Research article Available online www.ijsrr.org ISSN: 2279–0543

International Journal of Scientific Research and Reviews

Identification of Hazardous Road Locations for Vulnerable Road Users Using Kernel Density

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ABSTRACT

Compared to other road users, the vulnerable road users i.e. the pedestrians, bicyclists, and motorised two-wheeler riders are more prone to injury as they are not protected by vehicle shell. These road users tend to account for a much higher proportion of road traffic injury and deaths in the low income and the middle-income countries, than the high income countries. Kernel density maps are plotted and hazardous road intersections and midblock segments are presented. This paper discusses the pattern of hazardous road locations, land-use around such locations and other significant parameters for different cases. The paper discusses possible remedial measures to improve the safety after studying the role of associated spatial and non-spatial factors in traffic crashes. Most of the locations with high density of road accidents for all the three types of vulnerable road users are four-lane divided major roads of the city. The presence of hazardous road locations for pedestrians along the mid-block sections show poor road crossing infrastructures. High priority should be given to improve pedestrian safety by providing better road crossing facilities for pedestrians. Within city area, it is also recommended to incorporate pedestrian timing in the traffic signal to increase their safety. This paper helps the policy makers to take appropriate remedial measures in terms of traffic management to reduce injury crashes and to allocate the fund judiciously to set the priority for improvement.

KEYWORDS: Vulnerable road users, GIS, Hazardous road locations, kernel density estimation

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INTRODUCTION

During 2016, a total of 4,80,652 road accidents were reported[1] in India. Of these 1,36,071 (28.3 per cent) were fatal accidents. The number of persons killed in road accidents were 1,50,785 i.e. an average of one fatality per 3.2 accidents. The proportion of accident victims from pedestrian, bicyclists and motorised two-wheeler riders in 2016 was 10.5%, 1.7% and 34.8% respectively.

In urban areas, sustainable proportion of trips up to 1-2 km are performed by foot. Compared to other road users, vulnerable road users; i.e. pedestrians, bicyclists, and motorised two-wheeler riders are more prone to injury as they are not protected by vehicle shell. These road users tend to account for a much higher proportion of road traffic injury and deaths in low income and middle-income countries, than high income countries. In India, the share of vulnerable road accidents accounts for 47% of total road accidents in year 2016. It is necessary to identify the hazardous road locations of road traffic crashes and to explore influence of spatial factors. The paper discusses possible remedial measures to improve the safety after studying the role of associated spatial and non-spatial factors in traffic crashes.

The identification of accident location, analysis and treatment of hazardous road locations are widely regarded as one of the most effective approach to road accident prevention. The development of urban transport system has not kept pace with the traffic demand both in terms of quality and quantity. As a result, the use of personalized transport mainly two wheelers and intermediate public transport is growing at a rapid speed in medium sized Indian cities. The advancements in GIS is able to manipulate and visually display numerous types of data for easy comprehension. GIS is a technology for managing and processing location and related information. It visually displays the results of traffic accident analysis has been pursued towards improving the efficiency and effectiveness of traffic accident countermeasures. Also, GIS would make analysis less time consuming and less tedious which otherwise would become very labour intensive. Thus, GIS will offer a platform to maintain and update accidents record database and use it for further analysis.

Various road safety strategies and countermeasures have been used at different stages of network development. This method of seeking to prevent road accidents mainly involves conscious planning, design and operation roads. One of the most important factors in this method is the systematic identification and treatment of hazardous locations. The main objective of the study presented in this paper is to develop a model necessary to identify these hazardous locations on roads commonly termed as black spots. In general, the various factors that cause accidents can be broadly categorized into road related, vehicle related and driver related. In this paper, an attempt is made to implement the road related factors for predicting the accident-prone points on roads and thus help in identifying the required remedial measures.

Methodologies for predicting accidents have been widely studied in the past. The prediction models are mostly causative types in which the number of accidents is taken as a function of number of independent variables. Recently there have been studies to identify accident-prone locations using GIS. The most common methodological approach used in the research efforts to model interaction between the highway geometries, traffic characterization and accident frequency is regression analysis. The ease of modelling readily favours the regression approaches. However, such methods are highly dependent on traffic flow data like average daily traffic (ADT) and data collected by the traffic police from the accident sites. But traffic flow data rarely available in sufficient quantity or accuracy to justify these regression approaches. Moreover, the traffic police may not be able to collect all the necessary data required to carry out the analysis using that data.

This paper presents a methodology using Kernel density estimation of traffic crash data in Geographical Information Systems based on one-year (2012) traffic crashes of medium size city, Vadodara. Minor, major and fatal traffic crash data used in this study are collected from Vadodara police department. Traffic crash location of each crash has been worked out based on description given in the First Information Report (FIR) of police record. Minor, major and fatal traffic crash are geo-registered on GIS platform over road network of the city. Kernel density maps are plotted and hazardous road intersections and midblock segments are presented.

LITERATURE REVIEW

Density analysis takes known quantities of some phenomena and spreads it across the landscape based on the quantity that is measured at each location and the spatial relationship of the measured quantities. Kernel density estimation[2] considered a more refined statistical hot spot identifier when compared to cluster analysis. It involves placing a symmetrical surface over each individual point, evaluating the distance from that point to a referenced location based on mathematical function, and summing the value of all surfaces for that referenced location.

Xie and Yan presented a case study[4] of road accidents (year 2005) of Bowling Green, Kentucky and introduced a new approach to estimate the density of accident points. The road network space was represented with basic linear units of equal network length, termed as lixel (linear pixel). All the accidents were assigned to lixels, nearest road segment on which accident was happened. The density value of centre point of a lixel was computed as the sum of kernel-function derived densities from all the source lixels within a specified search bandwidth. The importance of search bandwidth has been studied in this paper taking different search bandwidth like 10, 20, 100, 250, 500, 1000 and 2000 m. It was observed that narrow bandwidths (20, 100, and 250 m) may produce patterns suitable for presenting hotspots at smaller scales. As search radius increases from 20 to 2000 m, the local hotspots gradually combined with their neighbours and larger cluster appeared. It was noted that maps at wider search bandwidth (500, 1000 and 2000 m) seemingly give better sense of locations of the hotspots at larger spatial scales.

Erdogan et al.[5] have studied the road accidents occurred on highway within Afyonkarahisar district of Turkey. The analysis was based on 7634 accidents recorded during 1996 to 2006 on 400 km highway. Accident magnitude values have been calculated per 0.5 x 0.5 km2 areas with a 500 m bandwidth for every year period based on quadratic kernel function with ArcGIS.

Anderson[6] presented a methodology using kernel density estimation to study spatial pattern of injury related to road accidents based on police data from 1999 to 2003 for London. He has also later employed clustering methodology using environmental data to determine casual indicators. He has demonstrated different spatial levels of road accidents and classified clusters on the basis of similar attributes. These clusters were then organised into groups, based on similarity of clusters. The hierarchical process allowed a classification of the road accidents within hotspots or of the environmental and land use of hotspot area.

Prasanna kumar et al.[7] conducted GIS based study using accident data for the year 2008 collected from Thiruvananthapuram city (a South India city). Total 1468 accidents were geocoded as x and y coordinated along with attribute data such as place, month, date, day, time, vehicle type, reason, fatality etc. Moran's I spatial autocorrelation test has been used for spatial pattern analysis. When a Moran's Index comes near +1.0, it is considered as a clustered data, while an index comes near -1.0 data considered as dispersed data. The accident data exhibits clustered pattern when Moran's Index comes greater than 0 and pattern is dispersed when the index is less than 0. The results of spatial analysis finally shown accident hotspots and cold spots. Authors have analysed accidents near religious and educational institutions (spatial) and accidents occurred during monsoon and non-monsoon period (temporal).

Rankavat and Tiwari[9] carried out a study using road accident data for Delhi for year 2006-2009. They have identified accident prone-locations for pedestrians. It was concluded based on geographic distribution of pedestrian victims, the widespread insecurity people experiencing in Delhi while walking. It was observed that roundabout have less number of accidents and clusters of accidents found at intersections and at the foot of flyovers.

Kernel Density Estimation[11] is a non-parametric method to estimate the probability density function of a variable that produces a smooth density surface of point events over a 2-D geographic space (i.e. planar space). KDE tends to produce a smooth density surface of point events over space by computing event intensity as density estimation. The kernel function is usually expressed as a function of the ratio between distance and search radius (bandwidth). The hotspot analysis focussed on highlighting areas which have higher than average road accidents. The clustering analysis has been carried out using road accident data for year 2013 for the state of Indiana

DATA

The road network of the city is digitised using Google Map for Vadodara city and then imported as a shape file in ArcGIS. The road network shown is digitised for major roads and urban highways; not the roads classified as streets. The part of National Highway 48 (previously known as NH 8) is part of the analysis as it is fall under the municipal limits of city. Many victims of road accidents on this NH 48 are residents of the city. The locations were determined based on FIR description, which has been collected from police department. Later with the help of Google Map, the final location of accident has been determined. Every possible attempt has been made to locate the accident spot in terms of latitude and longitude as accurate as possible. Later the Excel worksheet having location data imported in ArcMap module with X, Y data option. The X and Y points represent longitude and latitude of accident place respectively. The other data related to accidents like date, time, road type, collision type and collision spot as well as victim detail like age, gender, injury severity, etc. were recorded as attribute data. These maps are output from ArcGIS software and these maps also helped to decide whether the crash is on mid-block or on intersection by GIS query.

There were 764 traffic injury crashes recorded within urban limits of Vadodara city in year 2012; out of which 45% were minor crashes, 41% major crashes and 14% fatal crashes. Almost 75% crashes occurred on mid-block, while in 36% crashes, victims were non-motorised road users. The maps were generated using Kernel density, which shows hotspots for pedestrians, bicyclists, and motorised two-wheeler riders separately. This paper discusses the pattern of hazardous road locations, land-use around such locations and other significant parameters for different cases. This paper helps the policy makers to take appropriate remedial measures in terms of traffic management to reduce injury crashes and to allocate the fund judiciously to set the priority for improvement.

Total number of road accidents reported in all 16 police stations of Vadodara city is 764 from which minor, major and fatal accidents were 45%, 41% and 14% respectively. There are total 1100 people injured in road accidents; out of which 862 were male and 238 were female. About 86% pedestrian accidents were occurred on mid-block and 9% on intersection. In 50% pedestrian accidents, motorised two-wheeler was the impacting vehicle. The maximum pedestrian accidents occurred while crossing the road. There were 8% (62) road accidents reported bicyclist as victim.

The highest accident risk to bicyclists is from M2W users as in 66% accidents, following by car as an impacting vehicle. The proportion of minor, major and fatal bicycle accident was 63%, 34% and 3%. Majority of the victims were from the young age group bicycle users. The highest 63% bicycle riders were going on work while accident occurred. Social trip and shopping trip have share of 8% and 10% respectively in bicycle accident. Hit from back was the main collision type. There were 75% bicycle accidents observed on mid-block.

Total 605 motorised two-wheeler users injured and 54 killed in 487 road accidents. The proportion of minor, major and fatal road accidents was 45%, 45% and 10% respectively. The most affected victim type is motorised two-wheeler (M2W) and is approached 64% (487) while second most affected victim type was pedestrians 25% (192).

SPATIAL DATA ANALYSIS

The kernel density estimation carried out by spatial analyst tool helps in determining spread of road accidents on road network. It identifies the clusters that defines the area of higher accident risk. Based on spatial dependency, this tool work out the areas having increased likelihood of accidents. This helps in understanding geometric details of the road and land-use nearby these risky clusters. The principle of Kernel function (Anderson 2009) to find out density estimates from individual kernels for spread of accident spots can be given by

$$f(x,y) = \frac{1}{nh^2} \sum_{i=1}^{n} K\left(\frac{d_i}{h}\right)$$

where, *f(x,y)* is the density estimate at the location x,y (expressed as longitude and latitude of accident spot), *n* is number of observed accidents, *h* is bandwidth or kernel size, $d_i$isdistance between the location (x,y) and the location of ith observation

The effect of placing these kernels over accident points is to create a smooth and continuous surface. Each kernel is a circular area of specific bandwidth or search radius. The kernel method divides the entire study region into predetermined number of cells and applies circular neighbourhood around each point (depicts an accident). The quadratic kernel function[12] then applied that goes from being highest at the point of accident to zero at the neighbouring boundary. Individual cell value is assigned to each cell and this is a value of kernel function at the centre. The final density of each cell is calculated by adding its individual cell values. When the search radius is increased (see Figure 1) the circular neighbourhood will include more point features and the result in smoother density function.

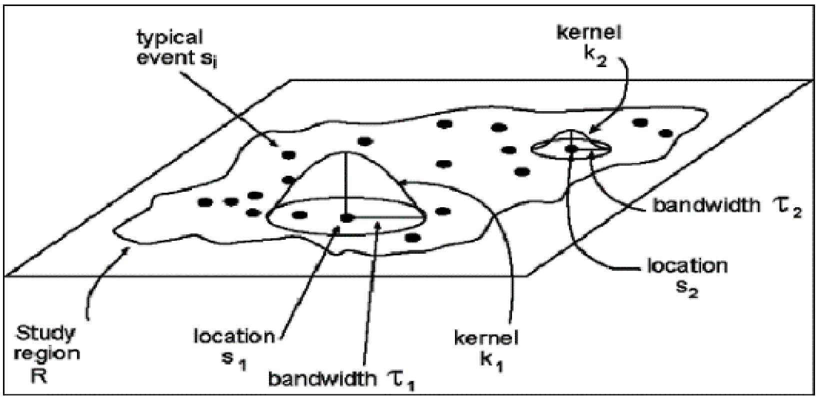

Fig. 1 Diagram explaining how kernel density estimation function work[13]

RESULTS AND DISCUSSION

Separate kernel density maps were generated for pedestrian, bicycle and motorised two-wheeler riders' accidents to identify hazardous locations for the victims of these vulnerable road users. The reason for preparing separate map is the different possible causes for occurring of road accident with these road users

Fig. 2 Kernel density map for pedestrian accidents

The density map for pedestrian accident shows higher accident density on road near railway station and education campus of University. There is heavy pedestrian movements of commuters around railway station and heavy pedestrian movements of students near University's academic area. Some mid-block sections of National Highway-48 where some development has taken place on outskirt of the city. Other areas having higher density of accidents are around main government hospital of the city and some sections having very high commercial activities along road-side. Maximum pedestrian accidents (86% out of total pedestrian accidents) have been observed on mid-block.

Fig. 1 Kernel density map for Bicycle accidents

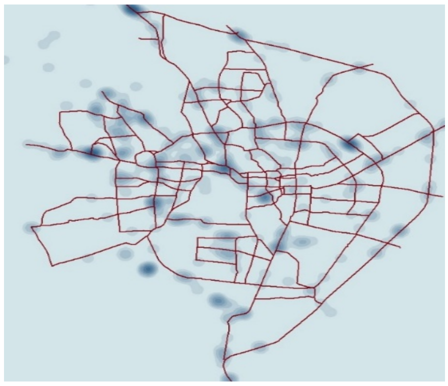

Fig. 2 Kernel density map for motorised two-wheeler (M2W) accidents

The mid-block sections witnessed 75% road accidents out of total bicycle accidents, while 19% accidents were observed on intersections. The proportion of bicycle accidents on National Highway, major roads and streets was 6%, 71% and 23% respectively. High density of bicycle accidents is exhibited on four-lane divided roads where traffic is very high.

The proportion of motorised two-wheeler accidents on NH, major roads and other roads was 12.5%, 61.4% and 26% respectively. More than 70% M2W accidents were observed on mid-block, while 24% accidents were on intersections. Locations with high density of M2W accidents are more on wide divided roads either having on-street parking or road-side commercial activities.

Most of the locations with high density of road accidents for all three types of vulnerable road users are four-lane divided major roads of the city. The presence of hazardous road locations for pedestrians along mid-block sections shows poor road crossing infrastructures. High priority should be given to improve pedestrian safety by providing better road crossing facilities for pedestrians. Within city area, it is also recommended to incorporate pedestrian timing in the traffic signal to increase their safety. Speed is the major responsible for road accidents and as speed is increasing, the accident severity also increases. The accident trend and spatial spread of M2W also shows that their contribution is very high in total road accidents. It is very much needed to reduce the speed of traffic flow by providing speed breaker at all identified locations. The police records should have additional details like exact accident location recorded by GPS, road pavement condition at crash like wet or dry, whether helmet and seat belt was worn by M2W rider and car user or not. Precise location of accident will help to decide the role of geometric design of particular spot along with spatial analysis.

The accidents within high density area and outside this area can be evaluated separately as the causes and accident patterns of these two categories of accidents may be different[3]. Different approach should be taken for remedial measures to be worked out by further study to reduce the road accidents.

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