ON ACCIDENT PREDICTION FUNCTIONS FOR URBAN ROAD INTERSECTIONS

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Due to social costs of road accidents, traffic safety has to represent a main concern in urban planning policies. The need of tools to assess proposed measure to traffic risk reducing has been emphasized in delineating of European road safety strategy in the last decade. In this frame, the paper presents a study on Accident Prediction Functions (APFs) for road intersections in urban areas. APFs are used to identify factors that are associated to the risk of road accident occurrence and, afterward, as tool in traffic risk assessment for different urban planning scenarios. In this paper, the APFs for intersections are defined and calibrated based on available data on severe road accident recorded in Bucharest for the years 2008 to 2012.

Keywords: traffic risk, accident prediction function, urban road network.

1. Introduction

Analyses of the road accidents and, especially, identifying direction of actions to prevent road accidents represent the main topic in many studies at international and European level [1] - [8]. Since the social costs of accidents are estimated quasi-overall as very high, urban traffic risk should be included as a supplementary criterion in selection of the best alternative of urban planning.

If road safety research refers to measures proposed to minimize the frequency and severity of accidents, then studies on traffic risk analyses the probability of a road traffic accident occurrence, with consequences for users and surrounding people. Generally, traffic risk studies aim to identify key aspects for future planning scenarios, analyzing potential factors that might have negative consequences. This goal involves development of a set of tools that provide decision makers a-priori estimates of traffic risk associated to each considered urban planning alternative. Taking into account this issue, the paper presents a

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study on Accident Prediction Functions (APFs) for urban road intersections from Bucharest.

APFs represent useful tools to estimate the average frequency of accidents on road network entities, as intersections and road sections. These estimates are mainly used to identify factors that influence the accident occurrence and, next, to estimate effects of the planned measures to road safety enhancement. There are three main classes of accident prediction functions for entities of urban road network (Tab. 1). Each class includes a set of functions defined according to categories of urban streets and intersections [5], [8] - [11].

Table 1

Classes of accident prediction functions [9]

Class of functions	Features used to group the accident prediction functions
I. Accident prediction functions in major intersections, where flows from major and arterial streets interact	▪ Signalized four-legged ▪ Signalized three-legged ▪ Unsignalized four-legged ▪ Unsignalized three-legged
II. Accident prediction functions in minor intersections, where flows from major and arterial streets and flows from collector and residential interact	▪ Signalized four-legged ▪ Signalized three-legged ▪ Unsignalized four-legged ▪ Unsignalized three-legged
III. Accident prediction functions for section between intersections (mid-block)	▪ Two lane roads ▪ Four lane ▪ Six lane roads

The choice of risk variables for each category of functions is performed after the analysis of road accident statistics and traffic flow and depends fundamentally on the data availability.

The next section presents the general structure of APF for intersections. Then a study case for definition and calibration of APF for intersections from Bucharest is described. Starting from the data base of recorded road accidents in Bucharest for the time period of 2008 to 2012, and annual average daily traffic (AADT) recorded in 2012 and attributes describing the configuration of the urban road intersections, two classes of APF are defined and calibrated: APF for unsignalized intersections and APF for signalized intersections.

2. Structure of accident prediction functions for intersections

Accident prediction functions express the average frequency of road accidents as function of traffic flow and a set of characteristics of road network entities. Various forms of APFs for different types of intersections are described

in traffic safety literature, but generally, for each class of functions the following form [12] is initially used:

$$\mu_k = \beta_0 \cdot Q_1^{\beta_1} \cdot Q_2^{\beta_2} \cdot e^{\sum_j \alpha_j \cdot x_{kj}}, \text{ (accident/year)} \qquad (1)$$

where μ_k is   the expected number of accidents for intersection type k;

   Q_1, Q_2 -   entering traffic flow in intersection from the major, respective minor road section;

   β_0 -   intercept;

   β_1, β_2 -   effect of traffic volume on the expected number of accidents (elasticity);

   x_{kj} -   explanatory variables, other than traffic;

   α_j -   parameters to be estimated, representing the effects of variables j^{th} on accident occurrence.

Because road accident represents seldom events in intersections, the assumption of using exponential functions to model the effects of risk factors seems to be appropriate. The eq. (1) is adapted in each case, function of peculiarities of road network entities and available data for calibration.

The reliability of such functions is enhanced when data for several years are available. For data for several years, the needs of analysis of the year to year variation appear. The identifying of the trend which quantifies the changes of yearly explanatory variable effects could lead to better results of APFs. Investigating the series of data for each year as separate observations, the eq. (1) becomes:

$$\mu_{kt} = \beta_0 \cdot Q_{1t}^{\beta_1} \cdot Q_{2t}^{\beta_2} \cdot e^{\sum_j \alpha_{jt} \cdot x_{kj}}, \text{ (accident/year } t) \qquad (2)$$

where μ_{kt} is   the expected number of accidents for intersection type k, for year t;

   Q_{1t}, Q_{2t} -   entering traffic flow in intersection from the major, respective minor road section, for year t;

   α_{jt} -   parameters to be estimated for year t.

It is usually assumed that the values of the estimated coefficients β_0, β_1 and β_2 remain constant from year to year.

This approach leads to disaggregate model which presents difficulties due to the temporal correlation. Several models have been proposed to estimate the APFs with trend, which can be grouped in three categories [13]: marginal models,

transition models and random effects models. Generally, the marginal models are recommended for APFs [13], [14].

Nevertheless disaggregate models are recommended to be applied to calibrate APFs with trend [13] - [15], in this stage of our research we have not been able to overcome the difficulties imposed by time correlation. This difficulty is explained mainly by the insufficient detailed data on road accidents, and on traffic flow and also by the heterogeneity of road intersections in Bucharest. We started based on data base of severe road accidents recorded in Bucharest for each of the years 2008 to 2012. The selection by type of intersections with recorded accidents led to insufficient data samples to proper calibration of APFs with trend. Consequently, we applied an aggregate model to define APF, using the annual average of road accidents computed for time period of 2008 to 2012 and annual average daily traffic (AADT) recorded in 2012.

3. Calibration of accident prediction functions

3.1. Data processing

The data base used to define APFs for entities of Bucharest road network contains 350 sites with a sum of 1360 severe accidents for time period of 2008 – 2012. We used Geographic Information System (GIS) facilities to design geo-databases with the location of road accidents and with their correlation to the digital model of the urban road network (Fig. 1). GIS procedures were further applied for selection and classification of the network features by structural characteristics. The obtained data constituted the basis for defining and calibrating each category of accident prediction functions.

For the study presented in this paper, we selected just the accidents records for intersections crossed by major roads with available traffic date for year 2012. The main characteristics of selected data are described in Table 2.

Table 2

Main characteristics of road accidents at intersections

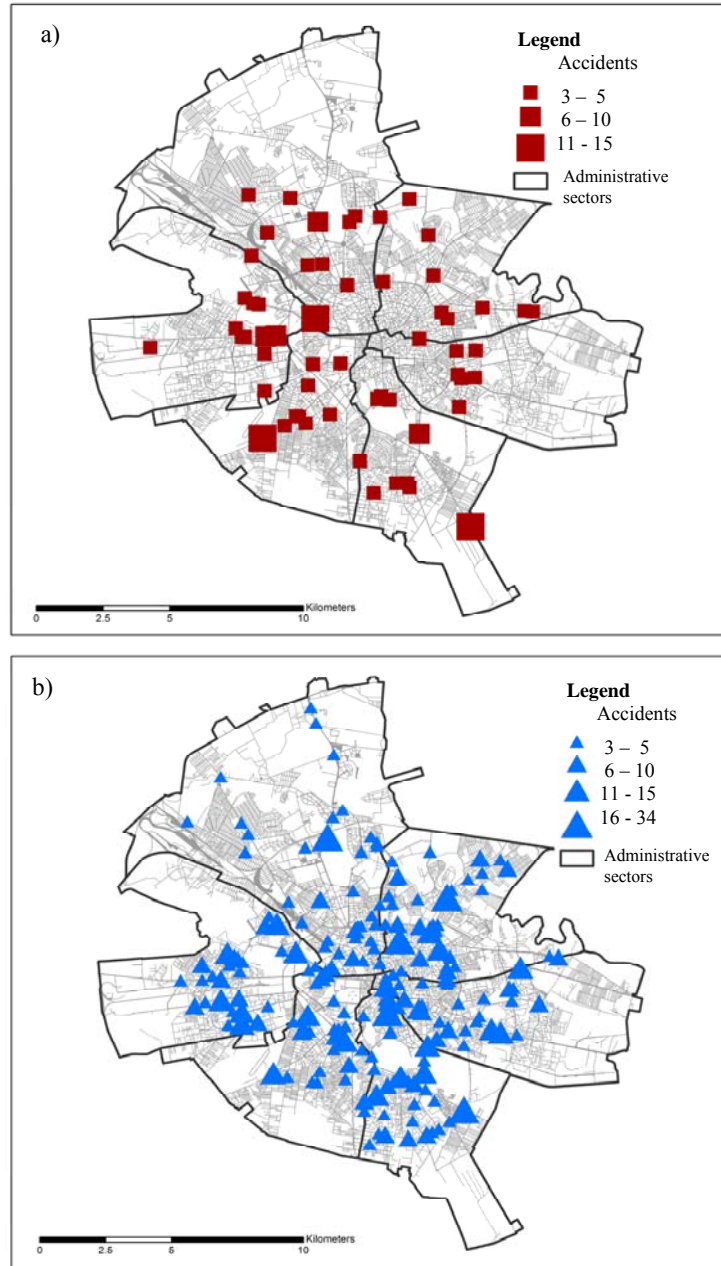| Year	Accidents at intersections	No. of intersections with recorded accidents	Accidents/entity Non-zero min. – Max. - Average – Variance
2008	258	62	3 – 11 – 4.16 – 2.37
2009	232	54	3 – 11 – 4.15 – 2.38
2010	212	56	3 – 9 – 3.81 – 1.29
2011	167	42	3 – 13 – 3.97 – 1.41
2012	227	60	3 – 11 – 3.77 – 1.44
Overall	1096	191	3 – 34 – 5.76 – 2.07

Fig. 1. Location of road accidents in Bucharest urban area (2008 – 2012)
(a) at road sections; (b) at intersections.

In traffic risk studies it is recommended that separate functions to be defined and calibrated for different type of intersections [15]. Therefore we used a set of attributes to describe the intersection layouts (Tab. 3).

Table 3

Description of intersection types

j	Attribute x_i	Description
1	Type of intersection design	• 3-way intersections: T-, Y- or skewed Y- intersections; • 4-way intersections: regular cross, skewed 4-legged intersections; • 5-way intersections; • Roundabouts: conventional-roundabouts, multi-lane roundabouts.
2	Type of signalizing	• Signalized intersections; • Unsignalized intersections.
3	Sight conditions	• Adequate sight conditions; • Inadequate sight conditions due to urban facilities or buildings; • Inadequate sight conditions due to vegetation.
4	Existence of public transport stops	• No stops in intersection; • Regular side stops; • Median tram stops; • Metro stops.
5	Existence of pedestrian crossing	• No pedestrian crossing; • Unsignalized pedestrian crossing; • Signalized pedestrian crossing; • Double-signalized pedestrian crossing with median traffic island.

Selections by type of intersection design and type of signalizing were made on the data set of intersections with recorded accidents. Besides the usual difficulty caused by the temporal correlation of annual data series in estimate of APF with trend, in our study an additional issue emerged. The low dimension of the data subsets for each intersection type and for each year did not supply sufficient sample to estimate coefficient of APF for each year. Consequently, we decided to develop an aggregate model using selection of intersections with recorded accidents for all 5 years (2008 – 2012).

The next section presents the method applied to select the appropriate form of APF and to calibrate the APF coefficients.

3.2. Selection of APF form

Due to the constraints caused by the available data on road accident, traffic flow and road network attributes, the dependent variables considered in the selection of APF form were:

- Q_1, Q_2 - annual average daily traffic (AADT) on major, respective minor road sections that intersect (average values recorded in 2012);
- x_1 - variable characterizing the pedestrian crossing at intersection (having the values: 1 when no pedestrian crossing is located at intersection; 2 for unsignalized pedestrian crossing; 3 for signalized pedestrian crossing and 4 for double-signalized pedestrian crossing with median traffic island);
- x_2 - variable which describes the location of public transport stops next to intersection (having the values: 1 when no stops are located at intersection; 2 for regular side bus stops; 3 for metro stops; 4 for median tram stops and 5 for more than one type of stops);
- x_3 - variable which describes the tram facilities at intersection, with the values: 1 if the intersection is dedicated just to road vehicles and 2 if the intersection includes tram track);
- x_4 - variable which characterizes the sight conditions at intersection, having the values: 1 for inadequate sight conditions due to urban facilities or adjacent buildings; 2 for inadequate sight conditions due to vegetation and 3 for adequate sight conditions.

The procedures of selection of APF without trend [16] - [18] were applied for two separate series of accident data from Bucharest: *(i)* accidents located at unsignalized intersections and *(i)* accidents located at signalized intersections.

We applied several tests of correlation on the subsets of data for unsignalized intersections, respective signalized intersections in order to find significant variables x_i (*i=1..4*), besides the explanatory variables Q_1, Q_2 (AADTs on major, respective minor road sections). Using correlation coefficient R^2, adjusted correlation coefficient R^2, Akaike information criterion *AICc* and variance inflation factor *VIF* as evaluators [19] - [21], x_1 and x_4 resulted as significant variables in estimate of accidents at unsignalized intersections and x_1 and x_3 for signalized intersections.

For unsignalized intersections the resulting AFM is:

$$\mu_1 = 3.09 \cdot Q_1^{0.0024} \cdot Q_2^{0.004} \cdot e^{0.02 \cdot x_4 - 0.06 \cdot x_1} \text{, (accident/year)} \tag{3}$$

and for signalized intersections the AFM is given by:

$$\mu_2 = 2.86 \cdot Q_1^{0.015} \cdot Q_2^{0.01} \cdot e^{0.09 \cdot x_3 - 0.03 \cdot x_1}, \text{(accident/year)} \qquad (4)$$

Applying the eq. (3) on the accident data set selected for unsignalized intersections, the values of 0.76 for correlation coefficient R^2 and 0.71 for adjusted correlation coefficient R^2 resulted. In case of signalized intersection, eq. (4) lead to values of 0.74 for correlation coefficient R^2 and 0.70 for adjusted correlation coefficient R^2. These values demonstrate that eqs. (3) and (4) are appropriate to estimate the accidents for the two analysed classes of intersections (especially taking into account that road accidents are consequences of a complex of factors and the fact that this approach aim to assess only the intrinsic risk exposure). Additional variables (e.g. land use attributes, variables which characterize the pedestrian flow) could enhance the calibration, but in this phase the obtained APFs represent useful tools to estimate accidents in urban planning studies.

4. Conclusion

In the last decade, research on road safety and traffic risk assessment [1] - [8] has concluded that the risk assessment has to be added as an additional criterion in selection of the best alternative of urban planning. Therefore tools are necessary to estimate of the traffic risk for different urban development scenarios and, also, to estimate the effects of planned measures of road safety enhancement.

Several studies demonstrate that APF could be useful tools in traffic risk assessment [8] - [18]. These studies present different methods to define and calibrate APFs. The aim of our study was to develop and calibrate APFs appropriate to peculiarities of Bucharest urban environment.

Because in Romania there was no concern on collecting of necessary data to define and calibrate the accident prediction functions, one of the main difficulties in our study consisted in processing of data on recorded road accidents and in modelling of urban road network attributes.

Based on the developed digital macroscopic model of urban road network from Bucharest, containing attributes of intersections and road sections and on the available statistical series on road accident for time period of 2008 to 2012, we defined and calibrated APFs for unsignalized and signalized intersections. The lack of any previous studies to assess the level of road safety, and the complexity and heterogeneity of urban road intersections from Bucharest and the spatial dispersion of the network features with available data were main causes that impeded the defining of APFs with trend.

However, we could define and calibrate aggregate APFs for intersections using annual average daily traffic recorded in 2012. Although in order to include

risk assessment as criteria in urban planning evaluation, further extensive efforts is needed to collect and analyse detailed data on road accident, to define and calibrate functions for several classes of intersection and also for road sections.

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