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RISK RANKING ON EXISTING TWO-LANE RURAL ROADS WITH RESPECT TO ALIGNMENT AND AT GRADE INTERSECTIONS

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Abstract

The objective of this paper is the elaboration of a suitable methodology capable of deploying elements that characterize the existing infrastructure on two-lane rural roads, regarding road geometric elements (horizontal and vertical alignment, superelevation, sight distance), as well as location and geometric elements of intersections with the scope to evaluate the built-in road safety. The overall target is the utilization of these elements to lead to evaluation coefficients that point out the risk level of the examined road sections, as well as the critical areas, in terms of safety levels, curved sections and intersections. In this context, a hierarchy of critical parameters affecting the risk rating of a road network with respect to geometric design and at-grade intersections was primarily carried out. Appropriate mathematical equations were created for each parameter, based on current road design guidelines and the corresponding Crash Reduction Factors (CRF) presented in the literature. Initially, case studies were conducted, out of which special diagrams were produced to assess the risk level of each parameter. Subsequently, a basic statistical analysis of the results was carried out , using regression factors aiming at developing an appropriate mathematical model for the estimation of the risk level. The same analysis was performed for each parameter separately and appropriate weight coefficients were sought in order to obtain a combined rating that characterizes each road section, while at the same time identifies those critical intersections that present high probability of accident occurrence. Finally, data were collected from a significant sample of the existing two-lane road network of Greece, about 1000km of road network with more than 4000 intersections (unpaved road intersections were also included), in order to assess the results of the proposed methodology.

Keywords: two-lane rural roads, horizontal and vertical alignment, superelevation, sight distance, road safety

1 Introduction

This research was inspired by the fact that around 51 % of the fatalities in Greece [1], 55 % in Europe [1] and 51 % in USA [2], relate to incidents occurring in rural two-way highways. A characteristic of the majority of accidents in these road sections are the inconsistent, for the road condition, traffic velocities, which in combination with the inconsistency of geometric design often lead to violation of driver's expectation and increase the likelihood for potential accident occurrence. Moreover, many existing intersections studied and constructed many years ago are characterized by a poor geometric design, while the lack of adequate roadway

signing and the inadequacy of required sight distances, further increase the occurrence of incidents in these locations. The existing intersections that are not complying with the updated regulations need to be demonstrated through a quick evaluation in order to upgrade them.
In this framework the objective of the present research is to develop a methodology that exploits a great amount of data regarding the existing infrastructure on intersections collected in a very short time, while appropriate mathematical calculations are arising and rating intersections with an increased chance of road accident occurrence, aiming at proper care and prevention.

2 Literature review

A fundamental parameter influencing the safety of a road section is the operating speed of moving vehicles. It is noted that the V_{85} operating speed has been used in the literature in order the road construction to be evaluated on the basis of its deviations from the design speed V_e and also from the deviation shown by the V_{85} operating speeds between two consecutive and independent geometric elements of the road (two successive curves, a curve and an independent tangent, etc.) [3-8]. The limits established internationally are defined as follows:

- Correlation between operating speed V_{85} and design speed V_e

<u>Case 1:</u>	Good quality design	$\lvert V_{85} - V_e \rvert \leq 10$ km/h
<u>Case 2:</u>	Medium quality design	10 km/h $< \lvert V_{85} - V_e \rvert \leq 20$ km/h
<u>Case 3:</u>	Poor quality design	$\lvert V_{85} - V_e \rvert > 20$ km/h

- Correlation between the operating speeds V_{85} of two consecutive geometric elements on the road

<u>Case 1:</u>	Good quality design	$\lvert V_{85i} - V_{85i+1} \rvert \leq 10$ km/h
<u>Case 2:</u>	Medium quality design	10 km/h $< \lvert V_{85i} - V_{85i+1} \rvert \leq 20$ km/h
<u>Case 3:</u>	Poor quality design	$\lvert V_{85i} - V_{85i+1} \rvert > 20$ km/h

Based on the above methodology each individual curve of every road section is evaluated (by considering the long tangents as an independent element) and the spots with a deviation of more than 20 km/h are defined in order to propose improvement measures. The philosophy of the methodology lies in the fact that roads with better consistency lead to smaller operational speed differences occurring along each road section and therefore to an improved road safety level, based on crash rates collected from historic research.
The utilization of the above methodology is based on the determination of the operating speed V_{85}, either by actual on-field measurements, if the road is in operation, or otherwise by appropriate mathematical expressions that are being presented in the literature. The estimation of operating speed has been adopted by many researchers in the past and many mathematical expressions have been presented that estimate operating speed V_{85} [9-13]. All mathematical relationships include the horizontal curve radius R (or the curvature 1/R) and several additional parameters that have been utilized, such as CCR (Curvature Change Rate), road width, length of the circular arc, deflection angle, longitudinal gradient, etc. In many cases, the above methodology and the mathematical expressions have been integrated into the State regulations, and is used until today.

3 Contribution of operating speed V_{85}

In this framework the research has tried to combine all the evaluation parameters of intersections, with the magnitude of speed and at the same time enable the execution of the method for any speed, that the researcher desires to use (design speed, allowable speed, operating speed etc.).
This research adopts the use of the V_{85} operating speed as being more appropriate, considering that it incorporates most of the travelling vehicles (85 % of the vehicles) and that has often been adopted in the bibliography by a mathematical expression in relation to the CCR (Curvature Change Rate) of the road. Because the present research took place by utilizing data from Rural two-lane highways located in Greece, the mathematical expression of operating speed presented in the Greek Regulations [1] is used, incorporating the longitudinal gradient, as resulted from recent measurements. The mathematical expression used in this research is presented as follows:

$$V_{85} = \frac{1000000}{10150.10 + 8.529 \cdot K_E} + 5 \cdot (b - 3.75) + 25 \cdot \bar{s} \tag{1}$$

where:
V_{85} (km/h) - the operating speed;
K_E (grad/km) - the CCR of the considered road section;
b (m) - the width of the traffic lane;
$\bar{s}$ (-) - the mean gradient of the considered road section

It is noted that the operating speed resulting from this mathematical expression refers to Rural two-lane highways in free flow conditions. In intersection areas the operating speed is assumed to be lower [14], but at this time the relative research is rather poor, in order to define a new mathematical expression concerning the operating speed levels in the functional area of an intersection. By deploying the operating speed levels of the highway outside the functional area of the intersection it is anticipated that the analysis presented herein will be on the conservative side.

4 Critical parameters that are taken into account

In this new attempt it was not possible to exploit and evaluate all the parameters that may affect the provided road safety at intersections and road alignment. In this context, specific parameters have been selected, which are considered to be the most critical in this section. For each parameters an attempt was made to extract a mathematical expression of hazard level based on the bibliography as presented in Greece and worldwide. In the present study, in order to examine the hazard level of an intersection, the following parameters were evaluated:
1. Required stopping sight distance and intersection sight distance
2. Required time for safe passing
3. Adequacy of right-turn and left-turn lanes
4. Existence or absence of triangular or dividing islands
5. The vertical and horizontal signage both along the major and the minor road.
6. The appropriate road lighting of the intersection
7. The operating speed V_{85} of the major road, as calculated by expression (1).

It is noted that roundabouts have not been considered as they eliminate the concept of free and uninterrupted flow on the major road, a parameter which is a basic prerequisite in this methodology. Hereafter follows a brief description of mathematical expressions that char-

acterize the hazard level as determined by Greek and international bibliography, using the basic expressions of science and traffic dynamics. Also, in order to examine the hazard level of a road section, the following parameters were evaluated:
1. Minimum radius of horizontal curve
2. Radius of consecutive horizontal curves
3. Longitudinal gradient of the road (influences only the operating speed V85)
4. Required superelevation in the horizontal curve
5. Required stopping sight distance
6. The operating speed V85 of the major road, as being estimated by expression (1)

5 Methodology application

The methodology for evaluating the geometric elements and intersections of a road network, as presented in the previous paragraphs, took place on approximately 1000 kilometers of existing Rural two-lane highways in Greece. To extract the geometry of each road axis, a topographic survey was made using appropriate instruments placed on the roof of a moving vehicle and synchronized to take a speck every 3-5 meters. The vehicle made a go and return on each road section to capture the right and left boundaries of each road. With proper processing of the X, Y, Z coordinates, the axis of the road was produced as the geometric mean of the two boundaries. Finally, through the generated X, Y, Z coordinates, the horizontal and longitudinal elements were extracted to be used in the calculation of the operating speed, as shown by the expression (1). In order to accelerate the procedure, the FM17 road design software (upgrade of H12 road design software used in the past [15]), has been used. It should be noted that for the majority of the road axles that were examined there were no data of existing superelevations available and for this reason the coefficients concerning the superelevations were ignored.

5.1 Geometry evaluation

After determining the horizontal and vertical alignment, as well as the superelevations in the curves (wherever possible), there were all the necessary elements to complete the evaluation of the geometry of each road.

5.1.1 Rankings of individual horizontal curves
- Rating from 0 to 50 corresponds to high level of road safety.
- Rating from 50 to 100 corresponds to medium level of road safety.
- Rating from 100 to 150 corresponds to low level of road safety.
- Rating above 150 corresponds to very low level of road safety.

Each road section, depending on the final rating, was evaluated over the level of road safety, according to limit values, which resulted from correlation with reported road accidents:

5.1.2 Rankings of road sections
- Rating from 0 to 150 corresponds to high level of road safety.
- Rating from 150 to 300 corresponds to medium level of road safety.
- Rating from 300 to 450 corresponds to low level of road safety.
- Rating above 450 corresponds to very low level of road safety.

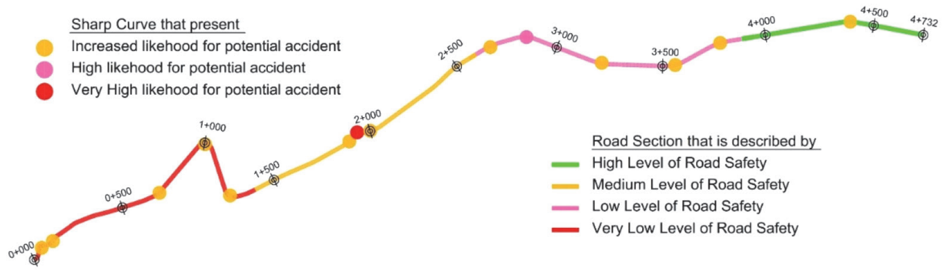

Figure 1 Graphic Colour Presentation of Road Sections Depending on the Level of Road Safety/Highlighting of Hazardous Horizontal Curves

5.2 Intersection evaluation

In order to evaluate each intersection, an attempt was made to collect all the elements described in the previous paragraphs. The angle of intersection, the geometric features of the left and right-turn lanes and the existence of the dividing island were extracted through the Google Earth maps, while the adequacy of lighting was evaluated through the Street View feature that provides the same software. The existing vertical signage and the assessment of traffic volumes were made by appropriate video recordings.
At the same time, the results of the evaluation of each intersection were summed up to determine the total coefficient of each road section, as divided into segments of 1-2 kilometers length. The purpose of this process is to evaluate furthermore the number of intersections in a road section. This marks the road sections that are highly rated due to the high frequency of intersections even if these intersections have a low score. In this context, all the hazard coefficients of individual intersections located within the same road section are summed up. The resulting total coefficient is divided by the length of each road section L and a weighed factor per kilometer is calculated and characterizes each road segment.

5.2.2 Methodology for an independent intersection

Many parameters can be estimated in a very short time by using the information taken by the Google Earth images, as shown in figure 1, like the intersection angle, the existence of a left or right turn lane, the width of the left turn lane, the existing lightning poles and the vertical signage (through Street View operation). Other parameters need to be taken from the site, like the slope of the minor road, the traffic volumes, while the geometry of the major road can be exported from topography measurements. Operational speed can be measured or calculated by the equation (1).

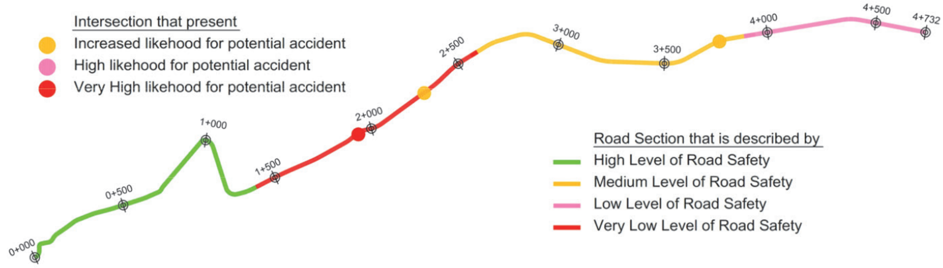

Figure 2 Graphic color presentation of road sections depending on the level of road safety/Highlighting of hazardous intersections

5.3 Total score

Finally, the sum of the above scores determined the final hazard level of the road sections, while the critical positions of the road network were determined from the previous stages. The color presentation based on the hazard level of both geometry and intersections is shown in Figure 3.

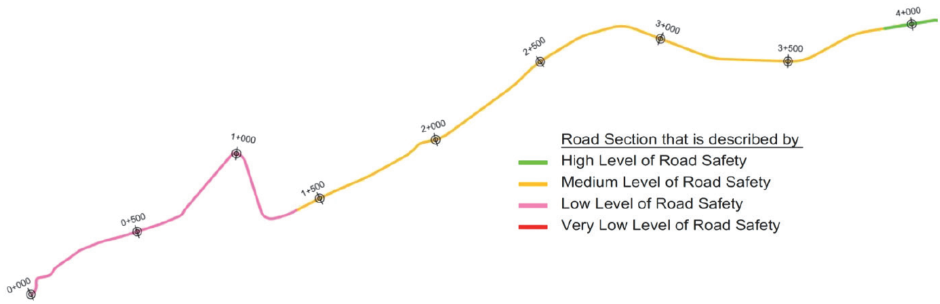

Figure 3 Graphic color presentation of road sections depending on the level of road safety, regarding both geometry and at-grade intersections.

6 Conclusions

The present study aimed to present a new approach of evaluating the road safety of a Rural two-lane highway, based on the geometric elements of the road, introducing the concept of the hazard score and ranking. In this context, an integrated methodology has been presented that evaluates and takes into consideration several critical parameters that affect the road safety in a road section in terms of geometry. For each of these parameters, appropriate mathematical expressions were identified using data from Greek and international literature, while simultaneously the results were evaluated based on the results of the IHSDM software and recorded accidents. The created mathematical expressions lead to the estimation of the hazard level, so to extract a total score for each individual horizontal curve and a total score for each road section. The present methodology and mathematical approach to the hazard level offers the following advantages:

Each parameter is calculated individually, but every curve and every road section is ranked according to a final score summed from all the parameters considered critical to the road safety. It is noted that it is possible to add any parameter considered critical and has not been utilized, as long as a mathematical expression that determines the hazard level of the parameter results from a research. With the distinct score for each design parameter, the parameters responsible for the high score of the black spots are highlighted by demonstrating immediately the improvement treatments that have to be implemented.

Individual curves of a road network are evaluated and ranked, while the entire road segment get evaluated by a weighted rating that characterizes each road section in terms of road safety.

It has built a background based on the concept of ranking due to hazard level, where additional parameters critical to the level of road safety, such as geometry and configuration of intersections, pavement conditions, the roadside clear zone widths, road insurance, road lighting, etc. can be included and evaluated. The hazard level of these parameters could be integrated into this methodology in order to provide a wider model of road evaluation that would highlight the black spots not only due to geometry.

Based on the proposed methodology approximately 1000 kilometres of rural road network were investigated. For faster data processing and simple and immediate export of the final scores, a new computer software by the research team was created. This new software enables the evaluation of a large number of road sections in a very short period of time and at the same time to correlate the results with recorded accidents and the results of other software like Interactive Highway Safety Design Model (IHSDM).

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