

Evaluation of accident black spots on roads using Geographical Information Systems (GIS)

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Abstract

Road safety is a major concern in the present situation. There are many steps required to achieve the road safety measures. This paper presents a method by which the accident-prone locations on roads, commonly termed as accident black spots, can be identified. The methodology incorporates a model which implements prioritization of roads for accident occurrence, followed by analysis using a Geographic Information System (GIS). The GIS software used for this purpose is ARCVIEW 3.1. The various factors required for the analysis are modeled using Microsoft Visual Basic6.0 and Microsoft Visual C++6.0 software packages. The model is applied to the road network in the BITS PILANI campus and the results obtained are analyzed to check the accuracy of the model.

Introduction

It has been estimated that over 300,000 persons die and 10-15 million persons are injured every single year in road accidents throughout the world. Detailed analyses of global accident statistics indicate that fatality rates per licensed vehicle in developing countries are very high in comparison with the industrialized countries. Moreover, road accidents have been shown to cost around 1% of annual gross national product (GNP) resources of the developing countries, which they can ill-afford to lose. Hence it is necessary to incorporate steps, which can reduce road accident rates and implement mitigating actions, which can be taken to reduce the number and severity of road accidents. (Baguley et al, 1994)

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 operations of 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 (black spots) on roads and thus help in identifying the required remedial measures (Kalga and Silanda 2002).

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 fuzzy and neural network classifier approaches. The most

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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 modeling readily favors the regression approaches. However such methods are highly dependent on traffic flow data like Average Daily Traffic (ADT) and the data collected by the traffic police from the accident sites. But traffic flow data are 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 (Kalga and Silanda 2002).

Consequently considering all the factors mentioned above, it is necessary to develop a model which can assist in predicting black spots on a given road network without the requirement of the traffic flow data with considerable accuracy. This paper describes a model developed to identify black spots on roads using prioritization and GIS. A road network is distributed over a given area. Hence it always possesses a '*spatial characteristic*' i.e., it always has the geographic locations associated with it. Thus, in order to model a road network, an information system capable of processing spatial data is required. A GIS can easily handle, store, analyze, manipulate and retrieve spatial data. Therefore a model for identifying accident-prone location on roads can be easily implemented using a GIS.

Methodology

The model described in this paper requires a map of the desired road network digitized in a suitable form and certain specified road attributes to carry out prioritization. The analysis then identifies accident black spots on the given road network. While carrying out the analysis the model only incorporates the road related factors such as road geometries, which lead to accidents. The factors considered for evaluating accident prone locations on road are as follows:

- Road width.
- Number of lanes.
- Approximate number of vehicles per day.
- Type of road.
- Drainage facilities.
- Surface condition of the pavement.
- Frequent vehicle type.
- Presence of shoulders, edge obstructions, median barriers and ribbon development.
- Radius of horizontal curve.

In order to model the mentioned factors and achieve the desired result, a step-by-step procedure as given below is adopted.

- 1) Scan the map containing the desired road network and input this image to ARC VIEW for digitizing.
- 2) Digitize the road network with due considerations for separation of every link and assign id number to every link.
- 3) Specify the attributes for every road link using the questionnaire provided.
- 4) Export the road attribute table generated in dbase format so that it can be imported by Arcview.
- 5) Join the road attribute table to the digitized road map and prioritize the road network for accident occurrence using total weights assigned to every link.

- 6) Rasterize the road-network by assigning the absolute minimum radius of curvature as cell values.
- 7) Export the rasterized image (known as Grid in Arcview) in ASCII raster format to obtain a text file.
- 8) Input the text file obtained above to an executable file to determine the suitability of the provided horizontal curves.
- 9) Combine the results obtained by prioritization and curvature analysis to determine the accident black spots on the given road network.

Prioritization of roads for accident occurrence

Prioritization involves assigning suitable weights to different factors so as to achieve a desired result. In this model, the various factors, which tend to influence the occurrence of accidents on roads are assigned weights on a scale of 0-10 in such a manner that the factors which tends to increase the probability of the accidents have *lower* weights. These factors are entered into the model using a user-friendly graphical interface developed using Visual Basic6.0. Thus the road attributes along with their suitable weights can be easily assigned to the given road network. In order to prioritize roads for occurrence of accidents, the various factors considered and the weights assigned to them are given in following table.

Table 1.1 Factors used in Prioritization with their weights

Factors affecting occurrence of accidents	Possible variations	Weights Assigned
Number of lanes in each direction	0	2
	1	4
	2	6
	3	8
	4	10
Approximate number of vehicles per day	Less than 1000	10
	Less than 2500	7
	Less than 5000	4
	Greater than 5000	1
Width of the road	Single lane 3.75 m	2
	Two lanes without raised kerbs, 7.0 m	4
	Two lanes with raised kerbs, 7.5m	6
	Intermediate carriageway	8
	Multi-lane pavements	10
Type of road	National Highway	10
	State Highway	8
	Major District Roads	6
	Other District Roads	4
	Village Roads	2
Drainage facilities provided	Good	10
	Satisfactory	7

	Poor	4
	No Drainage	1
Surface condition of the pavement	Concrete	10
	WBM	8
	Surface Painted	4
	Other Bituminous	6
	Earth Roads	2
Frequent vehicle type on the road	Bus / Truck	2
	Car	4
	Two Wheelers	6
	Bicycles	8
	Carts	10
Presence of shoulders	Yes	10
	No	4
Presence of edge obstructions like advertising hoardings, trees etc very close to the road	Yes	4
	No	10
Provision of median barriers to channelize the traffic	Yes	10
	No	4
Presence of ribbon development near roads	Yes	4
	No	10

The final weight assigned to each road link is obtained by adding all the individual weights and normalizing the value using maximum weight (in this case 110) that can be assigned.

Hence,

$$\text{Total weight} = (\sum \text{Individual Weights}) \times 100 / 110.$$

Thus road links with high final weight are less prone to accidents than the road link with low final weight. The classification of roads for occurrence of accidents based on final weights is done using the following classification scheme.

Table 1.2 Prioritization Scheme

Final Weight (%)	Accident Prone Level
80 - 100	Very Low
60 - 80	Low
40 - 60	Medium
0 - 40	High

Principles of Horizontal Curves

A horizontal highway curve is a curve in plan to provide change in direction to the central line of a road. Horizontal curves are part of the geometry of a roadway. They are geometrically

sections of circles. The geometry is thus quite simple. As there is no universal notation, the most used are shown in the following figures.

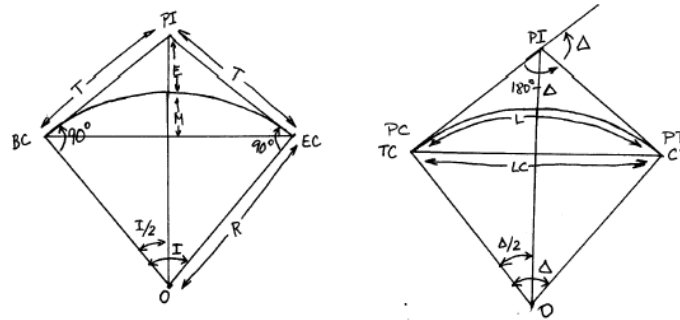


Fig 1.1 Notations for Simple Circular Curves

Beginning of Curve - This is represented as BC and corresponds to the point where the road enters the curve. At this point, the road becomes tangent to the curve. This point is also known as TC (Tangent to Curve) or Point of Curvature (PC).

End of Curve - This is represented as EC and corresponds to the point where the road exits into the second road. At this point, the curve meets the tangent road. This point is also known as CT (Curve to Tangent) or Point of Tangency (PT).

Point of Intersection - This is represented as PI and corresponds to the point of intersection of the extended entering and exit roads to the curve.

Tangent - This is represented by T and corresponds to the distance between the BC and the PI. The exiting tangent corresponds to the distance between the PI and the EC, which is similar to the entering tangent, due to the symmetrical characteristics of an arc of circle.

Radius - This is represented as R and corresponds to the radius of the arc that is tangent to both the entering and exiting roads.

Interior Angle - This is represented as I and corresponds to the angle measured at the origin of the arc (O), from the direction of the BC to the EC. This can also be represented by Δ . It is very important to notice that, by geometry, the angle between the extension of the entering tangent and the exiting tangent is also Δ . The angle between the direction of BC (or EC) and the PI is half of the interior angle $\Delta/2$.

Length of Arc - This is represented by L and corresponds to the distance along the curve between the BC and the EC.

Length of Long Chord - This is represented by LC and corresponds to the distance between the BC and the EC in an Euclidian straight line.

Middle ordinate - This is represented by M and corresponds to the distance between the chord and the arc of the curve, measured along the bisector of the arc. The bisector of the arc is the line from the origin O to the PI.

External distance - This is represented by E and corresponds to the distance measured along the arc bisector, from the arc to the PI.

Radius of Horizontal Curve

When a vehicle traverses a horizontal curve, the centrifugal force acts horizontally outwards through the center of gravity of the vehicle. The centrifugal force developed depends on the radius of the horizontal curve and the speed of the vehicle negotiating the curve. This centrifugal force is counteracted by the transverse frictional resistance developed between the tyres and the pavement which enables the vehicle to change the direction along the curve and to maintain the stability of the vehicle. Centrifugal force P is given by the equation:

$$P = (W \times v^2) / (g \times R), \text{ where}$$

P = centrifugal force, kg
 W = weight of the vehicle, kg
 R = radius of circular curve, m
 v = speed of vehicle, m/sec
 g = acceleration due to gravity = 9.8 m / sec²

The ratio of the centrifugal force to the weight of the vehicle, P/W is known as the centrifugal ratio or the impact factor.

Thus,

$$\text{centrifugal ratio} = v^2 / gR$$

For a certain speed of vehicle, the centrifugal force is dependent on radius of the horizontal curve. To keep the centrifugal ratio within a low limit, the radius of the curve should be kept correspondingly high. The centrifugal force, which is counteracted by the super elevation and the lateral friction is given by the relation

$$e + f = v^2 / gR = v^2 / 127R$$

where, e = rate of super elevation; the maximum value of e is taken as 0.07 at all the regions except at hill roads without snow where it is taken as 0.1; f = design value of transverse skid resistance or coefficient of friction, taken as 0.15

Hence,

$$e + f = 0.07 + 0.15 = 0.22 = v^2 / gR = V^2 / 127R$$

Thus the ruling minimum radius of the curve for ruling design speed v m/sec or V Kmph is given by:

$$R_{\text{ruling}} = v^2 / (e + f)g$$

$$R_{\text{ruling}} = V^2 / 127(e + f)$$

When the minimum design speed V' Kmph is adopted instead of V Kmph, the absolute minimum radius of horizontal curve R_{min} is given by:

$$R_{\text{min}} = V'^2 / 127(e + f)$$

The absolute minimum values of radii of horizontal curve of various classes of roads in different terrain (as per the latest IRC specifications) is given in the following table.

Table 1.3 Minimum Radii of Horizontal Curve for Different Terrain Conditions, m

Classification of roads	Plain Terrain	Rolling Terrain	Mountainous terrain in areas not affected by snow	Mountainous terrain in snow bound areas	Steep terrain in areas not affected by snow	Steep terrain in snow bound areas
National	230	155	50	60	30	33

Highways and State Highways						
Major District Roads	155	90	30	33	14	15
Other District Roads	90	60	20	23	14	15
Village Roads	60	45	14	15	14	15

Algorithm for Determining Radius of Horizontal Curve

The radius of horizontal curve for the given road network is determined using an algorithm given in the flowchart. This algorithm is implemented in Visual C++. The algorithm is designed to determine the radius of simple circular curves and determines if the radius provided is greater than the minimum radius required.

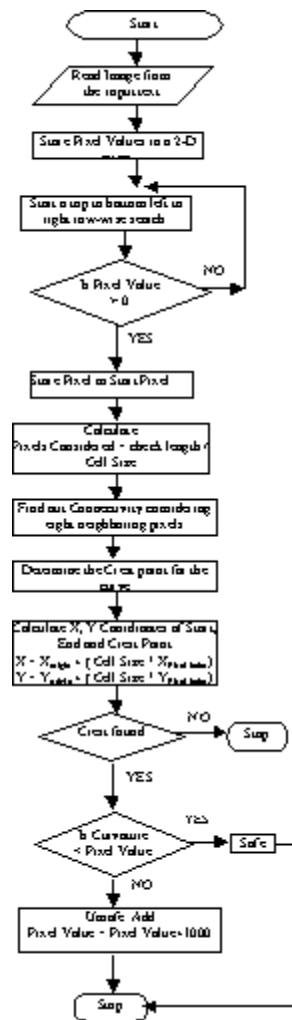


Fig 1.2 Flowchart for Curvature Analysis

GIS Technology

A Geographic Information System (GIS) is a computer system for capturing, storing, querying, analyzing and displaying geographic data. GIS represents a new paradigm for the organization of the information and the design of information system, the essential aspect of which is the use of concept of location as the basis of structuring of information systems. GIS technology can be viewed as an offshoot from two major software technologies i.e., database management system (DBMS) and computer aided design (CAD), with the addition of specialized functions for managing and analyzing spatial data i.e., data that can be referenced to a geographical location. The objective of any GIS system is to capture, store, manage, analyze, and visualize geographical data.

GIS is a powerful computing tool for managing large amounts of heterogeneous data. A GIS can be effectively used to identify accident black spots on roads. The capability of GIS to link attribute data with spatial data facilitates prioritization of accident occurrence on roads and

the results can be displayed graphically which can be used for planning and decision making. The process of rasterization, which involves conversion of vector data into raster data, helps in determining the suitability of horizontal curves provided on the roads. The results thus obtained can be combined using spatial and aspatial queries to obtain the desired results.

In the present study, GIS analysis is performed using ARCVIEW GIS 3.1 package. The road theme is classified for prioritization using classification theme mentioned in table 1.2. The results of Prioritization and Curvature Analysis are combined using a query which finds places on low accident prone level roads and having critical curve points. The results obtained are the required accident black spot locations

Case Study

The methodology developed for evaluating accident black spots on roads was applied for road network in BITS Pilani Campus. The results obtained are given below.

**Digitized Campus Road Map
(with link ID)**

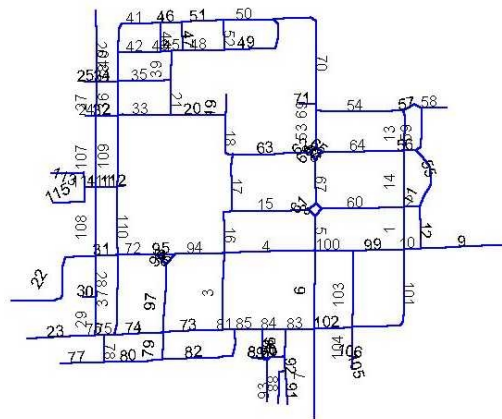


Fig 1.3 Road Network in BITS Pilani Campus

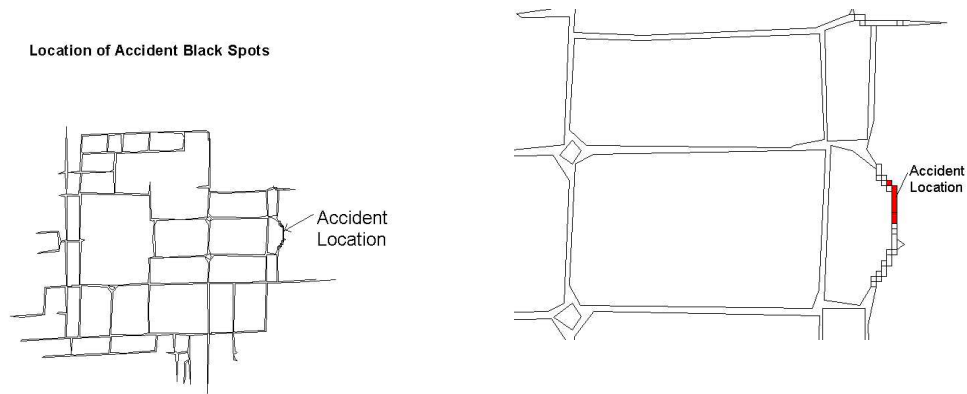


Fig 1.4 Location of Accident Black Spots

Conclusion

The main advantage of using this approach for identifying accident black spots on roads is that it requires very less additional data other than the road network map. So the results obtained from this model can easily be used for planning road safety measures. Also these can be supplemented with the results obtained by using other approaches. Moreover the results can act as a quick guideline for road network planners and the authorities concerned with accident mitigation measures.

However the accuracy of this model highly depends on the way in which the road network is digitized. The road geometry can be inferred incorrectly if it is not properly digitized. Even the selection of proper resolution during rasterization and suitable check length for curvature analysis can affect the results.

References

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