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GIS-based Economic Cost Estimation of Traffic Accidents in St. Louis, Missouri

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Abstract

The economic loss due to total traffic accidents in St. Louis remains high every year. This paper presents an effective approach to spatially identifying potential casualty areas and their economic losses. In this study, five years of traffic accident data, from 2007 to 2011, collected in the City of St. Louis and the adjacent counties, is used. Using Geographic Information System (GIS)-based techniques, e.g. Kernel Density Estimation (KDE), two maps are generated and compared: 1) traffic accident rate map based on the number of traffic accidents per year and 2) the economic costs map. The locations with high economic costs but with low accident rates are identified and shown in a 3-D visualization format. The results can be used as a foundation for the traffic accident cost estimation related research and serves as a guideline for practitioners to investigate the areas with high traffic accident severity levels.

Keywords: Traffic Accidents; Kernel Density Estimation;Geographic Information Systems; Economic Cost

1. Introduction

In modern society, the advantages of the rapid development of roadways have been offset by their contribution to the loss of life and their high economic cost. In fact, the deaths and injuries caused by traffic accidents are the serious problem around the world (Prasannakumar et al, 2011). This problem has certainly caught the eye of many transportation agencies, leading them to spend significant effort to reduce the number of traffic accidents. In 2010, 32,885 fatalities were attributed to vehicle crashes in the United States. It is necessary to identify

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effective approaches to reducing the number of fatalities on the roadway in the United States. Many U.S. cities have been trying to identify the contributing factors of traffic accidents. However, it may not be realistic for each city to tackle all roadway accidents problems concurrently due to limited resources. Generally, traffic safety practitioners would focus on traffic accidents at some particular "hot spots" first.

A "hot spot" can be defined as an area with high accident frequencies, and are commonly the locations traffic engineers look at when making improvements (Sims & Somenahalli, 2010). Hot spots are commonly found through the use of the Geographic Information Systems (GIS) technology. Generally the GIS commercial software package provides powerful visual effects and analysis functions, making the software easy-to-use tools for managing, processing, analyzing and visualizing data. Spatial information is one of the most important characteristics of traffic safety data in identifying hazardous zones and hot spots (Erdogan et al., 2007). Therefore, the geographic location and coordinate information of the traffic accidents may provide more detailed information compared to traditional statistical analysis methods.

The purpose of this research is to identify the risk potential locations that require more safety engineers' attentions in the City of St. Louis, Missouri and the adjacent counties to the City in Missouri, including St. Louis County, Jefferson County, St. Charles County, and Franklin County. The City along with these counties has been identified by the state as high risk areas that may require more special attention. Two types of hot spots are identified in this study. Traffic accident rate distribution, based on the number of accidents, will be described first. The second type of hot spots is to identify the estimated economic cost of injuries and fatalities based on severity level. A further analysis of identifying the areas of high economic costs with low accidents is conducted based on the calculation of the two types of hot spots.

2. Literature review

Economic costs due to the traffic accidents have been a serious issue all over the world. Chen et al (2012) examined the group of young people to investigate the relationship between the factors of traffic accidents and the hospitalization costs in Australia. Connelly& Supangan (2006) utilized the detailed roadway traffic accident data to estimate and compare the economic impacts in territories, state and national level in Australia. In the U.S., Zaloshnja et al (2006) took the roadway geometry design into consideration. They estimated the costs by the categories of crash geometry types and speed limit. From a different perspective, a study on highway crash costs in the United States was conducted by the categories of driver age, blood alcohol level, victim age and restraint use (Miller, T R., Lestina, D C. & Spicer, R S, 1998). Zaloshnja & Miller (2004) investigated the costs resulting from the large truck accidents in the United States. However, few papers focused on applying the spatial analysis techniques on analysing economic costs of traffic accidents

GIS technology has been utilized as a means to solve traffic safety issues by many researchers. Truong and Somenahalli (2011) used GIS to find a pedestrian vehicle crash hot spots and unsafe bus stops. Hotspots were found by the Getis-Ord Gi* method to rank unsafe bus stops and find areas with high pedestrian vehicle crash frequencies. The Getis-Ord Gi* can identify where low and high index values cluster. Erdogan et al. (2008) developed a traffic accident analysis for Afyonkarahisar, Turkey. Their analysis manages the data by using the kernel density estimation to identify hotspots and to find causes of the accidents there. Kernel density estimation is useful in finding high frequency locations and obtaining the location's ranking of locations with high frequency accidents.

Several studies have been conducted to compare the methods used in spatial analysis. Kuo et al., (2011) explained three different methods to identify hot-spots. Kuo et al., not only compared Getis-Ord Gi*, polar KDE and NetKDE methods, either with network restriction or without network restriction but also provided useful guidelines for selecting the appropriate method of identifying hotspots. Deshpande et al., (2011) developed a comparison between Kernel density estimation and spatial autocorrelation to find the more appropriate method for analyzing data. As a conclusion of this research, KDE has the advantage of being easily implemented and understood, and spatial autocorrelation has been implemented on spatial parameters, such as demographics and geometric design. Xie & Yan, (2008) developed a comparison between planar KDE and NetKDE. Planar KDE conducted a smooth density surface of spatial point in 2-D space; while, the NetKDE focuseed on spatial points in a line or a 1-D linear Space, which meant NetKDE concentrated on the roadway network. In this study, the planar KDE is preferred as an appropriate method of analysis.

3. Methodology

The purpose of this study is to identifying high economic cost but low accident rate areas using two GIS-based traffic accident maps. The first map focuses on the high traffic accident rate areas. This map is commonly used to identify hot spots. The second map shows the high economic cost areas caused by traffic accidents. The economic costs caused by the traffic accidents are the major output of this map. The economic cost of each traffic accident is calculated based on the number of fatalities or injuries multiplied by the severity cost.

The economic costs for each traffic accident are calculated by the number of fatalities or/and injuries multiplied by the comprehensive economic cost of the corresponding accident severity level. The detailed information on the injury severity level and the relevant comprehensive social cost is tabulated as Table 1. The comprehensive economic cost of a fatality reaches to $4,008,900, about 20 times as expensive as a disabling injury.

Table1. Crash Costs by Injury Severity Level (FHWA, 2011)

Injury Severity Level (crash code)	Comprehensive Economic Cost
Fatality (K)	$4,008,900
Disabling Injury (A)	$216,000
Evident Injury (B)	$79,000
Fatal/Injury (K/A/B)	$158,200
Possible Injury (C)	$44,900
Property damage only (PDO)	$7,400

In terms of spatial analysis for generating the two types of traffic accident related maps, a preliminary comparison of the different spatial analysis methods is presented. An appropriate method is selected for generating the two types of maps. The high economic costs areas with low accidents are identified by the spatial differences of the two types of maps.

There are several methods to identify these hot spots, and most popular way is to use spatial data analysis techniques, such as density estimation, Getis Ord Gi* and Spatial autocorrelation. Density estimation includes point density, line density and kernel density. Among these three methods of density estimation, kernel density has proven to be able to show the well self-explained results because the highest value at the point with the decreased distance can give kernel density estimation a smooth curved surface on each point (Deshpande, 2011). Therefore, Kernel Density Estimation (KDE) is found suitable for identifying hot spots in this study.

KDE is usually used to estimate unknown density functions, and KDE is one of the methods of non-parametric density estimation. KDE is the density distribution of the point features in a region. The general kernel density equation is given as:

$$\lambda(s) = \sum_{i=1}^{n} \frac{1}{\pi * r^2} * k * \left(\frac{d_{is}}{h}\right) \quad (1)$$

Where $\lambda(s)$ means the location density, h means bandwidth (search radius) of KDE, k is the weight of a point which means number of accident in same location.

Besides general function of kernel density, other three KDE functions are also commonly used (Xie and Yan, 2008), including:

Gaussian function:

$$k * \left(\frac{d_{is}}{r}\right) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{d_{is}^2}{2 * r^2}\right), when\ 0 < d_{is} <= r \quad (2)$$

$$k * \left(\frac{d_{is}}{r}\right) = 0, when\ d_{is} > r$$

Quartic function:

$$k * \left(\frac{d_{is}}{r}\right) = \mathrm{K}\left(1 - \frac{d_{is}^2}{r^2}\right), when\ 0 < d_{is} \le r \quad (3)$$

$$k * \left(\frac{d_{is}}{r}\right) = 0, when\ d_{is} > r$$

Minimum variance function:

$$k * \left(\frac{d_{is}}{r}\right) = \frac{3}{8}\left(3 - 5 * \frac{d_{is}^2}{r^2}\right), when\ < d_{is} \le r \quad (4)$$

$$k * \left(\frac{d_{is}}{r}\right) = 0, when\ d_{is} > r$$

In this study, the general kernel density estimation is used to generate the two types of accident related maps because the general KDE is found most effective and efficient to implement.

4. Data description

Five years of traffic accident data (2007-2011) is provided by the Missouri Department of Transportation (MoDOT). This dataset covers five counties, St. Louis City, St. Louis County, Jefferson County, St. Charles County, and Franklin County. Many traffic accident attributes are associated with the accident data, including the dates accidents occurred, travel way information, and accident severity, and number of injury, disabling and fatalities. Moreover, the locations of these traffic accidents are geocoded as shapefile format, which can be easily visualized in a GIS environment. Freeway network dataset, provided by MoDOT, covers the roadways in the City of St. Louis and the adjacent counties as well.

5. Results and discussion

Within the study area, an average of 45,007 accidents occurred each year from 2007 to 2011. According to the statistical results, about 76% of accidents caused property damage, and nearly 24% accidents caused either death or a disabling injury.

Figure 1(a) shows the first map of traffic accident rates in City of St. Louis and surrounding areas from 2007 to 2011. The red areas indicate hot spots with a high traffic accident rate; while the blue areas represent the areas with a low traffic accident rate. Figure 1(b) shows the map of economic costs caused by the traffic accidents in City of St. Louis and surrounding areas from 2007 to 2011. The purple areas indicate the areas with high economic costs; while the yellow areas represent the areas with low economic costs.

Figure 1(a) and Figure 1(b) show that the accident rate and economic costs due to the traffic accidents remain at a high level in St. Louis County and the City of St. Louis. Furthermore, most accidents happened at either interchanges or intersections. This leads the high economic costs to emerge at either interchanges or intersections.

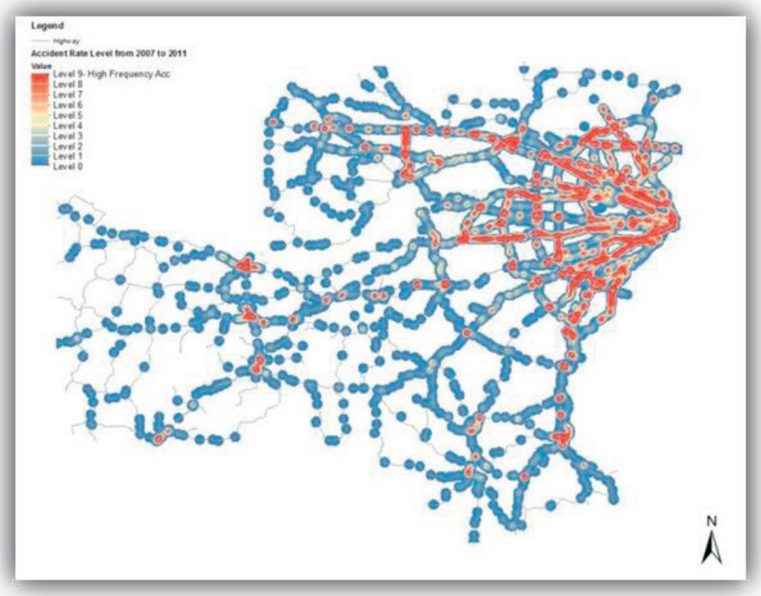

Figure1 (a). Accident rate map from 2007 to 2011 in St. Louis and adjacent counties

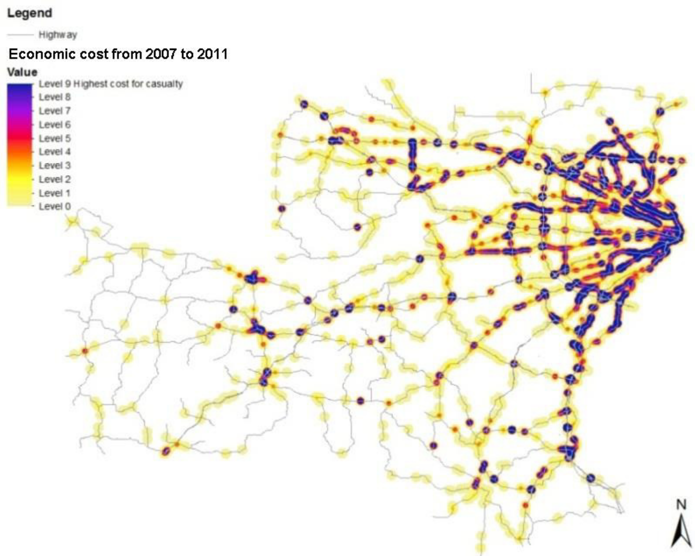

Figure 1(b). Economic cost map from 2007 to 2011 in St. Louis and adjacent counties

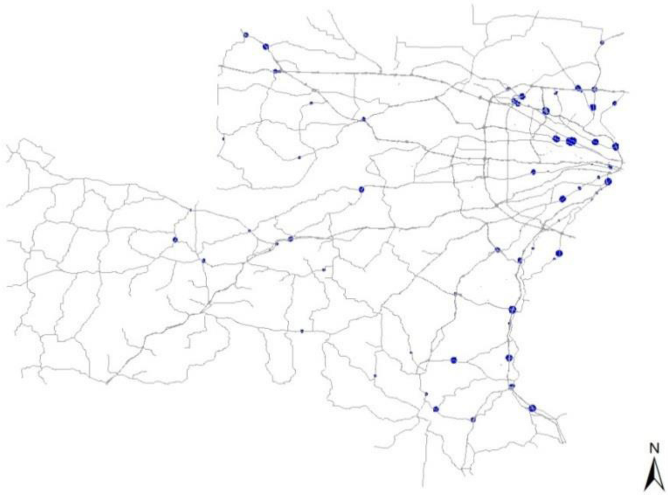

Figure 2. High economic cost areas with low accident rates

By calculating the spatial difference between the two types of maps shown in Figure 1(a) and (b), the high economic cost areas with low accident rate are highlighted in Figure 2. These areas may need further attentions from city traffic safety engineers.

In order to clearly demonstrate the areas associated with the high ratio of economic cost to the accident rate, 3-D view is generated in Figure 3. The areas with high ratio of economic cost to the accident rate are illustrated with different peak heights. The taller the areas are, the higher the ratio is. These areas also show that a majority of high severity level accidents happened resulting into high economic costs.

Table 2 lists the top nine areas with the highest economic-cost-to-the-accident rate ratios. Obviously, these areas are located either at the interchanges or intersections. Noted that most of these areas are situated along either I-55 or I-70. Both of I-55 and I-70 are closed to the Mississippi River. One of the possible reasons may be that these traffic accidents are truck related accidents, causing more severe accidents. More studies need to be done to investigate truck related accidents in the future studies.

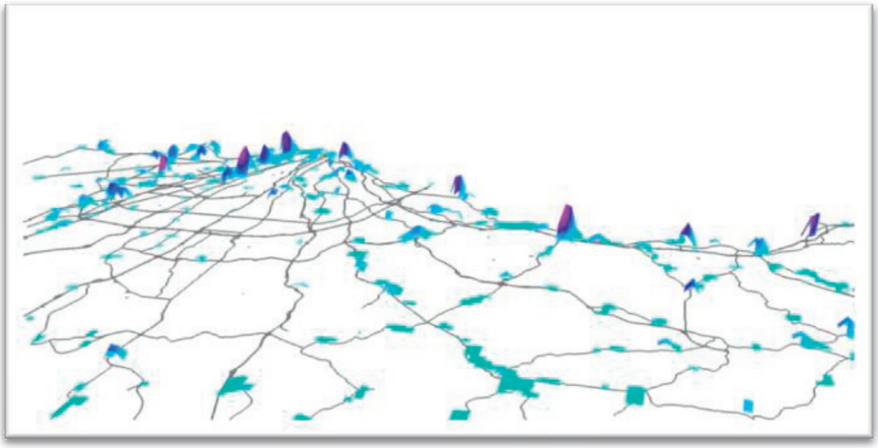

Figure3. 3-D view of high economic cost hot spots

Table2. Location description of high economic cost hot spots

ID	Segments and location
1	Interchange of Hwy 170 and Hwy 70
2	CST Gooffellow BLVD and CST Laurel ST S
3	CST TURNER AVE N
4	Interchange of Hwy 70 and CST 14TH ST S
5	Interchange of IS 55 and Broadway ST
6	231 with Pvtoakville middle school and CRD Susan Road E
7	Interchange of IS 55 and RTM N
8	Interchange of SP61 nad IS 55
9	Interchange of US 61 and IS 55

6. Conclusion

The purpose of this study is to examine the case of the economic costs in the City of St. Louis and surrounding counties. This study uses Geographic Information Systems (GIS) technology to identify two types of traffic accident related hot spots. The findings are listed below:

1) Both traffic accident rate map and economic cost map show that St. Louis city and St. Louis County account for the a large number of accidents and economic costs.
2) The high economic cost areas with low accident rate are identified. Most of these areas are located along the freeways crossing the Mississippi River.
3) The economic costs on I-55 and I-70 take a large portion of the economic costs in the entire study region.

These results can be used as a foundation for the traffic accident cost estimation related research and serves as a guideline for practitioners to further investigate the areas with high traffic accident severity levels.

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