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Identification of safety hazards on existing road network regarding road Geometric Design: Implementation in Greece

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ABSTRACT

This paper deals with the identification of potential hazardous locations on existing roads as related to road alignment. The project aims to create a large data base, to be continuously updated, containing several hundreds of road kilometers of all road categories. A large part has been investigated aiming to identify locations that present significant deviations from current geometric design guidelines in Greece, Germany and USA.

Initially, coordinates (X, Y, Z) have been taken in order to survey axis and side-lines in a large part of national and local network in Greece. The coordinates have been taken with a GPS placed on the roof of a moving vehicle that was scheduled to record one point every about 3 meters. Coordinates (X,Y,Z) were processed and horizontal and vertical alignment were generated, using a specific software package which was developed by a research team at the National Technical University of Athens (NTUA). Additionally appropriate statistical methods were adopted in order to approach as closely as possible the existing alignment.

The produced alignment of each road has been evaluated and compared with existing guidelines. Using appropriate parameters in software, the locations where geometry had critical deviations from guidelines were identified. These locations were initially categorized and classified according to their order of importance and finally those with the greatest severity for road safety were identified. Further checks were made based on Road Safety Audit guidelines currently used internationally. On site investigations are scheduled to verify the results.

Keywords: Road geometric design, hazardous locations, road safety hazards

INTRODUCTION

The need for a direct evaluation of the National Road Network aiming to improve road safety and minimize severe traffic accidents constitutes a National target. It is also a challenge for the engineering community who is called to track, evaluate and suggest improvements for those road elements that constitute safety hazards. This challenge brings the engineer against many difficulties whereas it demands for a productive and substantial improvement of the road network.

Within this framework, this project has the main target to identify the geometric road elements that do not comply to the applicable standards, thus constituting potential safety hazards. The methodology is based on the use of the topo survey (coordinates X,Y,Z) of both the centerline and the road edges. Using these coordinates all geometric road elements are being extracted (plan, profile, superelevations, cross-sections, widening,etc). To expedite the procedure for treatment of the survey data, a specific new software was developed which produces the best fit of the geometric design elements using statistical methods. Further the program checks the produced geometry against the applicable road design standards, thus identifying the deviations that may constitute potential accident locations.

COLLECTION AND PROCESSING OF DATA

This project includes the processing of the survey data of about 1000 kilometers of national and rural road network all over the Greek State. The data comprises of edge and/or centerline coordinates with the objective to produce the geometry of each road section (plan and profile).
The survey was accomplished by a set of instruments that were placed on the roof of a moving vehicle and were synchronized to record data every 3-5 meters. The vehicle run each road both ways in order to record the right and left sides of the road. By appropriate manipulation of the X, Y and Z coordinates the road centerline was generated as the middle point of the two edges. Finally, using the produced X, Y and Z coordinates, the geometry of the road centerline (plan and profile) was estimated.

BRIEF PRESENTATION OF H12 SOFTWARE

In order to accelerate the data processing a specific software was developed by a research group within the NTUA, called H12. A flowchart of this approach is given in Figure 1 below.

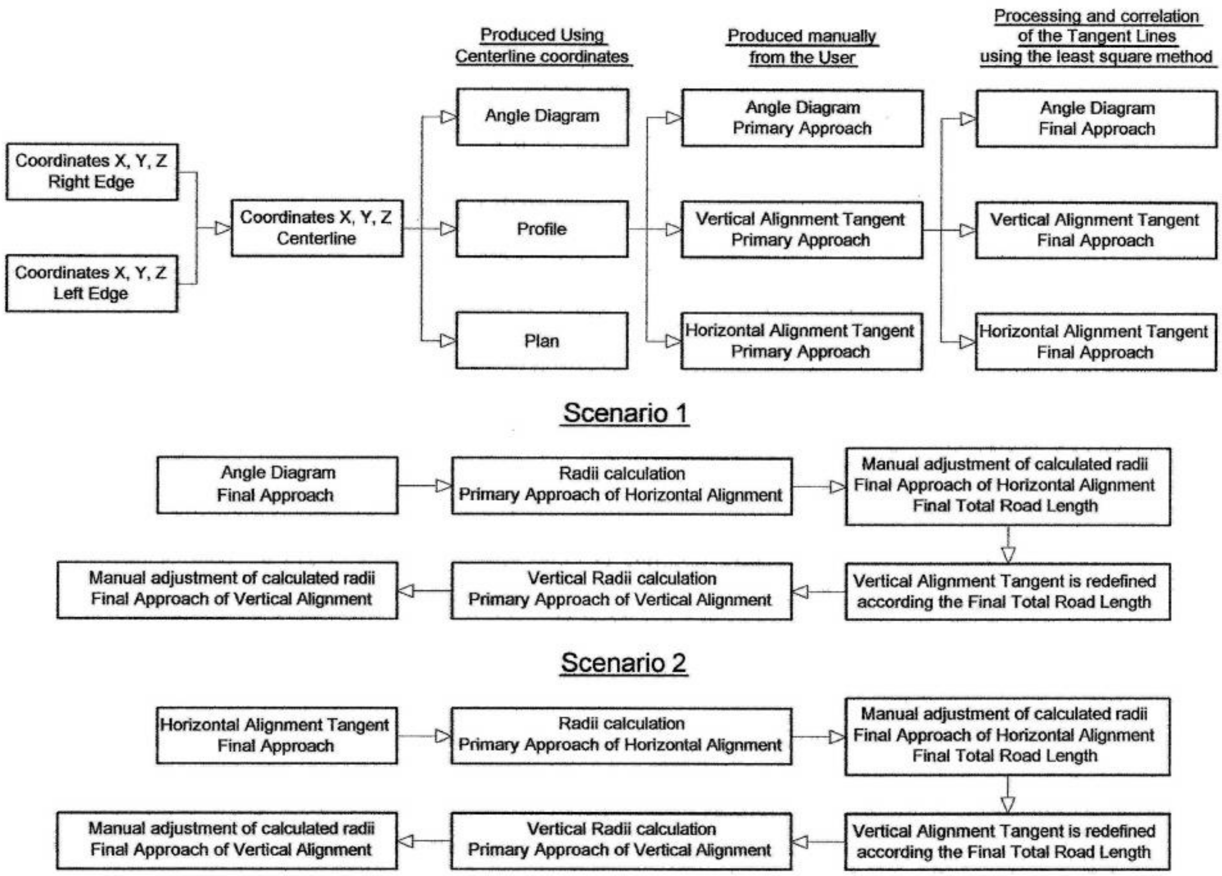

Figure 1: Flowchart for H12 Program

Each step is briefly described as follows:

1. The basic input are the X, Y and Z coordinates for the left and right road edges as given by the topo survey. Also the coordinates of the road centerline if taken in the field.
2. Should there is no data for the road centerline, it is assumed that it exists at the midpoint between the two edges.
3. The original data is being processed and an initial estimate of the plan, profile and angle diagram is produced in DXF format (Autocad, Microstation format, etc).
4. The DXF file is then being worked manually by the user to reach a primary approach of the horizontal and vertical alignment tangents and the angle diagram. These tangents are reassessed in the system.
5. An automated processing and correction of the tangent lines is made, using the least square method, to best fit the survey data.
6. The horizontal curvature radii are estimated by two approaches; initially from the angle diagram. Secondly from the horizontal alignment using the least square method to best fit a circular curve within the survey data. The vertical curvature radii are similarly being approached.
7. The program produces two scenarios: (a) Through the angle diagram an initial horizontal alignment is being produced which concludes to the adjustment of the total road length and thereof the final profile and (b) by means of the primary approach of the horizontal alignment tangent another primary horizontal alignment is being produced which again leads to the adjustment of the total road length and thereof the final profile.
8. In both cases about 10% of the estimated radii, both horizontal and vertical, present a significant deviation from the survey data (especially in areas with hair-pin bends). Therefore a manual adjustment is needed to be made graphically.
9. Finally the program reruns the two scenarios and produces the final plan and profile of the road. It also calculates the accuracy of each scenario, which gives the user the opportunity to select which scenario to adopt.
10. If the user defines a design speed, the program checks the produced road geometry against the applicable standards and immediately identifies the locations of non compliance (hereinafter called as incidents of geometry failure or simply incidents).

It is worth to notice that the survey data were collected using a GPS with IMU (Inertial Measurement Unit) which provides, after the processing of steps 1-10, an accuracy of about 20cm in the horizontal level and 10cm in the vertical.

For a 50 km road (with around 200 PIs in both alignments) the time to perform steps 1-10 above is around 10 hours. If only one scenario is used the time is reduced to 6 hours.

It is also pointed out that if the road centerline is recorded in the survey, the program produces concurrently the superelevation and widening diagrams. However in this case a fundamental requirement is to have the least possible error in the survey data.

STUDIED NETWORK

About one thousand kilometers of road network have already been surveyed and processed. The studied network is presented in figure 2.

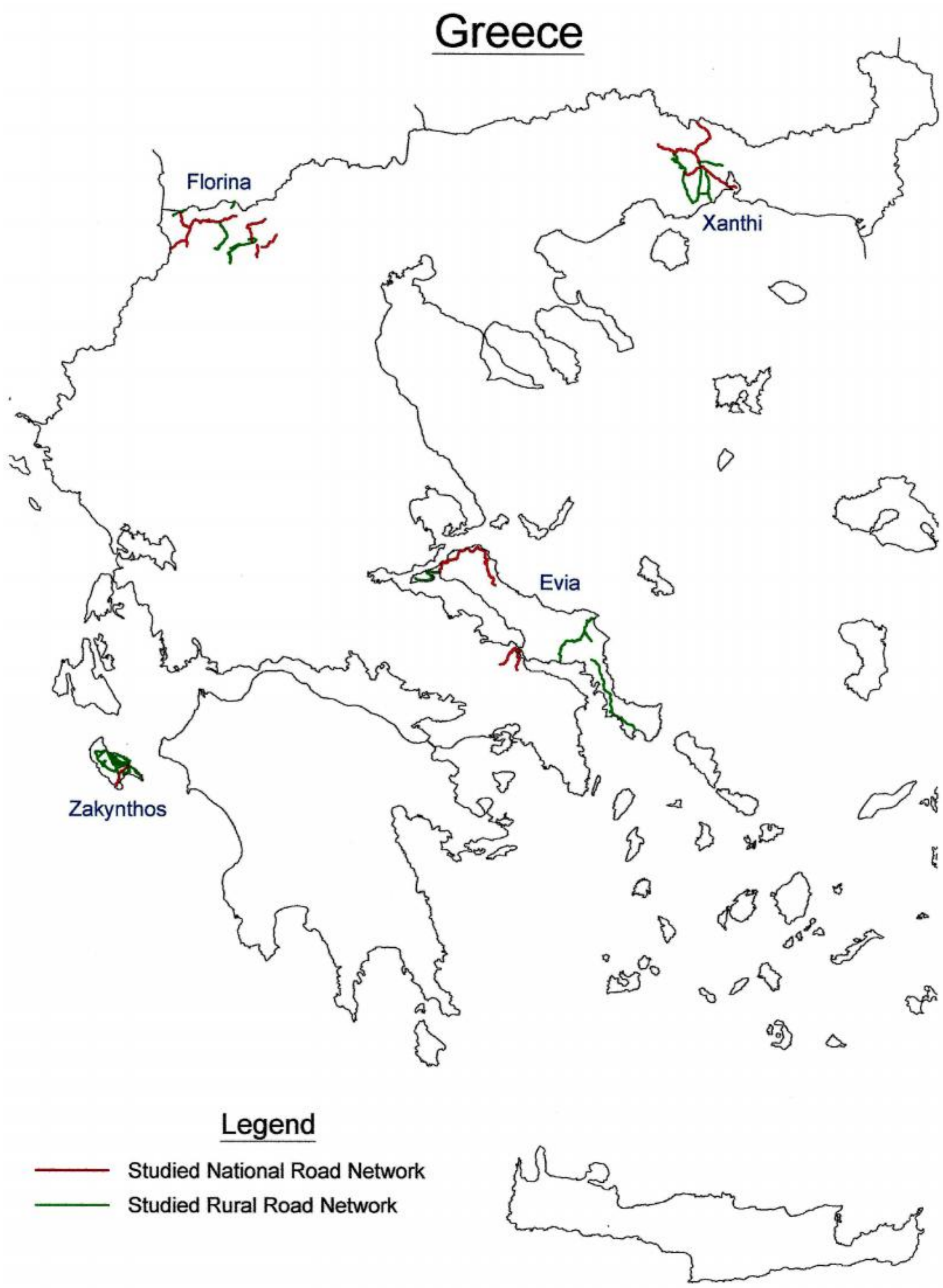

Figure 2: Studied National and Rural Road Network

ACCURACY IN ESTIMATING PLAN AND PROFILE

The surveillance was made by means of a GPS with IMU and only the road edges were registered. The centerline coordinates were extracted through the program (Step 2). Both scenarios (Step 7) were exercised. The one in which the horizontal alignment is adjusted by the user presents a smaller deviation than the one in which the user adjusts the angle diagram. The achieved accuracy is presented in Table 1.

Table 1 – Mean accuracy in approaching the road plan and profile

Type of road network	National	Rural
Studied length (km)	384,5	528,5
Accuracy in plan (m)	0,24	0,18
Accuracy in profile (m)	0,12	0,09

As depicted in Table 1 the accuracy that is achieved in the National Road Network is slightly less than the one achieved in the Rural Road Network. This might be due to the fact that the individual road elements (tangent or circular sections) are smaller in the Rural roads and are adjusted more accurately in the survey data.
At this point it should be noted that the centerline coordinates were produced as the geometric mean of the two edges. Therefore the superelevations were not taken into consideration, which produces an error in the Z values. This error might be significant in the production of the road profile and might affect the resulting geometry. It is much more accurate to record the road centerline data directly. This issue is not affecting the produced plan geometry, except in areas with widened pavement (e.g. at grade intersections).

COMPLIANCE OF ROAD GEOMETRY TO THE APPLICABLE STANDARDS

To enable road geometry evaluation, a design speed shall be assessed for each section. In the present study the posted speed limit was considered. Nevertheless it is crucial to check the adequacy against the operating speed (V_{85}) as well. This is scheduled for a subsequent stage of this research.
For each road section the program performs a high number of automated checks, the most significant being the following:

1. Horizontal curve radius (H.C.R.)
2. Maximum tangent length (Max. T.L.)
3. Minimum tangent length between curves of same direction (Min T.L.C.)
4. Length of circular arc (L.C.A.)
5. Radii of consecutive curves (R.C.C.)
6. Radii of sag and crest vertical curves (R.S.C.V.C.)
7. Maximum gradient (Max. S)
8. Minimum gradient (Min. S)
9. Minimum length of vertical curves (Min. L.V.C.)

The standards which were used in this project were the most recent Greek Directions for Road Design (OMOE-X, 2001 edition). Certain recommendation from the German (RAS-L) and the American (AASHTO) Standards were taken into consideration. The design parameter limits in respect to the design/posted speed limit are outlined in the following table 2:

Table 2 – Limit values for design parameters based on Standards used in Greece in respect to the design/posted speed limit

			Design Speed / Posted Speed Limit**						
Check ID *			**30**	**40**	**50**	**60**	**70**	**80**	**90**
1) H.C.R.		m.	25	40	95	140	200	280	370
2) Max. T.L.		m.	Equal to 20 times the design/posted speed limit (in km/h)						
			600	800	1.000	1.200	1.400	1.600	1.800
3) Min T.L.C.		m.	Equal to 6 times the design/posted speed limit (in km/h)						
			180	240	300	360	420	480	540
4) L.C.A.		m.	Minimum length is equal to the traveled length in 2 sec						
			16,67	22,22	27,78	33,33	38,89	44,44	50,00
5) R.C.C.			According OMOE-X, 2001 edition, Figure 7-4						
6) R.S.C.V.C.	**Sag**	m.	150	250	1.350	1.900	2.500	3.300	4.200
	Crest	m.	400	450	800	2.000	3.000	4.500	6.200
7) Max. S.		%	13	12	10	9	8	7	7
8) Min. S		%	0,5						
9) Min. L.V.C.			Equal to the design speed / posted speed limit						
		m.	30	40	50	60	70	80	90

* Check ID refers to the above numbering

** Speed 50-90 km/h : According to OMOE-X,
Speed 40 km/h : According to RAS-L (1984),
Speed 30 km/h : According to Greek Guidelines for road with low design speed

The evaluation results are shown in Table 3.

Table 3 – Locations presenting deviations from the Standards
(Incidents of geometric failure)

	National Road Network		Rural Road Network	
Check ID *	Number of locations	Incidents/km	Number of locations	Incidents/km
1) H.C.R.	312 out of 2.158 **(14,5%)**	0,8	814 out of 4.585 **(17,8%)**	1,5
2) Max. T.L.	6 out of 2.178 **(0,3%)**	0,0	19 out of 4.620 **(0,4%)**	0,0
3) Min T.L.C.	663 out of 707 **(93,8%)**	1,7	1.185 out of 1.239 **(95,6%)**	2,2
4) L.C.A.	87 out of 2.158 **(4,0%)**	0,2	522 out of 4.585 **(11,4%)**	1,0
5) R.C.C.	547 out of 2.118 **(25,8%)**	1,4	1.010 out of 4.515 **(22,4%)**	2,0
6) R.S.C.V.C.	350 out of 1.914 **(18,3%)**	0,9	774 out of 3.837 **(20,2%)**	1,5
7) Max. S.	22 out of 1.934 **(1,1%)**	0,1	107 out of 3.872 **(2,8%)**	0,2
8) Min. S	316 out of 1.934 **(16,3%)**	0,8	566 out of 3.872 **(14,6%)**	1,1
9) Min. L.V.C.	1.267 out of 1.914 **(66,2%)**	3,3	3.101 out of 3.837 **(80,8%)**	5,9
TOTAL	**3.385**	**8,8**	**7.794**	**14,8**

* Check ID refers to the above numbering

The table 3 indicates several thousands of incidents were non-compliance is observed. Despite the fact that design speeds of the Rural Road Network are smaller, it is evident that they present much more failure incidents. This might be due to poor road geometry of this network.
The percentage of deviations regarding the studied prefectures is presented in figures 3 and 4.

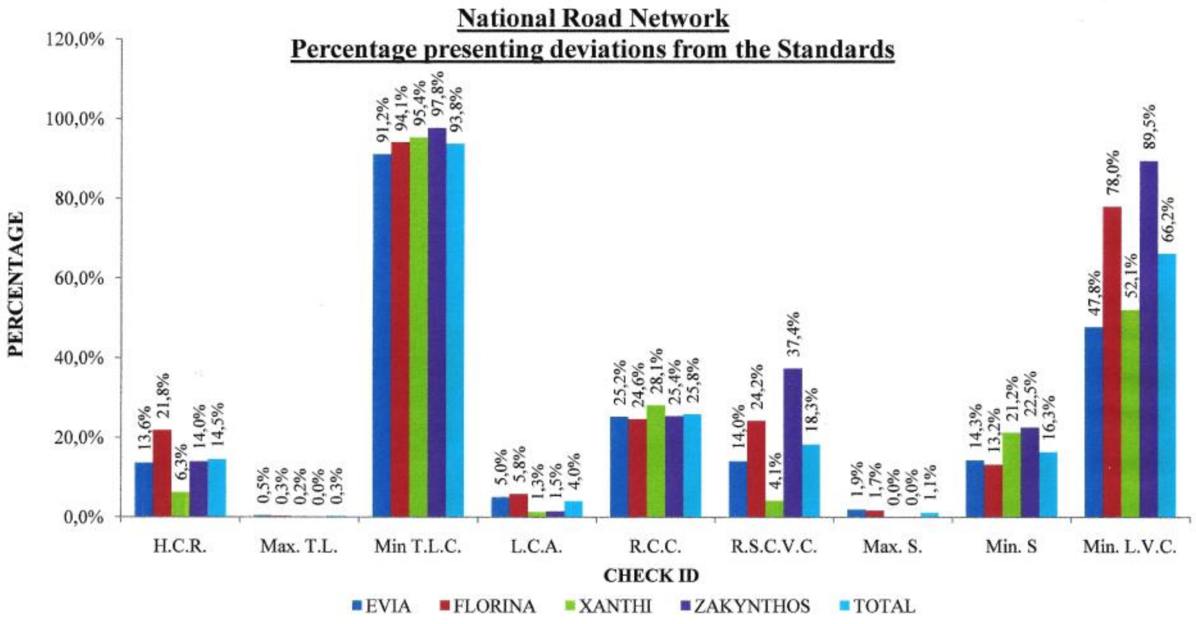

Figure 3: Percentage presenting deviations from the Standards - National Road Network

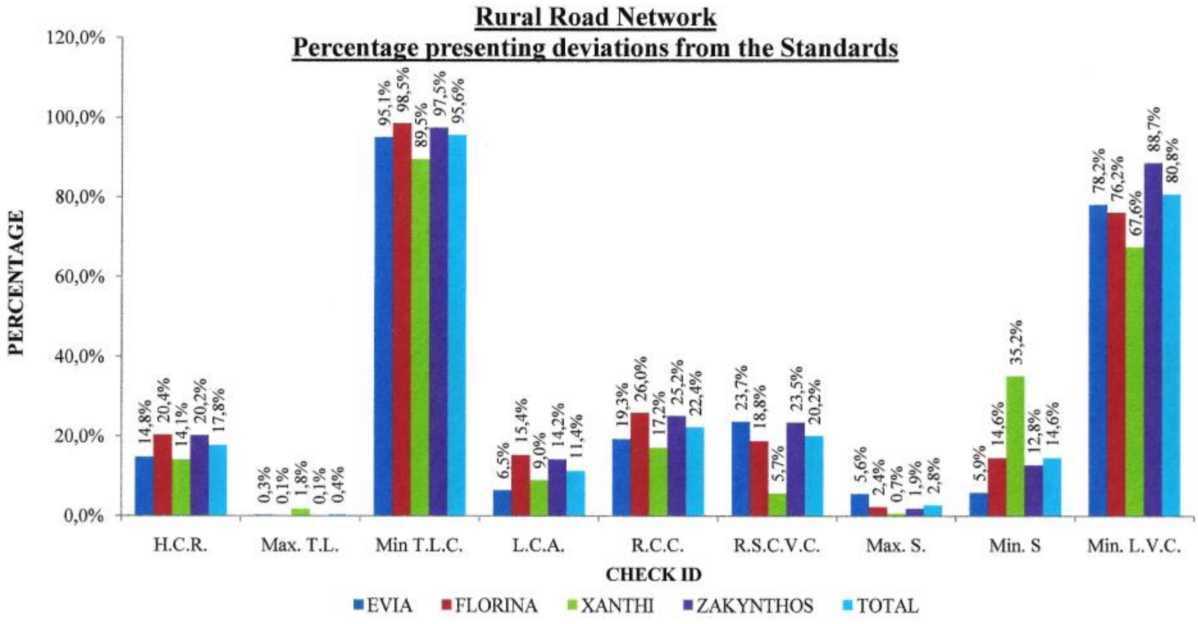

Figure 4: Percentage presenting deviations from the Standards - Rural Road Network

The results seem to be similar. Zakynthos appears to have slightly reduced geometric standards in respect to the other three prefectures. On the other hand Xanthi appears to have relatively higher geometric characteristics. This conclusion will be confirmed when the entire National and Rural Network of the prefectures mentioned above will be investigated.
The number of deviations per kilometer of road network is presented in figures 5 and 6.

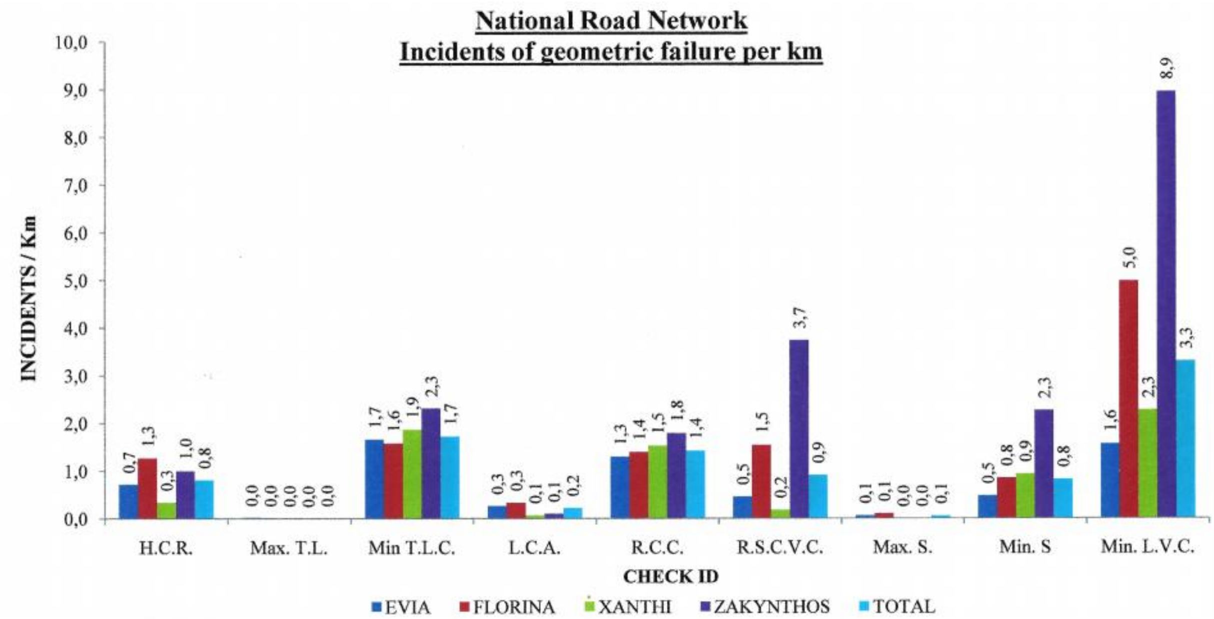

Figure 5: Incidents of geometric failure per km - National Road Network

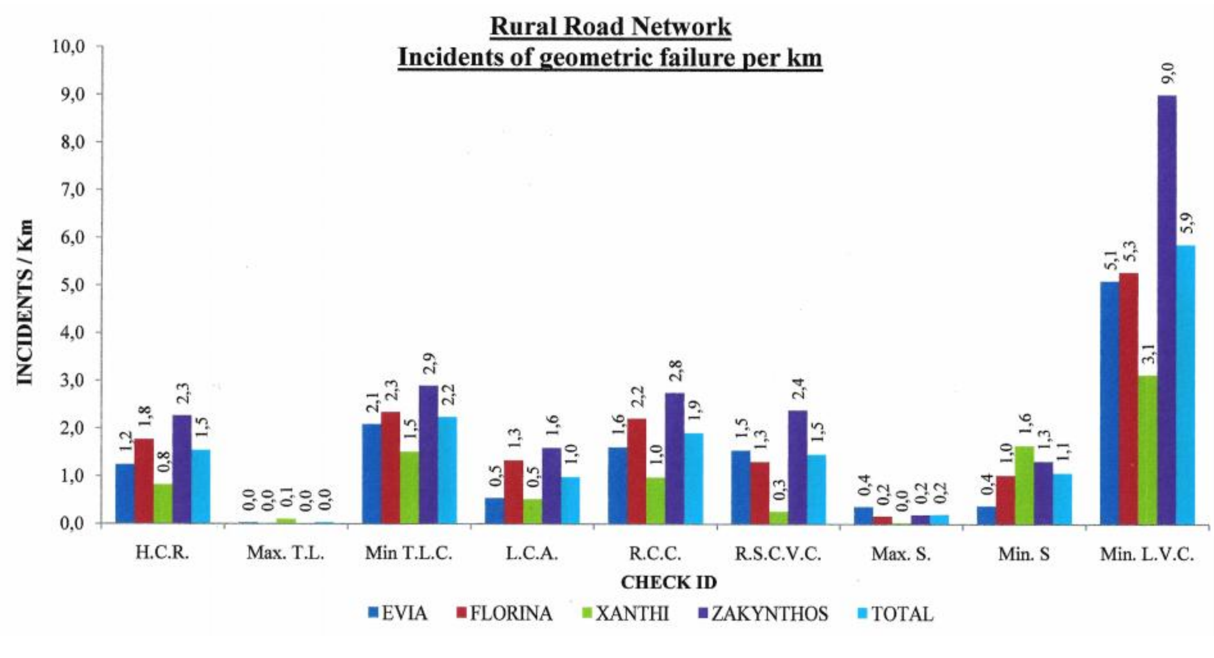

Figure 6: Incidents of geometric failure per km - Rural Road Network

Zakynthos appears to have highly substandard geometric characteristics whereas Xanthi prefecture seems to be more compliant to the Standards than the other prefectures.

The above data reveal that a substantial part of the road network encounters reduced geometrical characteristics which constitute potential areas for traffic accidents. Nevertheless an important step is to determine the degree of deviation in order to properly assess the deviation severity and importance on road safety.

Therefore the extent of the deviation shall be determined. This is expressed as a percent on the value being depicted by the Standards. Tables 4 and 5 present the number of incidents categorized based on the percentage of deviation.

Table 4 - National Road Network
Incidents categorized based on the percentage of deviation from the Standards

	National Road Network							
	Incidents categorized based on the percentage of deviation from the Standards							
Check ID *	< 10%		Between 10% and 40%		Between 40% and70%		>70%	
1) H.C.R.	56	**(17,9%)**	177	**(56,8%)**	74	**(23,7%)**	5	**(1,6%)**
2) Max. T.L.	1	**(16,7%)**	4	**(66,6%)**	1	**(16,7%)**	0	**(0,0%)**
3) Min T.L.C.	7	**(1,1%)**	56	**(8,4%)**	159	**(24,0%)**	441	**(66,5%)**
4) L.C.A.	22	**(25,3%)**	41	**(47,2%)**	19	**(21,8%)**	5	**(5,7%)**
6) R.S.C.V.C.	57	**(16,3%)**	141	**(40,2%)**	114	**(32,6%)**	38	**(10,9%)**
7) Max. S	10	**(45,5%)**	10	**(45,5%)**	1	**(4,5%)**	1	**(4,5%)**
8) Min. S	28	**(8,9%)**	103	**(32,6%)**	92	**(29,1%)**	93	**(29,4%)**
9) Min. L.V.C.	81	**(6,4%)**	358	**(28,3%)**	520	**(41,0%)**	308	**(24,3%)**
TOTAL	262	**(9,2%)**	890	**(31,4%)**	980	**(34,5%)**	706	**(24,9%)**

* Check ID refers to the above numbering

Table 5 - Rural Road Network
Incidents categorized based on the percentage of deviation from the Standards

	Rural Road Network							
	Incidents categorized based on the percentage of deviation from the Standards							
Check ID *	< 10%		Between 10% and 40%		Between 40% and 70%		>70%	
1) H.C.R.	145	**(17,8%)**	398	**(48,9%)**	231	**(28,4%)**	40	**(4,9%)**
2) Max. T.L.	3	**(15,8%)**	13	**(68,4%)**	2	**(10,5%)**	1	**(5,3%)**
3) Min T.L.C.	7	**(0.6%)**	57	**(4,8%)**	205	**(17,3%)**	916	**(77,3%)**
4) L.C.A.	140	**(26,8%)**	242	**(46,4%)**	101	**(19,3%)**	39	**(7,5%)**
6) R.S.C.V.C.	97	**(12,5%)**	307	**(39,7%)**	268	**(34,6%)**	102	**(13,2%)**
7) Max. S	48	**(44,9%)**	50	**(46,7%)**	6	**(5,6%)**	3	**(2,8%)**
8) Min. S	43	**(7,6%)**	147	**(26,0%)**	154	**(27,2%)**	222	**(39,2%)**
9) Min. L.V.C.	144	**(4,6%)**	690	**(22,3%)**	1.378	**(44,4%)**	889	**(28,7%)**
TOTAL	627	**(9,2%)**	1.904	**(28,1%)**	2.345	**(34,6%)**	1.908	**(28,1%)**

* Check ID refers to the above numbering

The tables indicate a relatively small percentage (around 9%) of the incident failures that deviate less than 10% from the designated values and therefore could be ignored. However, there is a more significant percentage (around 60%) where the deviation is quite high.
The following remarks are made for the horizontal alignment on the majority of the investigated road network:

1. The existing road curve radii are not sufficient.
2. In certain cases the existing tangent lengths are higher than the maximum.
3. The existing tangent lengths between curves of similar direction are insufficient.
4. The circular curve lengths are less than the ones required.
5. The radii of consecutive curve radii are out of standards.

The following remarks are made for the vertical alignment on the majority of the investigated road network:

1. The vertical curve radii are insufficient. The adequacy of the existing sight distances shall be further investigated.
2. The maximum gradient is generally below maximum with very few cases exceeding it.
3. There are many areas where the minimum slope is less than the minimum required by the standards for drainage purpose. Further investigation regarding drainage issues is encouraged.
4. The lengths of the vertical curves are generally out of standards (4.368 incidents out of 5.751)

All the above create potentially unsafe conditions for road users. However, the identified elements may not have the same impact on road safety. The influence of each element can be evaluated using recent traffic accident data and by taking into account other factors such as signage, safety barriers, pavement condition, etc.
The present paper deals only with the geometry of the road centerline and constitutes a small, though important, part towards improving road safety and reducing traffic accidents. There is no doubt that poor geometric design elements of a road section have a negative impact in road safety, and in combination with other factors (e.g. deteriorated pavement, bad weather conditions, object hindrances, driver disturbance, etc) may lead to increased traffic accidents. This research project provides the tools for a quick identification of hazardous locations where there are significant deviations from the road design standards, and therefore constitute potential areas for traffic accidents.

CONCLUSIONS

The present research has two objectives:

- To create a software package that produces the road geometry easily, quickly and reliably.
- To evaluate the road geometry against the applicable standards.

About 1000 kilometers of National and Rural road network in Greece were investigated. The main conclusions are as follows:

1. The mean deviation that was achieved in the production of road centerlines is about 20cm for the plan and 10cm for the profile. This deviation is relatively small taking into consideration the method by which the survey was done.
2. There is a large number of road sections with poor geometric characteristics which shall be upgraded, based on co-evaluation with other factors.

3. The failure incidents on the National network are far less than those of the Rural network.

All the above elements have started the creation of a data base for further use and evaluation. The target is to enlarge this data base and to relate the results to other factors affecting road safety. Such factors are the pavement condition, roadway drainage, signage, safety barriers, etc. Also to interrelate with actual traffic accident data.
The results of this research can be presented on a map which would be of great assistance to a Road Safety Auditor; because it provides a clear picture of the road geometry and attracts attention to specific areas that need further investigation. An additional objective of this project will be to enrich this information map with further data affecting road safety.

SUBJECT FOR FURTHER REASEARCH

This research project constitutes the beginning of an effort to produce road alignment information from a topographic plan. The small, though significant, data base that was created could be used as input for a wider research targeting to evaluate the safety of a roadway network. Within this framework the following topics could be the subject for further research:

1. Surveillance of an existing road with an accuracy to allow extraction of superelevation diagrams and existing road widenings. Combined checks of horizontal alignment, vertical alignment and superelevation diagrams as far as the road safety is concerned.
2. Investigate easy ways to obtain additional survey information about side hindrances (safety barriers, cut embankments, etc) to allow checking of existing stopping site distance on a wet pavement as well as passing sight distance.
3. Collection and processing of more kilometers of road network to extend the data base.
4. Interrelating the outcomes obtained under this project to other factors that affect road safety, such as pavement condition, drainage control, safety barriers, signage, etc., as well as with actual traffic accident data. This correlation will provide an index of the severity that each element has on traffic safety and will give a clearest view of the existing situation audits appraisal.

DISCUSSION

The following items may constitute topics for discussion and questioning:

1. The X, Y, Z coordinates of the road centerline in this project resulted as the geometric mean of the road edges. Therefore there is an inaccuracy involved, beyond the one included in the survey itself. This is particularly important especially in the production of the road profile that may include a considerable error. It is therefore desirable to obtain the road centerline data directly.
2. The speed that was used to do all the checking for the road geometry was the posted speed limit. A more realistic approach would be to consider the vehicle operating speed. The 85 percentile (V_{85}) provides a good estimate for this speed, however this shall be evaluated. At this point it should be noted that the applicable regulations concerning the friction coefficients need to be reviewed and possibly revised because the technological

development allows for the construction of better pavements and tires, which in turn allow for higher speeds at the same level of safety.

3. The checkings of the road geometry were based on the restrictions imposed by the Greek Directions for Road Design (OMOE-X, 2001 edition) and certain requirements set by the German (RAS-L) and the American (AASHTO) Standards. Obviously all requirements shall be fulfilled, though the effect of each design element on the road safety shall be assessed, in case of non-compliance. It is therefore imperative to conduct the required research to determine the degree of importance of each element and allow better and most effective evaluation of the road safety.
4. It would be of outmost importance to apply this program with topographic data from roads of other countries within the European Community and elsewhere. The outcomes would lead to interesting conclusions on the extent that road geometry standards are respected and how these are compared with the experience in Greece.

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