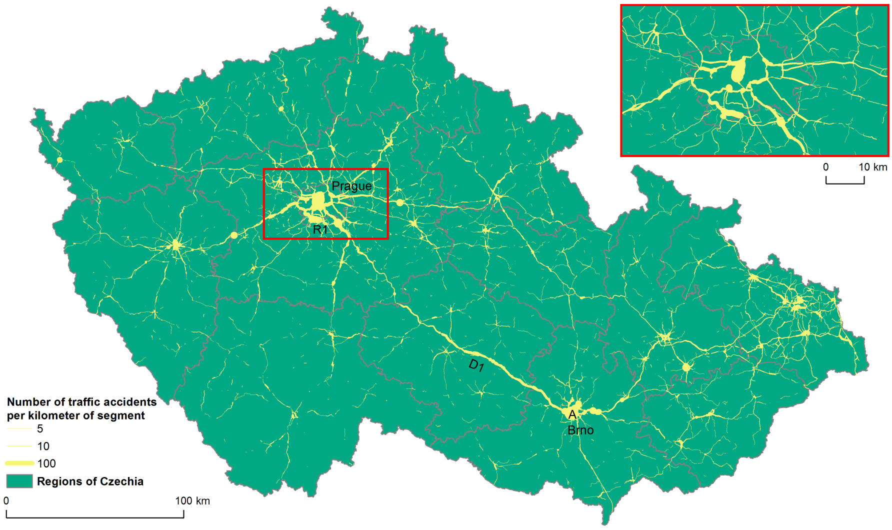

Fig. 2. Road segments in the Czech Republic 9/2009– 9/2013 with high densities of accidents (excluding intersections)

To evaluate the intensity of traffic accidents on road network not relying on a division into segments of varying lengths, the network Kernel Density Estimation (KDE) method is often used (Okabe et al. 2009). This method calculates the density of events in the network and is one of the key tools of spatial analyses for the assessment of clustering points. It is based on the classical planar kernel density estimation, but compared to the Euclidean distance it works with the road distance between individual accidents. The road network is decomposed into equally long segments and the density of points on the individual segments is subsequently calculated. The result defines a local intensity of traffic accidents up to a certain distance from the centre of the segment.

Parameters of the analysis are often determined based on the test evaluations for different parameter values and consequently the final setting is selected. In terms of the setting, a key aspect is the choice of bandwidth, which affects the result far more than the choice of the kernel function and the length of the road segment, which is often called lixel. Lixel (a contraction of the words linear and pixel) can be described as the basic linear unit of equal network length, and related network topology (Xie and Yan 2008). The use of lixel not only facilitates the systematic selection of a set of regularly spaced locations along a network for density estimation, but also makes the practical application of the network KDE feasible by significantly improving the computation efficiency. The kernel density estimation is often applied to a smaller area, and therefore the Ostrava territory was selected again. Compared to the previous results, it is not possible to exclude accidents near intersections, and thus all accidents that occurred during the analysed period enter into the calculation.

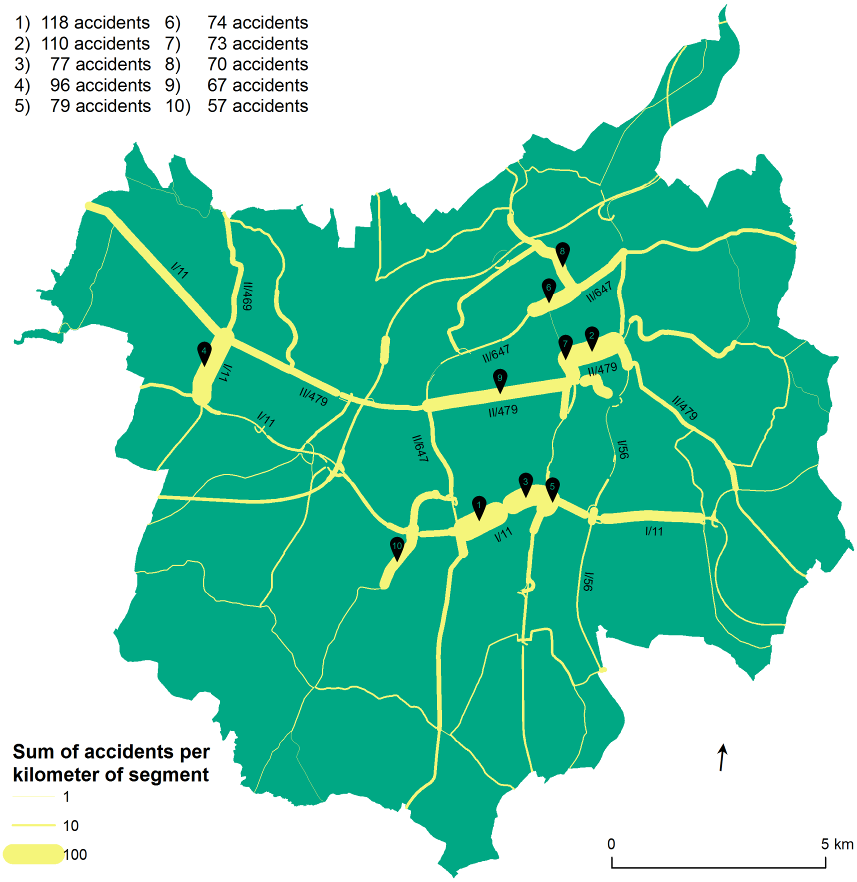

Fig. 3. Road segments with high accident density in Ostrava 9/2009–9/2013 (without intersections)

The bandwidth and cell size were set according to local situation in the city and are similar to distances used in other similar studies dealing with network KDE in urban areas (Tab. 1). Okabe and Sugihara (2012) defined a rule to set the network kernel density estimation parameters: the bandwidth is ten times larger than the cell size. Narrow bandwidths (smaller than 250 metres) produce patterns suitable for displaying local hot spots at smaller scales. With increasing bandwidth, local hot spots are gradually combined with their neighbours creating larger clusters. Results using wider bandwidths give a better sense of hot spots at larger spatial scales. Produit et al. (2010) tested bandwidths wider than 200 metres for the urban areas but results proved that larger bandwidths do not correctly evaluate the real accident level. Xie and Yan (2008) and Borruso (2003) also recommend values around 200 metres for the bandwidths. Borruso (2003) used the same rule for cell size and bandwidth settings as mentioned above. However, the recommended values for the cell size differ from 10 to 25 metres. The larger lixel lengths hide local variations. Finally, road network in Ostrava was divided into 101,206 segments (lixels) 20 metres long and bandwidth was set to 200 metres according to similar studies mentioned in Tab. 1.

Tab. 1. Literature review of bandwidth and cell size used for network KDE

Author	City – city district	Country	Bandwidth (m)	Cell size (m)
Okabe and Sugihara (2012)	Tokyo – Shibuya Ward	Japan	200	20
Xie and Yan (2008)	Kentucky – Bowling Green	USA	100	10
Borruso (2003)	Trieste	Italy	250	25
Produit et al. (2010)	Barcelona	Spain	100	10

Figure 4 shows an overview of the city and its three biggest neighbourhoods. It is evident that most accidents are concentrated near intersections, route exits, and on major roads. Compared to previous result depicted in Fig. 3, a more detailed road network is used including all local roads, and even on these roads the higher accident intensity is visible occasionally. More than 60% of all segments (20-m lixels) have an intensity of traffic accidents lower than 1. The maximum values of the lixel intensity ranged above 36 accidents. These segments correspond to the same segments identified in the analysis of accident rates per kilometre (Fig. 3), however the advantage of this method is the identification of specific locations in greater detail, since the previous method often involved longer segments of road.

The three-dimensional visualization provides observation of "peaks" of the accident rate (Fig. 5). Visualization enables the evaluation of the road network with a high level of detail of an observed accident. Closer examination may propose locations for field survey and situational analysis. Roads in the city centre with a low speed limit and busy traffic at peak times are also a major issue (this phenomenon was observed in most major cities in the country). The increased accident intensity at intersections themselves is also noticeable.

One of the tools working with distances between accidents, which is suitable for determining whether the traffic accidents cluster and if so at what distance, is Global Auto Nearest Neighbour Distance Method. This method corresponds to the *G* function (O'Sullivan and Unwin 2010) and works with the distances to the nearest accident and is thus a simpler form of the mentioned *K* function that works with distances to all accidents and is computational-wise demanding. The frequency of each shortest distance is gradually plotted on a graph, where a rapidly rising curve corresponds to the clustered spatial pattern, while a gradually rising curve corresponds to the dispersed pattern. To determine the statistical significance of the results simulation procedures based on the Monte Carlo method 300 simulations were used. The results (Fig. 6) demonstrate that accidents show a significantly shorter distance between the nearest neighbours and produce statistically significant clusters up to a distance of 30 metres. The spatial distribution is more dispersed in the case of greater distances. This result confirms the significant clustering of road accidents in spatially small areas, such as intersections and short segments of road with high accident intensity that are evident from the figures below (Figs. 4 and 5).

Fig. 4. Network kernel density estimation of traffic accidents on roads in Ostrava 9/2009–9/2013

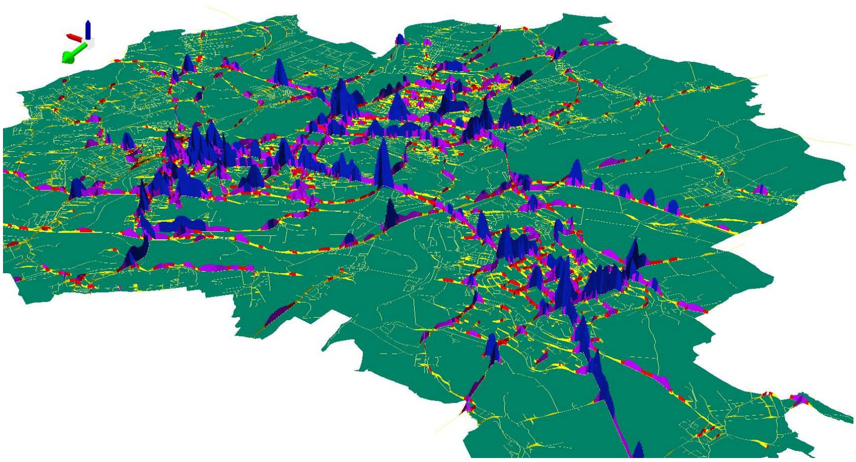

Fig. 5. 3D Visualization of kernel density estimation of traffic accidents in Ostrava 9/2009–9/2013

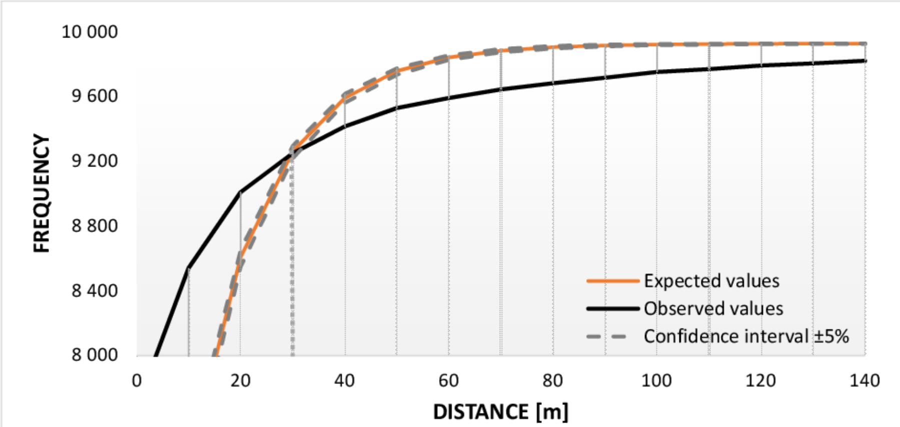

Fig. 6. Nearest neighbour distance between accidents, function for Ostrava

INTERSECTIONS WITH HIGH ACCIDENT INTENSITY

As mentioned above, the intersections were analysed separately from the individual segments of roads. Accidents at intersections occur most often (compared to lane departure and same direction accidents) due to a sight obstruction caused mainly by other vehicles and attention focused inaccurately (focus on a third vehicle). Other factors that have significant influence on accident (all types) occurrence include distractions (negative thoughts/emotions), masked stimuli (glare of sun), and reduced activity (medication) – see Staubach (2009). When analysing the intersections, a more detailed approach is needed and for this reason the area of Ostrava was selected again. Of course, the intersection analyses could be conducted for larger areas, but a smaller area was selected because of the demanding character of processing and clarity of results. Each intersection is of a different size in terms of number of inputs/outputs, number of lanes. They have different lighting and different rules for yielding, various shapes and degrees of complexity. In the Czech Republic roundabouts are popular and some of them are large in both the size and the number of inputs/outputs.

The first step of the analysis of intersections was to define intersections as the places at which the roads cross or meet and at the same time at least two of them are interconnected. Compared to intersections the crossing is a place where the roads intersect in a plain view without being interconnected (Široký 2013). Even the topology of a road network should reflect reality, all crossings and intersections have been manually checked using aerial images so that only real intersections were analysed and the results were not underestimated. The resulting dataset contains all intersections of higher category roads in Ostrava. The intersections of local roads were excluded from the analysis (levels of accidents are very low).

Subsequently, the intersections were merged into larger structural units so that one large roundabout would represent one intersection and not a set of several intersections for each interconnection separately. Similarly, several very close and interconnecting intersections were also merged together. These groups of intersections were formed using the buffer zones around the intersections and the intersection of overlapping buffer zones. Testing of the mutual minimum distances between individual intersections defines the most suitable buffer zone with a radius of 270 metres for the city of Ostrava. The last steps of pre-processing the data consist of manual adjustment and final verification of topological, geometric and factual accuracy. Subsequently, all accidents were joined to particular intersections using two different approaches. In the case of simple intersections a distance up to 50 metres from the centroid of the intersection has been used (Fig. 7 – A and C). In the case where the polygon encloses a group of roads connected to a roundabout or a number of nearby intersections, an equal distance from the edge of the polygon was selected (Fig. 7 – B). In the case of both merged and individually analysed intersections the emphasis was placed on the unique assignment of the accident to the specified intersection.

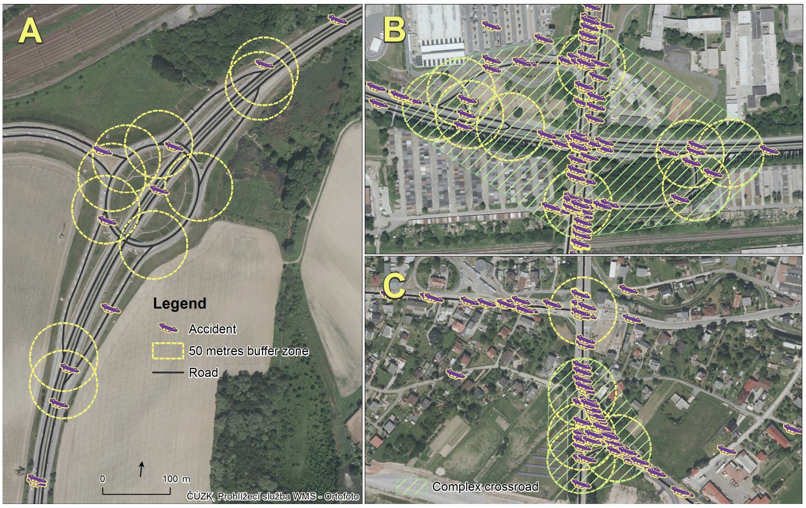

Fig. 7. Identification of accidents at intersections

A – accidents at three intersection; B – accidents at merged intersection; C – accidents at merged and simple intersections

A total of 118 intersections were identified in Ostrava, nevertheless the map shows the intersections with at least one accident (Fig. 8). However, only 10 intersections are without any accident for the analysed period. The average number of accidents per intersection is 15, however, this number is affected by the high number of accidents at the most problematic intersections (the median corresponds to 7 accidents). The overall highest number of recorded accidents corresponds to the results of critical road segments. Ten intersections with the highest accident intensity are located on roads I/11 and II/479 but still there are differences. The first and the second most problematic intersections connect road segments with low numbers of accidents while the other intersections are surrounded by problematic road segments. In the case of the second most problematic intersection, it is caused due to its complicated construction (a multi-level roundabout) where drivers are often confused about who is supposed to give a way.

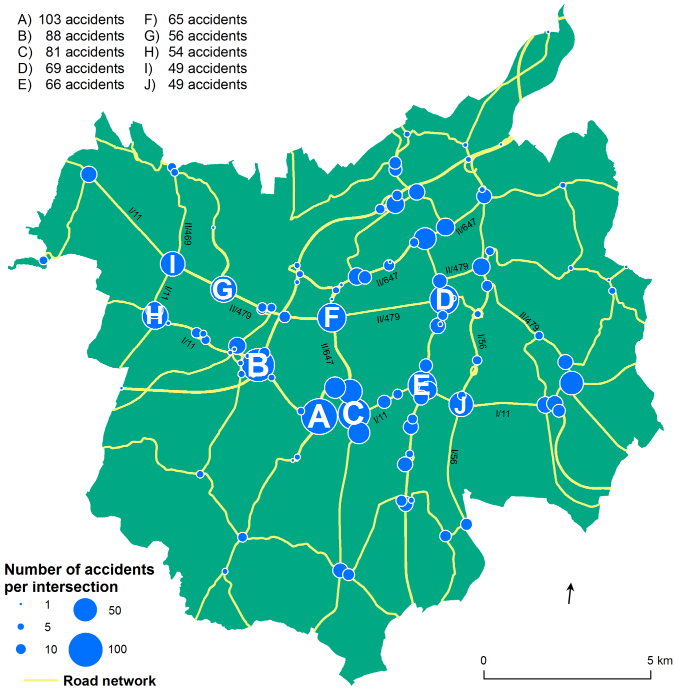

Fig. 8. Intersections with the highest accident intensity in Ostrava 9/2009 – 9/2013 (the letters correspond to the order of intensity)

STANDARDIZED DENSITY OF ACCIDENTS

The fact that with the increasing number of vehicles the number of traffic accidents is increasing has been proved in the case of both the accident on road segments, and the accidents at intersections. To eliminate this effect, it is appropriate to standardize the number of accidents per kilometre using the number of vehicles that will pass through this road segment. The data source used for this standardization was the 2010 Traffic Census that contains annual average daily traffic (AADT) for main roads in the country (highways, expressways and selected first class roads). There is unfortunately no other data source describing traffic intensity on the regional or even national level in higher detail in the Czech Republic. The accident data were standardized by AADT for the city of Ostrava. It was thus determined that the final 24-hour standardized density of accidents (*sda*), which corresponds to

$$sda = \frac{\frac{n}{d}}{AADT} * 1\,000,$$

where $n = \sum_{i=1}^{365} \frac{n_i}{365}$

is the number of accidents per average day during the year and d is the length of the segment. Since *sda* describes a daily situation, the resulting number was multiplied by 1,000. It can be interpreted as the number of traffic accidents that occurred on a kilometre of road segment for the average day per one thousand cars. In other words, it was the density of traffic accidents per 1 km versus the number of passing cars.

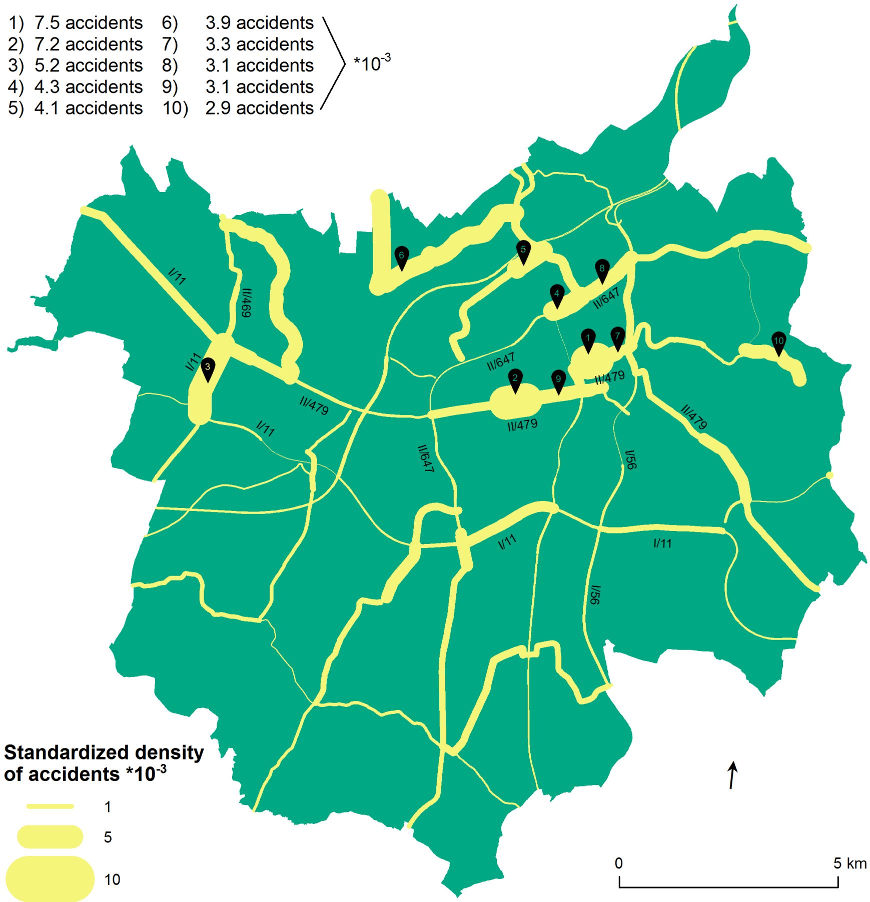

Fig. 9. Standardized density of accidents in Ostrava 9/2009–9/2013

The resulting map (Fig. 9) shows the resulting standardized densities of the accidents. It should be compared with the unstandardized results in Fig. 3. The situation with standardized values differs a lot. While previously five out of the ten most problematic segments were on the road I/11, after standardization there is only one segment that can be called dangerous. This segment is the only part of this busy road with only one line for each way and additionally with a tramway line and many pedestrian crossings. Others are more dangerous, but still not severe, and so the main factor causing accidents is the traffic intensity. The second road with dangerous segments (II/479) is now even more significant with two most dangerous road segments. The traffic conditions here are very similar to those previously described – one line per direction, tramway, pedestrian crossings, traffic lights and all traffic aspects belonging to a city centre. Two segments are completely new and despite the fact that previously there was not a large number of traffic accidents per kilometre, after standardization, these segments rank the sixth and tenth most dangerous road segments. Mainly the street with pin 6 is surprising. It can be described as a local street interconnecting more rural parts of the city with the city centre, and quite often the cause of accident is collision with an animal.

From these results it is obvious that standardization of number of accidents on a road segment is an important step that can evaluate the dangerousness of roads without an influence of traffic intensity. From a list of factors causing accidents, the vehicle factor is eliminated, leaving it to the factors such as the driver, road, and environment.

CONCLUSION

Despite a downward trend in the number of fatal accidents there is still a slightly increasing total number of accidents in general. A trend towards an increasing number of vehicles using roads continues and nobody expects their significant reduction anytime soon. Traffic volume thus remains high and there is an existing need to continuously monitor and analyse the occurrence of accident locations to meet the vision of intelligent mobility. Detailed data on traffic accidents are becoming more accessible but it is necessary to process and properly visualize these data for efficient localization and analysis of black spots. It is useless to display the raw data of particular traffic accidents in a smaller scale because of their high number. Similarly, visualization of aggregated data at a level of higher territorial units is not sufficient, since it is not possible to accurately identify problematic locations in the road network. This paper has introduced the possible methods for the analysis of such data using primarily density methods that separately analyse individual road segments and intersections.

An important element in analysing traffic accidents is the sufficient standardization of the data. The basic level of standardization is to relate the number of accidents to the length of the segment and to calculate the number of accidents per kilometre of road segment. This indicator is useful for comparing accident rates across the area and to alert the public to locations with a high frequency of traffic accidents. The paper deals with the road segments without the accidents in the vicinity of intersections. The most problematic segments of the road network were observed on busy roads through major cities, on motorways and expressways (especially in areas connecting to motorways and exits from cities).

The example of a situation in Ostrava also confirmed a significantly clustering distribution of all accidents to a distance of up to 30 metres. Accidents are thus largely concentrated in small areas. For this reason the accidents at nearby intersections were analysed (a total of 14% of all accidents) and the most problematic intersections were located in the city.

This high frequency is significantly affected by high traffic volume. To eliminate the influence of the number of vehicles on the road segment the Traffic Census data were used. The calculated indicator of standardized density of traffic accidents thus displays the dangerous locations without the influence of the number of passing vehicles. These locations can often be surprising and are often located outside the generally known areas. The road segments that were not considered dangerous according to the previous analyses, and that have an increased accident rate independent of the traffic volume, are observed.

As noted by Geurts and Wets (2003), the stages for a gradual increase of safety on the roads (black spot safety work) consist of three stages: 1) targeting hot spots on the road network; 2) prioritizing hot spots to be treated with safety improvement measures, and 3) before and after studies of the effect of treatment. The proposed analyses are suitable for quick evaluation of traffic accidents for both large and small scales, and for monitoring and analysis of the road safety situation (phase 1). The activities were targeted to increase safety, and a reduction in the number of accidents should follow (phase 2). Further investigation should focus on external influences that can greatly help to specify each road safety step.

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DOPRAVNÉ NEHODY NA CESTNÝCH ÚSEKOCH A NA KRIŽOVATKÁCH: LOKALIZÁCIA KRITICKÝCH MIEST V OSTRAVE

Veľkosť vozového parku, množstvo motorových vozidiel na cestách a počet dopravných nehôd vykazujú trvalý nárast. Napriek tomu, že sa počet smrteľných nehôd znižuje, naďalej je potrebné sledovať a analyzovať dopravnú nehodovosť na cestnej sieti. Predložený článok predstavuje hodnotenie dopravnej nehodovosti s dôrazom na rozdelenie výskytu nehôd na križovatkách a na ostatných úsekoch cestnej siete. Verejná správa disponuje údajmi o konkrétnych výskytoch dopravných nehôd, a tak často používané metódy analyzovania dopravných nehôd na základe ich hustoty mohli byť aplikované namiesto na tradične používaných administratívnych jednotkách priamo na úseky cestnej siete. Takzvaná analýza kritických miest (blackspots analysis) slúži na lokalizovanie úsekov a konkrétnych križovatiek s vysokým výskytom dopravných nehôd. Práve lokalizácia nebezpečných križovatiek a úsekov slúži ako prvá fáza pri zvyšovaní bezpečnosti na cestách (Guerts a Wets 2003).

Zdrojom dát boli záznamy z Národného dopravného informačného centra (NDIC) so sídlom v Ostrave. Celkové počty dopravných nehôd za celé štvorročné obdobie agregované na úroveň okresov prevyšujú počty nehôd podľa výsledkov Polície ČR, čo je pravdepodobne spôsobené inou organizačnou štruktúrou vykazovania dát a tiež ďalšími zdrojmi informácií v prípade NDIC. Všetky nehody boli rozdelené na tie, ku ktorým došlo na križovatkách, a ostatné. Tieto ostatné nehody boli priradené k jednotlivým úsekom cestnej siete rozšíreným o nárazníkovú zónu sedem metrov. Podobne, ako v prípade agregovania dát na administratívne jednotky, bolo potrebné aj získané dáta o dopravnej nehodovosti štandardizovať. Na túto štandardizáciu sa využila dĺžka segmentov siete diaľnic, rýchlostných ciest a ciest I., II a III. triedy. Nehody na miestnych komunikáciách (32,6 % z celkového počtu 385 506 nehôd) sa z analýzy vylúčili. Takto upravené dáta boli následne vizualizované, čo umožnilo identifikáciu najkritickejších miest v Českej republike s dôrazom na Ostravu. Priemerne vychádzajú za sledované štvorročné obdobie 3,4 nehôd na kilometer komunikácie, čo je výrazne ovplyvnené vzdialenými maximami (až 321).

Pri hodnotení nehodovosti bola taktiež využitá metóda jadrového vyhladzovania na línii, a to opäť na príklade Ostravy, kde bola celá cestná sieť rozdelená na identické lixely, pre ktoré sa počítala intenzita nehodovosti.

Vo všeobecnosti z dát vychádza, že nehody majú tendenciu zhlukovať sa do vzdialenosti 30 m, čo jasne naznačuje tendenciu vytvárať lokálne zhluky, ktoré sú často tvorené križovatkami. Tieto nehody boli preto hodnotené zvlášť. Za nehodu na križovatke bola považovaná každá do vzdialenosti 50 m od centroidu križovatky (14 % z celkového počtu dopravných nehôd). V prípade komplikovanejších križovatiek boli jednotlivé ich časti spojené do komplexného celku a hodnotené spoločne. Takto boli lokalizované križovatky s najvyšším počtom nehôd v Ostrave a výsledky boli tiež porovnané s nehodovosťou na úsekoch, ktoré ich spájajú.

Nehodovosť výrazne ovplyvňuje aj intenzita premávky motorových vozidiel na jednotlivých úsekoch ciest. Tento vplyv bol na príklade Ostravy eliminovaný pomocou dát zo sčítania dopravy, ktoré obsahuje ročné priemery denných intenzít dopravy vozidiel za 24 hodín. Výsledné hodnoty a lokality boli porovnané s predchádzajúcimi výsledkami a poukázalo sa na významné rozdiely vo výsledkoch. Ako najproblematickejšie úseky už neboli označené hlavné cestné ťahy v meste, ale často cesty v centre mesta, s vysokým výskytom križovatiek a električkových pásov. Lokalizované však boli aj cesty na okraji mesta, ktoré v predchádzajúcich výskum spadali do skupiny bezpečnejších komunikácií.