GIS TOOLS FOR ANALYZING ACCIDENTS AND ROAD DESIGN: A REVIEW

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ABSTRACT

A significant unexpected outcome of transportation systems is road accidents with injuries and loss of lives. In recent years, the number of studies about the tools for analyzing accidents and road design has increased considerably. Among these tools, Geographical Information Systems (GIS) stand out for their ability to perform complex spatial analyses. However, sometimes the GIS has been used only as a geographical database to store and represent data about accidents and road characteristics. It has also been used to represent the results of statistical studies of accidents but, these statistical studies have not been carried out with GIS. Owing to its integrated statistical-analysis capabilities GIS provides several advantages. First, it allows a more careful and accurate data selection, screening and reduction. Also, it allows a spatial analysis of the results in pre and post-processing. Second, GIS allows the development of spatial statistics that rely on geographically-referenced data.

In this paper, several GIS tools used to model accidents have been examined. The understanding of these tools will help the analyst to make a better decision about which tool could be applied in each particular condition and context.

1. INTRODUCTION

Road traffic accidents are increasingly being recognized as a growing major issue, particularly in developing countries. They provide significant social and economic losses. The global status on the road safety 2015 of 180 countries reported that the worldwide road traffic deaths reach 1.25 million people per year. Additionally, the highest road traffic fatality rates occur in low-income countries (WHO, 2015).

Recently the numbers of studies on the tools for analyzing accidents and road design have increased considerably. Among these tools, Geographical Information Systems (GIS) stand out for their ability to perform complex spatial analysis. However, sometimes the GIS, has been used only as a geographical database to store and represent data about accidents and road characteristics. It has also been used to represent the results of statistical studies of accidents, but, these statistical studies have not been carried out with the (Kazmi & Zubair, 2014; Chen, 2012; Loo, 2006; Liang et al., 2005). This paper reviews the accident studies made with GIS and presents several GIS tools used to perform spatial analysis of traffic accidents.
2. ACCIDENT ANALYSIS USING GIS

Usually, researchers combine GIS and statistical models to evaluate risk of road accidents. For example, Li and Zhang (2007) show how GIS and advanced statistical models can be used. All data preparation, segmentation, and screening are performed in GIS. However, Bayesian analysis is done outside of any GIS platform. This approach is effective because it allows users to work with data in both tabular and spatial contexts, and to export and import data from a variety of formats. Another characteristic of this traditional approach is that it allows using different statistical models (Poisson, lognormal Poisson, negative binomial, etc.) independently of GIS (Shankar et al., 1995). Another researchers use GIS tools to carry out spatial analyses of traffic accidents.

Table 1 shows the main studies carried out for analyzing road traffic accidents with GIS. Note that the table is not intended to make a comparison among different methods or studies. The most used methods for spatial analysis of road traffic accidents are Moran’s I statistic and Getis-Ord. In what follows, these studies are summarized attending to scope of the study, data and methodology used.

2.1 Scope of the study
There is a relatively high dispersion in the type of roads that are analyzed. Some researchers have analyzed both intersections and road segments (Erdogan et al., 2008; Castro et al., 2012; Ma et al., 2014). However, Moore et al. (2011) mentioned that intersections and roads were not analyzed together, because factors related to the accidents that occurred at junctions were different from factors on the road segment.

2.2 Data Description
The success of preventive actions depends on the traffic accident record analysis. Good quality, reliable and accurate data are needed in order to understand which factors affect for the road accidents. In addition, the spatial location of accidents is a critical aspect of accidents analysis.

2.2.1 Area type
Table 1 shows that eight studies analyzed urban areas, while six studies combined the data from rural, urban, motorway and suburban highways.

2.2.2 Accident data in the analysis
Several data, such as, road accidents, peak time of the accidents, pedestrians hit by buses, cars, scooters, and also, four years of accident data with individual differences and many other combinations, can be worked out (Rankavat & Tiwari, 2013). Steenberghen et al. (2004) used dynamic segmentation in order to locate accidents. Dynamic segmentation makes possible to locate accidents data in a network, when the position relative to milestone is known, and other locational data are missing. Erdogan et al. (2008) stated that the records include the parameters collected in the accidents. Relevant parameters comprise those...
related to the accident time (date, hour), location (highway code, kilometer), driver’s information (age, gender and alcohol consumption), environmental conditions (weather, lighting), type of vehicles involved and severity (property-damage only, number of people injured or killed). Some studies have also integrated the traffic and road geometry data in the analysis.

<table>
<thead>
<tr>
<th>Author and publication year</th>
<th>Area</th>
<th>Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kim &amp; Nitz (1995)</td>
<td>Mixed</td>
<td>Spatial tools describing the degree of spatial concentration and analyzed spatial patterns of different types of accidents.</td>
</tr>
<tr>
<td>Erdogan et al. (2008)</td>
<td>Mixed</td>
<td>Determination of hot spot with statistical analysis (Kernel density analysis and Poisson)</td>
</tr>
<tr>
<td>Erdogan (2009)</td>
<td>Urban</td>
<td>Moran's I statistic and Getis-Ord</td>
</tr>
<tr>
<td>Gundogdu (2011)</td>
<td>Urban</td>
<td>Hot pieces method to determine critical stretches of road accidents and Probable Hotspots to foresee the critical spots</td>
</tr>
<tr>
<td>Budiharto &amp; Saido (2012)</td>
<td>Urban</td>
<td>Accident blackspot: three methods (kernel density estimation, cluster and outlier analysis)</td>
</tr>
<tr>
<td>Çela et al. (2013)</td>
<td>Urban</td>
<td>Accident spatial patterns using network K-function and Network Kernel Density Estimation (KDE) to find clusters and identify the actual cluster locations.</td>
</tr>
<tr>
<td>Rankavat &amp; Tiwari (2013)</td>
<td>Mixed</td>
<td>Research the potential of utilizing GIS in identifying pedestrian accident prone locations.</td>
</tr>
<tr>
<td>Ma et al. (2014)</td>
<td>Urban</td>
<td>Quasi-Poisson model</td>
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</table>

Table 1 Studies analyzing accidents using GIS
2.3 Methodology
Table 1 shows the different methodologies that have been used for analyzing road accidents using GIS. Over the last two decades, the road accidents studies have been done by using GIS tools, for example, to examine the spatial distribution and pattern of their accidents (Kim & Nitz, 1995; Gundogdu, 2010; Truong & Somenahalli, 2011; Budiharto & Saido, 2012), and to investigate the accident-prone locations (Rankavat & Tiwari, 2013). In the recent years, the combination of GIS and statistical analysis is increasingly more used by many researchers for assessing the road accidents (Steenberghen et al., 2004; Erdogan et al., 2008; Erdogan, 2009, Ma et al., 2014; Tortum & Atalay, 2015; Yalcin & Duzgun, 2015; Benedek et al., 2016).

The most used methods are Moran's I statistic and Getis-Ord. These spatial tools are used to determine hot spots and analyze accident spatial phenomena. For example, whether there are locations where "cluster of accidents" or specific types of accidents occur. Section 3 provides a description of these GIS spatial tools.

In some cases, factor analysis is used. This analysis allows a small number of dimensions to explain most of the information in a large data set, if there is a sizeable redundancy. Tortum and Atalay (2015) made a factor analysis to identify variables that have a statistically significant relationship with the number of road accidents.

On the other hand, fuzzy logic has also been used. Effati et al. (2014) used a geospatial neuro-fuzzy approach for modeling hazardous locations. It was tested on a regional highway corridor and the hazardous locations found were compared with the existing black spots which were obtained using a statistical approach.

3. SPATIAL ANALYSIS TOOLS
In this section, spatial techniques in GIS used to analyze road traffic accidents are presented. Spatial analysis is used to geographically specify the locations where the crashes occurred, and to assess specific patterns of distribution through map visualization.

3.1. Moran's I statistic
Moran’s I is a statistical tool that measures the spatial dependence of the accident location (Moran, 1948). MI also evaluates if the spatial pattern clusters are dispersed or random and also determines the level of concentration. According to Erdogan (2009), MI provides a single value of the spatial correlation and checking the clustering of the spatial pattern. Heavy locations of the proximity between the two points are often defined as the inverse of the distance between them. The attribute similarity severity index of two points is defined as the difference between each value and the value of the global average. Pirdavani et al. (2014) developed crash prediction models using geographically weighted regression. It was carried out by computing Moran’s I for dependent and selected explanatory variables. The
result revealed the necessity of considering spatial correlation when developing crash prediction models.

3.2. Getis-Ord
G Statistics are a family of statistics that has a number of attributes that make them attractive to measure the dependence of spatially distributed variables, especially when they are used in conjunction with MI. They deepen the knowledge about the processes that lead to spatial dependency and improve the detection of local 'pockets' dependence that may not appear when using global statistics (Getis & Ord, 1992). The Getis-Ord statistic is used to identify hot spots of traffic accidents. A high value of the Getis-Ord statistic represents a group of high index value (hot spots), while a low value represents a low value of the index group. The hot spot analysis calculates Getis-Ord statistic for each feature in the data set.

3.3. Kernel density
Kernel Density Estimation (KDE) is a spatial data analysis of ArcGIS program. Budiharto and Saido (2012) measured Kernel Density for determining the risk spread of the accidents. The spread of risk can be defined as the area around the cluster where such risk may increase due to an accident. An analysis using KDE tool produces a raster output. Erdogan et al. (2008) used GIS as a management system for accidents analysis and determination of hot spots with statistical analysis (KDE and Poisson).

4. CONCLUSIONS
Many studies used GIS tools to show the location of accidents on a digital map and analyze the hot spots of traffic accidents. There is a great diversity in the number of accident data records and of the factors used. The number of accident data and the analysis of factors found depend largely on the availability of data.

Regarding spatial methods, the most commonly used are Moran’s I and Getis-Ord statistic. Since Moran’s I measures the spatial dependence of accident locations and clusters accident spots according to spatial patterns, it provides a powerful tool to study accident occurrence. On the other hand, the Getis-Ord statistic measures a single value of the spatial correlation and provides a measure of the clustering degree value in the spatial pattern.

Due to the great variety of methods and tools on GIS available in literature, researchers can perform many different highway safety studies and identify accident patterns on networks. The documentation of characteristics and limitations of the studies addressed in this review will help analysts to determine the best method for a particular study.
5. REFERENCES


