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Traffic risk generated by large urban commercial centers

Serban Raicu [a], Dorinela Costescu [a,*], Raluca Raicu [b], Mihaela Popa [a]

[a] *University "Politehnica" of Bucharest, Splaiul Independentei 313, Bucharest 060042, Romania*
[b] *University of South Australia, City East Campus, North Terrace, Adelaide SA 5000, Australia*

Abstract

As a consequence of development policies urban areas are substantially different in terms of road traffic risk. The shape, size and configuration of urban areas, the transport supply to meet people and goods mobility needs, as well as human behavior have huge influence on the road traffic volume and pattern and, hence, on the associated road crash risk. In this context, the paper reveals the effects of locating large shopping centers in the central areas of the city on the already over-congested road network. We use specific spatial analysis models in order to estimate vehicle and customers flows, attracted by one of the largest shopping malls in Bucharest. This approach gives theoretical and practical added value to the study: providing analysis tools to local decision makers for the ex-ante assessment of the consequences of locating large malls, in terms of traffic flow and associated crash risk.

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Keywords: Commercial centers location; traffic safety; crash risk; GIS modeling

1. Introduction

Amongst the concerns regarding the negative local and global urban traffic externalities, road crash risk has an increasingly central role. In order to accomplish the sustainable mobility requirements, analyses should be extended upstream of transport. More precisely, the interactions between land use, urban planning and transport need to be examined. Urban shape, size and structure decisively impact on the characterization of people and freight mobility needs. Satisfying these mobility needs leads invariably to the emergence of specific traffic flows.

* Corresponding author. Tel.: +40-21-40-29-547; fax: +40-21-318-101.
E-mail address: dorinela.costescu@upb.ro

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The rapid and radical changes of socio-economic life in Bucharest (major changes in urban commerce structure caused by the emergence of large commercial centers, new concentration of urban and suburban residential areas, spatial and structural changes to places of interest - for work, education, leisure, etc.) have led to changes in the size and structure of urban traffic flow in the last two decades. In an urban environment with an inadequate road network to accommodate increasing traffic flows and new motorization indices, coupled with large arterial areas occupied by parked vehicles, traffic congestion has increased. The flow-on effect is an increase in the number of crashes and their severity.

From our research study aiming to analyze the urban areas with high crash risk, we have selected for the purpose of this paper several aspects concerning "vulnerable zones with high injury risk". The large commercial and recreational spaces, which are located inside these areas with high density population (Fig. 1), generate and attract significant vehicle and pedestrian flows.

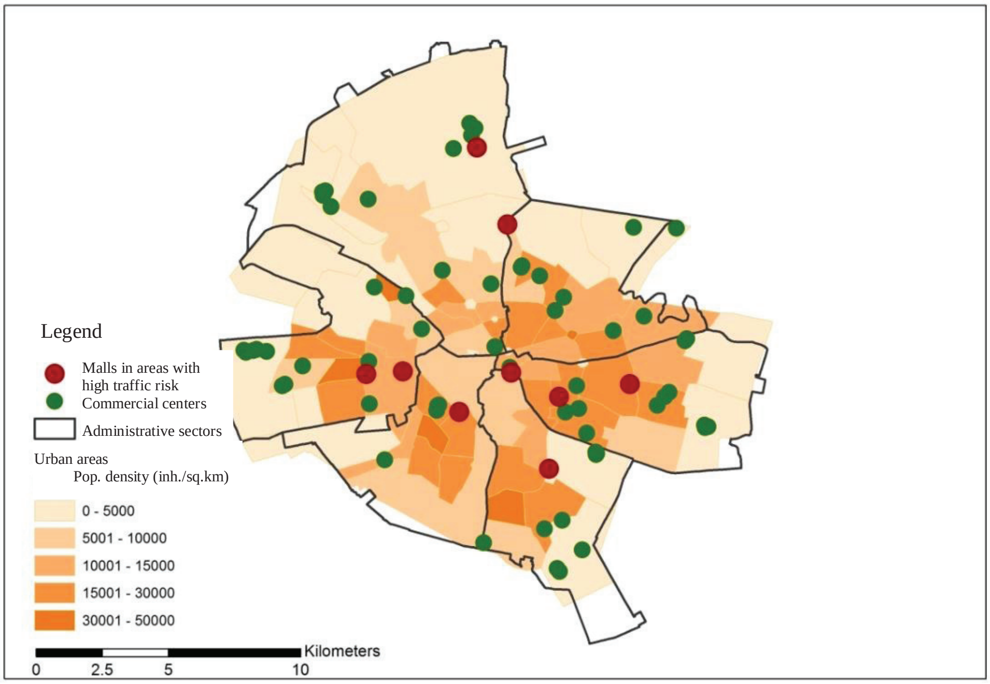

Fig. 1. Location of large commercial centers in Bucharest.

The supply needs of these large commercial centers produce important freight traffic. Overall, at the level of metropolitan Bucharest, about one million movements of freight vehicles are recorded weekly, of which 600,000 loaded, corresponding to an annual volume of about 14 million tons of freight. Urban freight distribution generates about 15-20 % of daily traffic expressed in physical units (Bucharest General Master Plan of Transport, 2008). Obviously, the level of traffic generated and attracted by large commercial centers is not the only contributing factor for road crash risk.

The road crash data analysis reveals multiple interactions specific to geographical urban zones. From a phenomenological point of view, the urban area is modeled as a complex system, where different levels of analysis are required, both synthetic and analytical. The traffic risk derives from the following classes of input features:

- *Object class* - defines the different types of elements which impact on risk, such as mobile entities (vehicles, cyclists, pedestrians, etc.) or elements of the technical and road urban infrastructure.
- *Actor class* - defines different groups or organizations that could influence the system; this category may include urban authorities, urban networks management, other associations, community.

- *Spatial structure class* - describes the topological configuration of the various elements and phenomena related to risk.
- *Temporal structure class* - defines time/location of the system entities, phases of activity / inactivity, intensity of daily / seasonal movement etc.

During the last two decades, all the above classes have experienced drastic changes in Bucharest. Due to increased mobility, the relative attractiveness of the interest places - conditioned by accessibility - has been fundamentally redistributed. The attractiveness of certain commercial centers could exceed 50 km when the access time is approximately 40 minutes (Beauvais Consultants, 2003). Thus, the dimension and heterogeneity of the urban road traffic increased, meaning the risk exposure increased. The dynamics of road crashes reveal significant changes too.

2. Spatial dispersion of the large commercial centers

In many studies, the Gini index and several other derived coefficients (Krugman, 1992; Brulhart, 2001; Combes et al. 2008) are used as a measure of the geographical specialization. In our research we choose to calculate the relative entropy h (Wilson, 2010; Wilson, 2012), in order to give a synthetic characterization of the spatial concentration in case of the large commercial centers:

$$h = \frac{H}{H_m} \tag{1}$$

with entropy H, computing as:

$$H = -\sum_{i=1}^{K} f_i \cdot log\, f_i \tag{2}$$

$$f_i = \frac{n_i}{\sum_{i=1}^{K} n_i} \tag{3}$$

and

$$H_{max} = log\, K \tag{4}$$

where f_i is the relative frequency of the commercial centres in a certain zone *i*;
n_i - the number of commercial centres in the zone *i* ($\sum_{i=1}^{K} n_i$ is the total number of commercial centres in the entire area of study);
K - the number of zones.

In our research we have considered 72 centers located in the 80 transport analysis zones (TAZ) defined by the Bucharest General Master Plan of Transport (2008). The results are $H = 4.9$ and $h = 0.8$, which means that there is a significant spatial dispersion of commercial centers. If we consider the spatial distribution of the commercial centers in relation to the total number of inhabitants (Fig. 2) and their purchasing power (Fig. 3), then the spatial dispersion is even more eloquent.

This means the developers took into consideration for their investment decision some other criteria other than the spatial distribution of the population and income. In fact the only criterion used for the location of large commercial centers is land availability. Obviously the principles of the modern urban development consonant with the city logistics principles (McKinnon et al. 2013; Taniguchi et al. 2013; Taniguchi, 2014) are completely ignored.

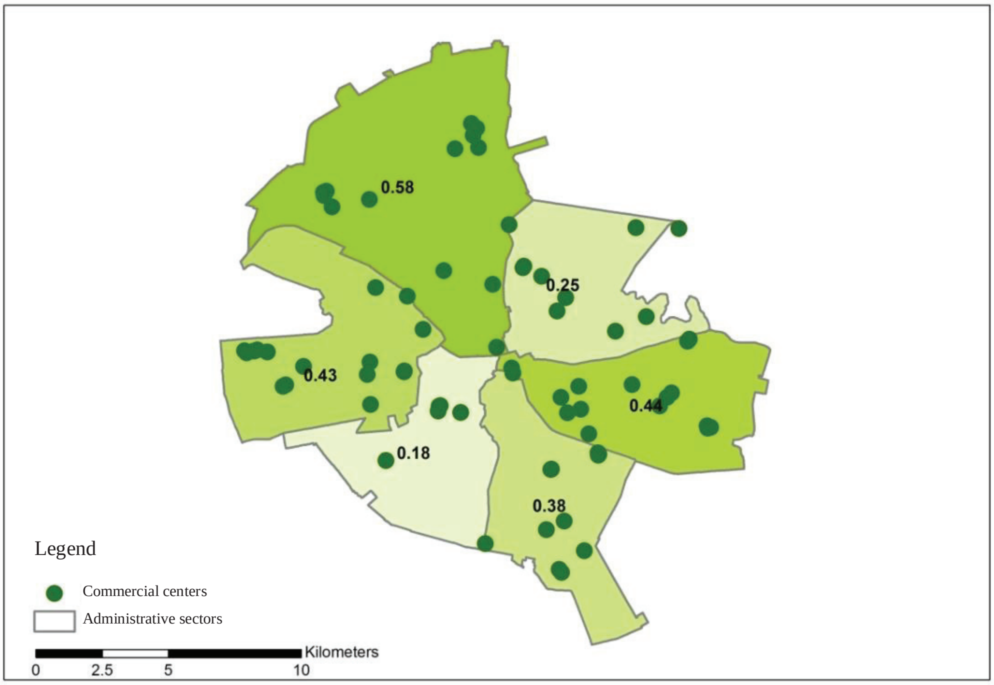

Fig. 2. Spatial distribution of the commercial centers in relation to the population of the six administrative sectors of Bucharest (No. of commercial centers/10,000 inhbs.).

3. Catchment area of the large commercial centers

The risk assessment in case of urban road traffic supposes traffic flow estimations. In our study, from the 72 large commercial centers (Fig. 1) we selected nine shopping malls with similar functionalities (Fig. 4). From the traffic flows surveys performed for the nine selected centers, we have data for the entering flows (cars, pedestrians, light freight vehicles). The origins of the light freight trucks for direct and reverse logistics are known, but the origins of the customers/visitors (cars and pedestrians) need to be estimated.

For this, we started with defining the attractiveness zone (meaning catchment area or trade area) for one of the selected shopping malls by applying the Converse model – the extended Reilly's Law (Goodall and Kirby, 1979; Ingram, 1982). According to this model, the definition of the catchment area between two shopping centers, denoted with *A* and *B*, located at distance d_{ab} and having the attractiveness potentials P_A, respectively, P_B (expressed by area, parking spaces, etc.) is determined by the following equation: where *x* is the trade breaking-point (the point having the equal attractiveness in relation to both malls or having equal probability of shopping at each of the two commercial centers) which is situated at distances d_{xA} from the mall *A*, respectively d_{xB} from the mall B:

$$\frac{P_B}{P_A} = \left(\frac{d_{xA}}{d_{xB}}\right)^2 \tag{5}$$

where *x* is the trade breaking-point (the point having the equal attractiveness in relation to both malls or having equal probability of shopping at each of the two commercial centers) which is situated at distances d_{xA} from the mall *A*, respectively d_{xB} from the mall *B*.

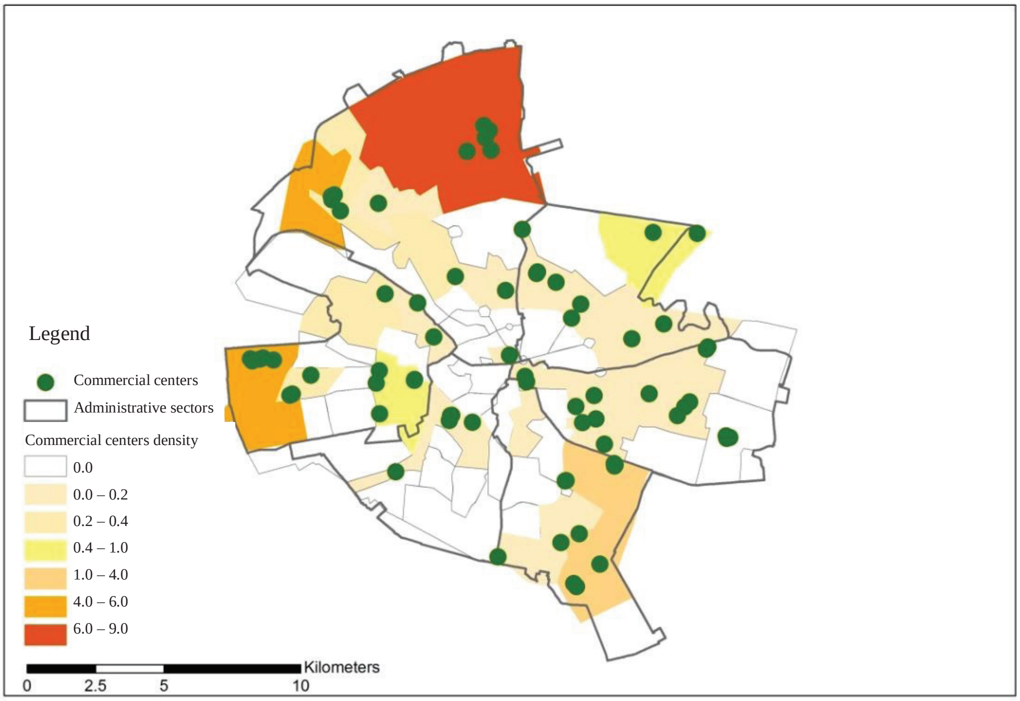

Fig. 3. Spatial distribution of commercial centres in relation to population density and monthly income (No. of malls/1,000 inhbs. income in Euro/month).

Hence, considering shopping mall *A*, the trade breaking-point is located at:

$$d_{xA} = \frac{d_{AB}}{1+\sqrt{\frac{P_B}{P_A}}}. \quad (6)$$

We applied the Converse model for a shopping mall located in a high crash risk area, denoted with *S* in Table 1, and other eight malls having similar features (*M1÷M8*). The distances between each pair of malls *S – Mi* (*i = 1 ÷ 8*) are determined on the urban road network. Then, the trade breaking point distances are computed in two cases: considering the attractiveness potentials expressed by (*i*) parking capacity and (*ii*) commercial area (Table 1). Fig. 4 shows the catchment area of S limited by the trade breaking point distances, computed as a function of parking capacity.

For the selected shopping mall (*S*) and TAZs located in the defined catchment area, we computed the customer flows in relation to population density (Fig. 5). We considered the 0.2 value for shopping frequency and 0.540 for motorization rate (Bucharest General Master Plan of Transport, 2008). Population located at less than 400 m from *S* was entirely allocated to the pedestrian flow.

Table 1. The trade breaking-point distances.

Code	Name	Parking capacit y	Commercial area (sq. m)	No. of shops	Distance between malls $S-Mi$ (m)	Trade breaking point distance $S-x_i$ (m)	
						(i) function of parking capacity	*(ii) function of commercial area*
S	AFI Palace Cotroceni	2500	214000	300			
M1	Plaza Romania	2400	41000	90	1850	934	1287
M2	Sun Plaza	2000	80000	130	7150	3774	4437
M3	Bucuresti Mall	2000	99000	110	7135	3766	4247
M4	Titan Mall	1500	60000	100	9670	5449	6322
M5	Promenada Mall	1300	55000	62	8300	4822	5508
M6	Baneasa Shopping City	1250	450000	200	11670	6836	4763
M7	Unirea Shopping Centre	1000	84000	90	4580	2806	2816
M8	Liberty Centre	700	25000	100	2900	1896	2161

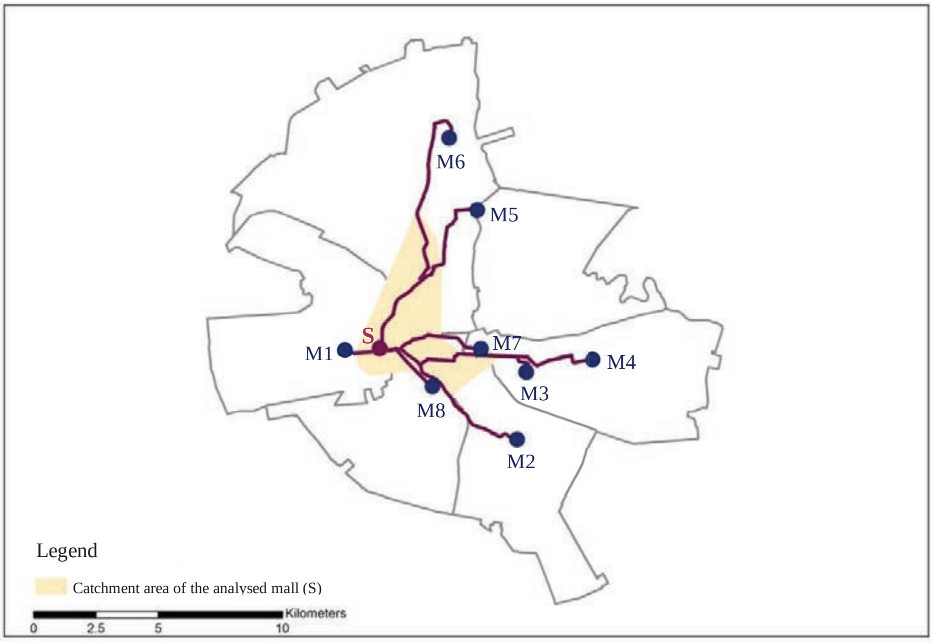

Fig. 4. The catchment area of the analyzed mall, computed in relation to parking capacity.

Fig. 5. Estimate of customer flows in the catchment area.

Under these conditions we obtained an average entering traffic flow of 18,930 cars and 10,890 pedestrians and a total flow of around 43,960 customers/day (quite close to the average value of 50,000 daily visitors resulted from surveys).

It has been confirmed that the estimation of the attractiveness zone using the Converse model can provide a good approximation of the traffic flows in a certain geographical area.

4. Traffic flows estimate

Further we used the Huff probabilistic model (Huff, 1964; Ingram, 1982) in order to assess the size and origin of the entering traffic flows in the selected shopping mall S; according to this model the daily customer flows from a zone *i* and for the mall *j*, F_{ij}, is:

$$F_{ij} = C_i \frac{\frac{D_j}{d_{ij}^{\lambda}}}{\sum_{j=1}^{r} \frac{D_j}{d_{ij}^{\lambda}}} \text{ (Customers/day)} \quad (7)$$

where C_i - the total population in zone *i* multiplied by the travel frequency for shopping purposes (and, in case of the cars, by the motorization rate);

D_j - the size of mall in zone *j* (market area, total number of parking spots);

λ - calibration coefficient;

d_{ij} - distance or travel time between TAZ *i* and *j*;

i - are those TAZs with the total car travel time less than 15 min, respectively, total transit time less than 30 min.

Based on the Huff model (Huff, 2003) we developed a GIS model to estimate the flows attracted by the nine malls in relation to their parking capacity. For the analyzed mall *S (j = 1)* with 2500 parking spots, we calculated the flows from 34 zones ($i = 1 \div 34$) located in its service area (Fig. 6). Overall, we estimated 45,300 customers/day, quite close to the value of 50,000 customers/day obtained from surveys.

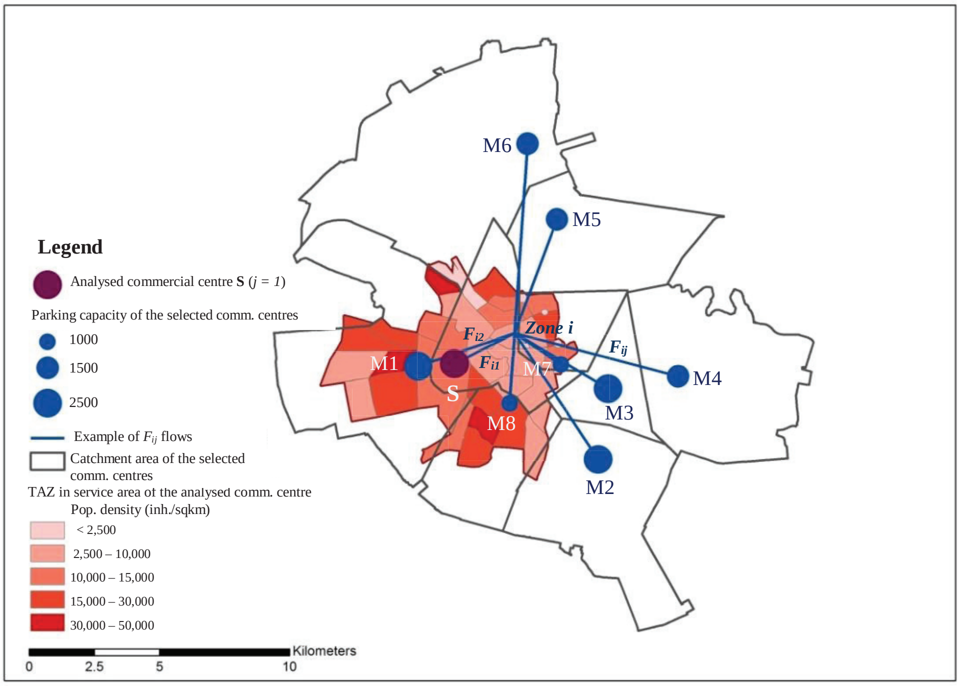

Fig. 6. Data sets configuration used for customer flows assessment.

The model also allowed the estimate of total travel (in car-km) attracted by the analyzed center. Around 33,500 car-km/day total travel corresponds to approximately 12,750 cars entering and leaving the center (considering the simplifying assumption of round trips home - commercial center). The obtained attracted flows are further used in traffic risk assessment.

5. Risk assessment

The area of the selected mall is road crash risk sensitive. It has specific features which sets it apart from other areas of Bucharest: volume of the car and pedestrian flows, and topological and geometrical characteristics of the urban space.

The crash risk exposure depends on the intensity of the general urban activity, meaning on pedestrian flows, *P*, and vehicle flows, *R*, generated and attracted by facilities specific to urban life (offices buildings, education institution, transport terminals) and by consumer oriented activities (shops, restaurants). The classification and selection of the high risk areas is made after analyzing the road crash data, and the following attributes (Fig. 7):

- Commercial areas
- Public transport stations
- Population density
- Intensity of traffic flows.

The crash risk vulnerable zones are obtained by the intersection of the layers with the four mentioned attributes. For further analysis, a 300 meters cell size grid is build and matrices are generated for the vulnerable zones.

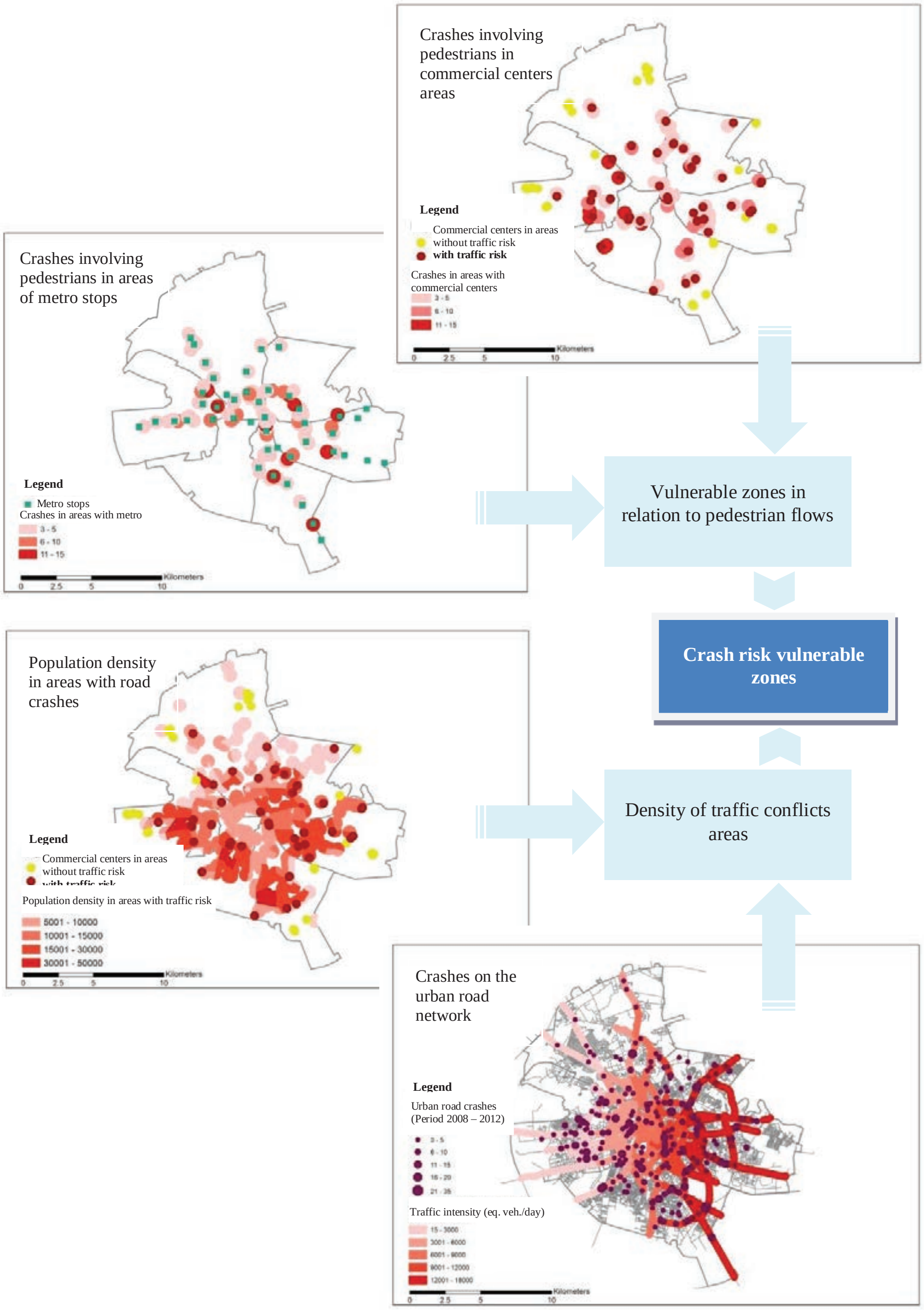

Fig. 7. Selection of the crash risk vulnerable zones.

From these zones, we selected the area where the analysed mall (*S*) is located, and we isolated six cells for risk estimation (Fig. 8). The traffic flows estimated in the previous section are assigned on features located in each cell.

For each of the six cells the pedestrian flows are divided in:

- P_1 - flows attracted by urban interest points (shops, offices, university campus) and
- P_2 - flows generated/attracted by public transport terminals.

The total road traffic flow (R) is obtained by adding the road traffic flow attracted by features located in each cell (R_1) to the general road traffic flow (R_2) transiting the cell.

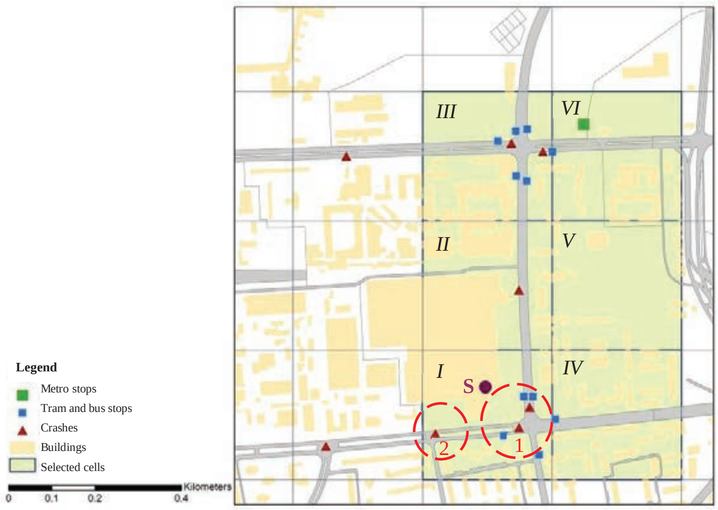

Fig. 8. Selected cells for detailed risk estimation.

We exemplify the crash risk estimation for the cell *I*, for the four-legged intersection 1 (Fig. 8), with 32 conflict points "vehicle-vehicle" and 8 conflict points "vehicle-pedestrian". For this intersection, the traffic flows generated by the analysed mall (*S*) are about 11,000 input and output movements/day.

For the selected intersection from the vulnerable area of the analysed commercial centre, we present one of the several studied models to estimate traffic risk, defined by (Lord, 2002):

$$A_R = \frac{E(k)}{F \cdot 365} \tag{8}$$

where A_R is the crash risk as number of crashes per intersection;
$E(k)$ - the expected number of crashes per year;
F - the turning traffic flows (right, through, left) in vehicles/day.

If $E(k)$ depends only on F for the other identical conditions, having the equation:

$$E(k) = \alpha \cdot F^{\beta} \tag{9}$$

results:

$$A_R = \alpha \cdot \frac{F^{\beta-1}}{365}, \quad (10)$$

meaning that for $\beta < 1$ the crash risk decreases when the traffic flow increases.

In the case of the analysed commercial centre this alternative is invalidated by statistical crash data. Furthermore, the essential changes in urban form and traffic make difficult to accept the dependence of *E(k)* only on traffic flows. Therefore we decided to use more complex models to estimate crashes in the selected area.

Examination of crashes in this four-legged intersection, would have required a breakdown by crash type, namely rear-end, head-on, side swipe, right angle, hit pedestrians etc. crashes. Due to lack of available crash data, we used a global evaluation of traffic flows conflicts.

Thus, in relation to the size and direction of daily flows *F* identified in our study, we calculated the “vehicle – vehicle” conflict index:

$$I = \sum_{(i,j)\in\{X_1\},i\neq j} F_i \cdot F_j + \sum_{(k,l)\in\{X_2\},k\neq l} F_k \cdot F_l + \sum_{(m,n)\in\{X_3\},m\neq n} F_m \cdot F_n \quad (11)$$

where $\{X_1\}$, $\{X_2\}$, $\{X_3\}$ are the sets corresponding to crossing points (16 points), diverging points (8 points), respective merging points (8 points).

Base on available statistical data on “vehicle-vehicle” crashes in this type of intersection, we calibrated the function to estimate the crashes:

$$E(k) = 1.54 \cdot 10^{-4} \cdot I^{0.42} \text{ (Crashes/year).} \quad (12)$$

Applying the empirical Bayes method (Hauer, 2001; Hauer et al., 2002; Persaud and Lyon, 2007), for $I = 5238 \cdot 10^6$ conflicts/day in the 32 conflicts points of intersection, we obtained an average of $\bar{k} = 1.85$ crashes/year. For the overdispersion $\varphi = 2.16$ corresponding to a negative binomial distribution and $A = 11$ crashes/5 years (recorded crashes in the selected intersection in the last 5 years), we estimate the future crashes by the equation (Hauer et al., 2002):

$$\hat{A} = \omega \cdot \bar{k} \cdot T + (1-\omega) \cdot A \text{ (Crashes).} \quad (13)$$

where T is the number of years with available data on crashes (T = 5 years in this case);
ω - weight function, calculated by equation:

$$\omega = \frac{1}{1+\frac{\bar{k}\cdot T}{\varphi}}. \quad (14)$$

We obtain $\omega = 0.19$ and $\hat{A} = 10.67$ crashes/5 years. The standard deviation of the estimated frequency is:

$$\hat{\sigma} = \pm\sqrt{(1-\omega)\cdot \hat{A}}. \quad (15)$$

The values $\hat{\sigma} = \pm 2.94$ crashes/5 years and the average $(\hat{A} \pm \hat{\sigma})/T = 2.13 \pm 0{,}59$ crashes/year result. The mentioned limits of the estimated crashes correspond to the number of crashes recorded in the available statistics.

The presented method for ex-ante estimation of crashes, based on calculation of conflict index, supposes many simultaneous assessments of traffic flows in the intersection conflict points. Therefore we apply another method to calibrate the function $E(k)$.

Most of the day the analysed intersection is operating close to capacity. For a quasi-stable daily traffic flow, the capacity of the intersection is determined by its configuration. This means that the intersection configuration is decisive in estimating the crash risk.

In the neighborhood of the analyzed intersection we identified other 13 saturated intersections with available statistical data on ”vehicle – vehicle” crashes. We calibrated the equation for the recorded number of crashes as a function of these characteristics:

$$E(k) = 2.1 \cdot e^{0,17 \cdot x_1 + 0,34 \cdot x_2 + 1,12 \cdot x_3} \quad \textit{(Crashes/year)} \tag{16}$$

where $x_1 \in \{1, 2\}$ describes the system of intersection traffic control;
$x_2 \in \{1, 2, 3, 4\}$ - the configuration of right and left turns;
$x_3 \in \{0, 1\}$ - the existence of dedicated transit lanes.

We also analysed the crashes for the group of two intersections located in the cell *I* (Fig. 8) (the configuration of the intersection 2 was modified at the opening of the commercial centre *S*). The distance of only 225 meters between the two intersections explains this correlated analysis.

The average numbers of recorded crashes are A_1 = 4 crashes/year in the first intersection and A_2 = 3.5 crashes/year in the second one. According to the layout of each intersection, the values $E_1(k) = 2.1^{0.7 \cdot 1 + 0.34}$ and $E_2(k) = 2.1^{0.17 \cdot 2}$, respective $\overline{k_1} \cong 1.61$ crashes/year and $\overline{k_2} \cong 1.11$ crashes/year are obtained. The values of overdispersion are $\varphi_1 = 1.8$ and $\varphi_2 = 2.2$. If the correlation between the crashes from the two intersections is not clear, then the weight is:

$$\omega = \frac{1}{1 + \frac{\sum_{i=1}^{2}\left(\bar{k}_i^{\,2}/\varphi_i\right)}{\sum_{i=1}^{2} k_i}} \cong 0.58\,. \tag{17}$$

The number of estimated crashes in the group of two intersections is:

$$\widehat{A_{1,2}} = \omega \cdot \left(\bar{k}_1 + \bar{k}_2\right) + (1 - \omega) \cdot (A_1 + A_2) = 5 \; \textit{Crashes/year} \tag{18}$$

with

$$\widehat{\sigma_{1,2}} = \sqrt{(1 - \omega) \cdot \widehat{A_{1,2}}} = 1.55 \; \textit{Crashes/year}, \tag{19}$$

meaning

$$\widehat{A_{1,2}} \mp \widehat{\sigma_{1,2}} = 5 \pm 1.55 \; \textit{Crashes/year}\,, \tag{20}$$

less than the recorded value of 7.5 crashes/year.

If we suppose that correlations regarding occurrence of crashes in the two intersections exist, then the weight is:

$$\omega = \frac{1}{1 + \frac{\left(\sum_{i=1}^{2}\sqrt{\bar{k}_i^{\,2}/\varphi_i}\right)^2}{\sum_{i=1}^{2} k_i}} \cong 0.47\,, \tag{21}$$

respective $\widehat{A_{12}} = 5.38$ crashes/year and $\widehat{\sigma_{12}} = 1.99$ crashes/year, namely a number of $\widehat{A_{1,2}} \mp \widehat{\sigma_{1,2}} = 5.38 \pm 1.99$ estimated crashes/year, having a better concordance with the average of recorded values. This proves that correlations between crashes in the two close intersections exist and they could be analyzed as a single complex intersection.

6. Conclusion

The large commercial centers, such as shopping malls and hyper-markets, which have commercial as well as recreational functions, attract and generate significant car traffic, light freight trucks for distribution/supply, and pedestrians from the neighborhood areas or from other zones.

The location decisions of large commercial centers need rigorous substantiation for both aspects of customer attractiveness in terms of accessibility and purchasing power, and the consequences on the road traffic and the associated crash risk, too.

In the metropolitan Bucharest case, the location of large commercial centers was almost entirely dictated by land availability, which was obtained through the decommissioning/ dismantling of factories, industrial areas, institutions, green spaces, etc. The proof of this statement is presented in this paper: the relative entropies of the location of large commercial centers were computed, and the lack of correlation between those locations and the density of population and average income was revealed. In other words, there is a lack of urban development strategy by comparison with the practices in other European countries.

The presented research provides a useful tool for an ex-ante assessment of the consequences of commercial centers location on car and pedestrian traffic. The crash risk has to intervene as an additional criterion in the decision on location of such commercial center.

Using a GIS application and spatial analysis models (Reilly, Converse, Huff) the authors identified the attraction zone of one of the most visited shopping malls in Bucharest, centrally located, and evaluated the car and pedestrian flows. The results are in line with the average values recorded over the last three years.

The available road crash statistics for the one of the large road intersection in the mall area allowed the validation of the model for the crash risk associated to traffic flows, in relation to the topology and geometry of the road network, the public transport lines, and the car and pedestrian flows. This estimation of the associated crash risk in the road traffic needs to be included with high priority among the other criteria used to decide the location of a new activity (commercial, but not only).

Acknowledgements

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