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Road safety evaluation using GIS for accident analysis

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Abstract

It is a very complex task to carry out safety analysis on an existing road network since it requires a detailed knowledge of all those factors that determine the dangerousness of the infrastructure.

In order to obtain good results, it is necessary to have complete and reliable information related to accidents, infrastructure features and traffic conditions.

It could be complex to manage simultaneously such different information, above all when it is necessary to carry out analysis on wide road networks. In such cases the organization of the information in databases is fundamental, their architecture must be planned opportunely also in consideration of the georeferencing requirement of some data. For this reason the use of Geographical Information Systems (G.I.S.), which allow the integration of alphanumeric information with cartographic data, is extremely effective

In this paper the procedures for analysis of the accident prone locations on two-lane rural roads have been defined with an effective use of G.I.S. to check safety conditions on existing roads. Using a specific GIS tool, a cluster analysis of the accidents in respect of their location along the road, led to a road segmentation with better results than the traditional approach.

1 Introduction

The target of the European Community program "European Transport Policy for 2010: time to decide" is for the reduction within 2010 of 50% of road fatalities. Such an ambitious target can only be reached by operating in a coordinated way on all the components of driver-road-vehicle-environment system, using a Safety Management System (SMS) approach. Such a way is the most suitable one to

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identify, select and implement effective strategies and road safety interventions involving all areas: Engineering, Enforcement, Education and Emergency, Cafiso *et al* [1]. In the SMS the Road Agencies liability and capacity is fundamentally on road factors and then in the Engineering field.

In this extent, due to the complexity of the problem, it is necessary to have an adequate methodology and an exact knowledge and organization of all information needed to entirely define both accident phenomenon and road characteristics.

For this reason, the use of Geographical Information System (GIS) which allows to manage simultaneously and to compare different information also referring to their location in the road network, is very helpful.

2 Safety evaluation on existing roads

For existing roads, accident analysis represents an effective procedure able to highlight particular risk conditions, characterized by an anomalous accident recurrence on specific road stretches.

The identification of hazardous locations allows one to find those road sections showing an accident rate (AR) greater than the expected one in normal conditions.

AR is defined for each stretch as the ratio of the observed number of accident and the risk exposure (given by the product of all traffic flow in the observed period for the stretch length). AR must be referred to homogeneous sections coming from a preliminary segmentation of the road, usually defined respect to geometric, traffic and environmental characteristics. Based on the use of the GIS tools, in the paper also a different procedure for the segmentation is defined.
The accident rate is given by the following formula:

$$AR_i = \frac{N_i \cdot 10^6}{\ell_i \cdot 365 \cdot \sum_t AADT_{it}} \qquad (1)$$

in which:

N_i = overall accident number on the i-th section in the investigated period;

ℓ_i = length of the i-th stretch (km);

$AADT_{it}$ = average annual daily traffic on the i-th section in the t-th year (millions of vehicles);

t = number of years of the investigated period.

The investigated period has to be at least two years long to be significant and no longer than five years in order to avoid non stationary phenomena.
The procedure to identify blackspots is normally based on statistical control of quality. The control is carried out on the hypothesis of the Poisson statistical distribution of accidents that better describes the phenomenon, on the basis of which the control limits for a level of confidence (δ) can be individuated.

Such values describe the casual variation of AR around the expected value into which the phenomenon should occur with a probability of (1-δ).

Therefore, stretches showing an accident rate (AR_i) higher than the upper limit of confidence interval, are defined as Blackspots.
The upper control limit (UCL) was calculated with the equation:

$$UCL = AR_R + k_\delta \sqrt{\frac{AR_R}{\ell_i \cdot 365 \cdot \sum_t AADT_{it}} + \frac{1}{2 \cdot \ell_i \cdot 365 \cdot \sum_t AADT_{it}}} \qquad (2)$$

where:

AR_R = average accident rate;

k_δ = value of the standard normal variable for a level of confidence δ.

The last term of the expression is due to the Poisson discrete distribution.
In order to calculate AR_R, the mean accident rate evaluated for a roads sample with geometrical characteristics similar to the investigated ones was used.

$$AR_R = \frac{\sum_i N_i}{\sum_i E_i} = 0.19 \quad [\text{accident} / 10^6 \text{ vehicles per km}] \qquad (3)$$

where:

E_i : exposure of the i-th section in the investigated period (10^6 vehicles × km).
As a matter of fact this procedure doesn't take into account the "regression to the mean" phenomenon and for this reason it can show errors in the exact location of black spots. Even though, there are researches related to methodologies more accurate, Cafiso *et al* [2], Higle *et al* [3], this procedure allow to achieve useful results considering its very simple applicability.

After the localization of black spots, a phase of detailed study of each accident occurred at those sites, can be carried out with the aim to verify the recurrence of one or more type of accident (dominant accident). Since, possible defects in the system road-traffic-environment can be associated to different accident typologies, the identification of the "dominant accident" will lead to define a list of "possible defects", D'Andrea *et al* [4] (table 1).

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Table 1: Correspondence of possible road, traffic and environment defects with accident type.

Accident Type	Possible Road Defects	Possible Traffic Defects	Possible Environment Defects
Head On	Sight distance, horizontal and vertical alignment, cross section width, horizontal and vertical sign, pavement	Speed, overtaking, value and composition of traffic flow, vehicle gap	Lighting, weather conditions, work zones
Side	Horizontal Sign, acceleration lane, deceleration lane, interchange	Value and composition of traffic flow, speed, vehicle gap	Work zones
Front/ Side	Sign, junction geometry, lighting	Traffic flow value, speed, observance of highway code	Sight obstacles, weather conditions, work zones
Rear End	Sight distance, horizontal and vertical alignment , junction, pedestrian crosswalk, sign, pavement	Traffic flow value, speed distribution, vehicle gap	Distraction causes, weather conditions, lighting, work zones
Hit permanent obstacle	Lanes width, horizontal sign, presence of lateral hazard elements, gutters, roadside, pavement.	Speed	Permanent obstacles, (trees, poles, buildings), weather conditions, work zones
Hit temporary obstacle	Sight distance, cross section width, horizontal sign , lighting, roadside	Speed, load hits vehicle	Sight obstacles, weather conditions, lighting, urbanization.
Out of control with non collision	Horizontal and vertical alignment, sign, pavement, lighting, lack of guardrails	Speed, traffic flow composition	Weather conditions
Pedestrians and Cyclists	Horizontal and vertical alignment, pavement, sight distance, sign, cross section	Value and composition of traffic flow, speed.	Presence of pedestrians or cyclists
Animals	Horizontal and vertical alignment, pavement, sight distance, sign, fencing.	Speed	Presence of animals

3 Database and GIS implementation

Data belong to the GIS designed for the management of road network were used in order to completely execute accident analysis, Pellet *et al* [5].

This GIS allows to represent and to manage simultaneously different information, visualizing the characteristics of the road and in particular:

1. cross section data (type, lanes and shoulders width);
2. geometric elements type (tangent, circular curve, transition curve);

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3. bending radius value;
4. curvature angle deviation;
5. length of geometric elements;
6. location and typology of junctions;
7. mile stones location;
8. geometric and mile stones distance of the beginning and ending points of each geometric elements.

Moreover the GIS is arranged for the dynamic segmentation of the road axis on the basis of geometric and mile stones distance of the beginning and ending points of the stretch. Furthermore the database contain traffic information on different road stretches (AADT, percentage of heavy vehicles).

Information on type and location of accidents, happened in the period 1997 – 2001 with at least an injury or fatality, have been inserted in the GIS, too.

4 Using GIS for road accident analysis

On a sample of about 180 km of two lane rural roads, a segmentation into homogeneous stretches was carried out on the basis of the information on geometric characteristics (lengths of tangents, bending radius and lengths of curve) and on traffic flow conditions. All information joined to safety evaluation were linked to each stretch: number of accidents in the period 1997÷ 2001, traffic flow in the same period, accident rate and control limit calculated with a 2-tailed confidence level of 90 %. In this way it was possible to identify all stretches in which the accident rate is greater than upper limit.
These stretches in the GIS define the theme "Stretch Blackspot" (figure 1).

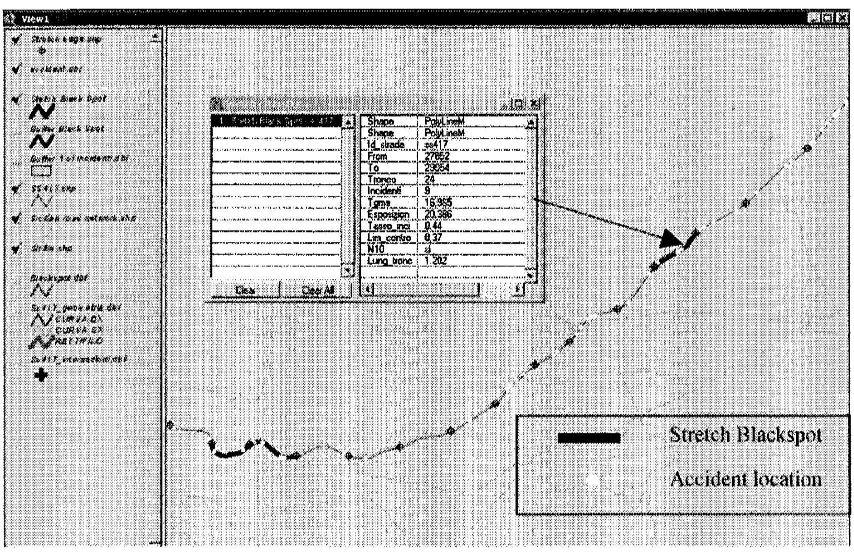

Figure 1: View of theme "Stretch Blackspot" in the GIS

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Using the GIS, a cluster analysis of the accidents respect to their location along the road, may lead to a road segmentation different from the previous one. Considering an "influence distance" of 150 meters for each accident respect its location along the road, a nearest neighbour cluster aggregation was conducted. Using the "Buffering" GIS tool, it was possible to clustery all the accidents nearest than 150 m. On these elements the quality control check was applied to verify the statistical significance of the accident rate respect to the 90% level of confidence to define new blackspots called "Buffer Blackspot" (figure 2).

The comparison between "Buffer Blackspots" and "Stretch Blackspots" showed a better ability of the former to identify those parts of the road where an aggregation of accidents occurs. In the case study, all sites identified as Stretch Blackspot were also identified as Buffer Blackspot. Moreover, some sites that were not identified with the Stretch procedure were identified as Buffer Blakspot due to a different correspondence between accidents and road segments (figure 2).

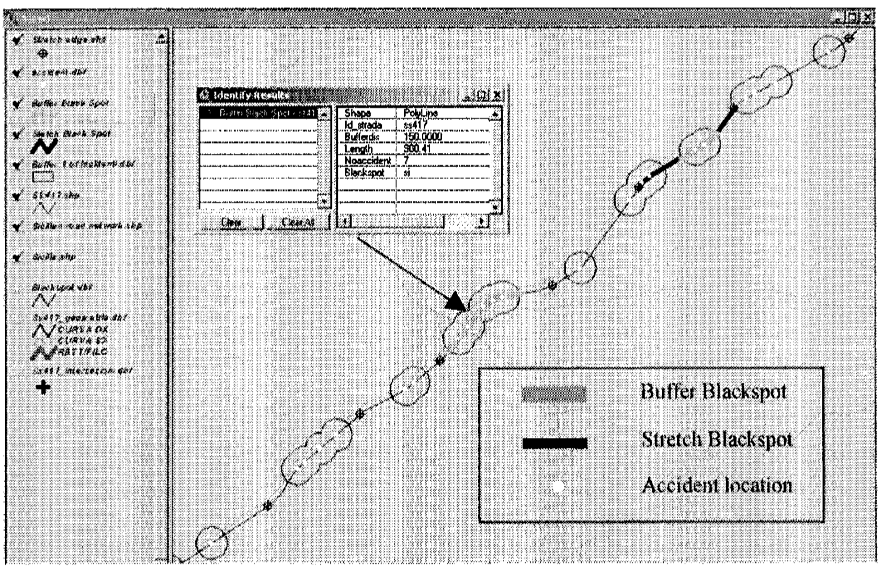

Figure 2: Comparison of themes "Stretch Blackspot"and "Buffer Blackspot"

For each stretch identified as blackspot, the GIS defines all information related to each accident belongs to it. For these accidents it was carried out a frequency analysis respect to the accident type in order to determine the "dominant accident" to which is associated the list of possible defects. (table1).

As example, in the figures 3, the frequency analysis of accident type for a Buffer Blackspot is shown. The stretch has a length of 1393 m with 18 accidents and an accident rate of 0.65 very higher respect to the upper limit of 0.34. The dominant accident type is "out of control" with 9 of 18 accidents. This type can be associated with horizontal and vertical alignment inconsistencies (table 1) that in the GIS can be associated with a sharp curve (180 m of bending radius) after a long tangent of 917 meters (figure 4). Furthermore this typology can also be associated with problems related to pavement conditions, lack of guard rails and road sign. The buffer segmentation includes also a junction that could be also cause of the other accidents localized in that area.

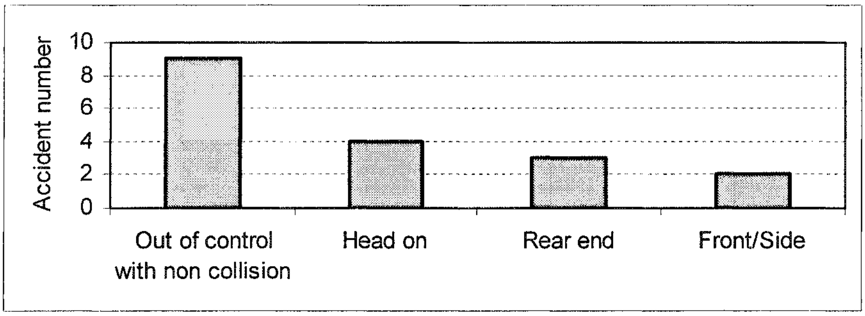

Figure 3: Frequency analysis of accident type for a Buffer Blackspot

The example shows as in the same site there was also a Stretch Blackspot due to the great number of accidents but the Buffer Blackspot better identify the part of the road where the accidents are clustered.

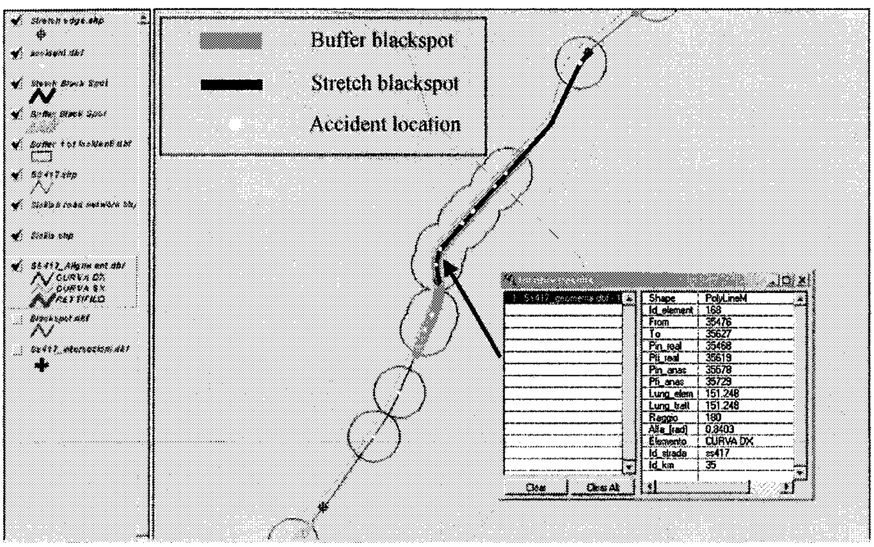

Figure 4: View of attributes of the theme "Axis elements" in the GIS

5 Conclusions

For existing roads, accident analysis represents an effective procedure able to highlight particular risk conditions, characterized by an anomalous accident recurrence on specific road stretches.

For this analysis it is very helpful the use of Geographical Information System (GIS) which allows to manage simultaneously and to compare different information also referring to their location in the road network.

Using a specific GIS tool, a cluster analysis of the accidents respect their location along the road, leaded to a road segmentation with better results respect to the traditional approach based on stretches defined respect to geometric, traffic and environmental characteristics. The comparison between "Buffer Blackspots" and "Stretch Blackspots" showed a better ability of the former to identify those parts of the road where an aggregation of accidents occurs.

Obviously the risk condition, and then the solution to the problem has not to be researched into each single stretch, but it is necessary to evaluate the overall safety in the alignment portion to which it belongs to.

Acknowledgements

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