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ROAD INFRASTRUCTURES' RISK ASSESSMENT: A VALUABLE TOOL FOR INVESTMENTS' DECISIONS

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Abstract

The aim of the paper is to present the results of the road safety assessment for a 3,600 km section of the Greek Trans-European Transport Network (TEN-T Network) through a comprehensive example and to illustrate the way that these results should be taken into account when designing road maintenance or rehabilitation investment plans. The road risk assessment was conducted by applying the internationally recognized iRAP methodology, which has been implemented in more than 90 countries worldwide for the inspection of more than 650.000 Km of road networks. During this inspection, a specially equipped vehicle collected information from the road and the surroundings in 100m road sections. This information was then analysed to assess the infrastructure risk factors that influence the likelihood of a crash occurring and its severity, the risk level of road sections and award the Stars Performance of the road (Star Rating). On the basis of this analysis, the appropriate action plans were determined, in order to improve the road safety, which will maximize the benefit over spent cost of the planned investments.

Key words

Road safety inspections; road safety ranking; road safety assessment; star rating; road safety audits; road safety investments

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1 INTRODUCTION

The road infrastructure of a country not only serves the basic need for safe transport of people and goods but is also considered vital for its growth and development. Decisions for public and private investments, related to these infrastructures are affected by the requirements for preventive or corrective maintenance within a specific budget while taking into consideration the safety level of the roads under construction.

Road traffic injuries are a global, man-made and preventable epidemic with a health burden on the scale of HIV/AIDS and Malaria. According to the World Health Organization in [1], about 1.24 million people die as a result of road traffic crashes every year, whereas the annual number of road deaths worldwide is projected to increase to about 2.4 million by 2030. Particularly in the European Union, the European Commission stated in [2] that in 2010, more than 30,900 people were killed and about 1.5 million persons were injured in more than 1.1 million car accidents. In Greece, according to the World Health Organization in [1], the number of deaths is about 1,500 per year, while the estimated Gross Domestic Product loss due to road traffic crashes reaches the 2%.

On this basis, the United Nations announced in 2010 the Global Plan for the Decade of Action for Road Safety 2011-2020, as cited in [3]. The Plan encourages countries and stakeholders to implement actions that contribute to the reduction of the forecasted road fatalities rate. The categories of activities (pillars) that the Plan proposes as focusing areas are: building road safety management capacity; improving the safety of road infrastructure and broader transport networks; further developing the safety of vehicles; enhancing the behaviour of road users; and improving post-crash care. Focusing on the Infrastructure pillar, the countries should be able to assess the safety capacity of the road network for all road users and further implement infrastructure improvements through targeted investment programs. Within this framework, the Commission of the European Communities in [4] expressed the need to carry out safety impact assessments and road safety audits, in order to identify and manage high accident concentration sections. It also set the target of halving the number of deaths on the roads within the European Union between 2001 and 2010, which is consistent with the current UN Decade of Action for Road Safety objective, to ‘stabilise and reduce’ road deaths by 2020. Finally, the European Directive 2008/96/EC on Road Safety Infrastructure Management in [5] provided the legal requirements for the safety management of the Trans-European Road Network that include Road Safety Inspection, Safety Ranking and Audits, suggesting investments on road sections with the highest number of collisions and/or the highest collision reduction potential.

2 LITERATURE REVIEW

According to the Global Status Report on Road Safety in [1], road traffic injuries are the eighth leading cause of death globally, and the leading cause of death for young people aged 15–29. Current trends show that by 2030 road traffic deaths will become the fifth leading cause of death unless urgent actions are taken. Actions can be taken at various levels including the stricter enforcement of the law, the efforts to change the driving behaviour and the road infrastructure improvement. The World Health Organization in [1] highlighted the important role that road infrastructure can play in reducing injuries among all road users. The fact that road conditions are easier to control than controlling the other road safety factors (e.g. the driving behaviour) implies that road maintenance and upgrading can prevent crashes and reduce injuries severity as Miller et al. claims in [6]. Numerous solutions could contribute to making the roadway environment safer for users, including either structural changes according to Mahoney et al. in [7] or cost-effective and immediate changes as Mattox et al. proposes in [8], within the framework of road maintenance or rehabilitation investment plans. Decisions related to the type, extent and priority of road infrastructures improvements require, among others, reliable Safety Impact Assessment analysis for the evaluation of the impact of a new road construction or an improvement of the existing network on the infrastructure's safety performance.

Many Safety Impact Assessment methods have been developed, targeting at cost-effective and efficient road maintenance programs. The Road Infrastructure Safety Assessment (RISA) is a procedure, which provides the New Zealand's Authorities with a tool to assess the risk of a road network and evaluate "what-if" scenarios when various improvements on the road infrastructure are applied, according to Appleton in [9]. The ROSEBUD project cited in [10] was funded by the European Commission as a thematic network to support users at all levels of government with information about road safety related efficiency assessment solutions. ROSEBUD recommends two main methods to assess road safety measures; the Cost Effectiveness Analysis (CEA) and the Cost Benefit Analysis (CBA). The main difference between them is that within the CEA the benefits are expressed in non-monetary terms (e.g. the benefit of saved lives), where as the opposite occurs within the CBA. The Australian National Risk Assessment Model (ANRAM) is supposed to be one of the most integrated models according to the Austroads in [11]. The safety scores are calculated for all road sections under inspection, countermeasures are defined and future funding programs are proposed. Using the iRAP's safety scores algorithms, the ANRAM method targets at the improvement of the road safety and proposes cost-effective investment plans, for both new and existing infrastructure.

Road Safety Audits (RSAs) are defined in the Directive 2008/96/EC in [5] as independent detailed systematic and technical safety checks related to the design characteristics of a road infrastructure and cover all stages from planning to early operation. Pietrucha et al. in [12] described the RSA as a process where a team of experts attempt to identify features of the roadway operating environment as potentially dangerous and work to eliminate or change those features in different parts of the design process. According to Wilson et al. in [13] the experiences in Europe and Australia have shown that the RSAs are both effective and cost beneficial as a proactive safety improvement tool. Studies have shown that in the UK the average number of fatal and injury crashes at 19 project sites that were audited fell by 1.25 crashes per year where as crashes at 19 comparable non-audited sites dropped 0.26 crashes per year

Road Safety Inspections (RSIs), in contrast to the RSAs are an ordinary periodical verification of the characteristics and defects that require maintenance work for reasons of safety, as defined in the Directive 2008/96/EC in [5]. Particularly, Cardoso et al. in [14] defines RSI as a preventive tool for detecting safety issues, consisting of a regular, systematic, on-site inspection of existing roads, covering the entire road network and being carried out by trained safety expert teams. The most common RSI methods in countries like France and Norway as Nadler et al. mentions in [15] follow the PIARC Guideline cited in [16], which proposes that an RSI should not require collision data analysis. Hence, as Nadler et al. claims in [15], in other countries like Austria and the Czech Republic, these data are almost mandatory. In Austria Nadler et al. mentions in [15] that the EVES (Electronic Safety Recording System) is used. Aiming at the quick interaction of the inspector with the system, so that the inspector can still concentrate on the road, this system is able to automatically locate the gathered events using GPS and provide the user with a clear interface. In Finland, the TARVA-tool is used both to estimate the present safety situation and the cost efficiency and safety impacts of the countermeasures as Nadler et al. in [15] mentions again. Finally, Nadler et al. informs in [15] about the Vidkon inspection program used in Norway, which is characterized by the little time-consuming field inspection as the main inspection is held in the office, as pictures and video are taken every 20 road meters.

The RSI leads to the Road Safety Ranking (RSR) of a particular road or road section. The Directive 2008/96/EC in [5] defines the RSR as a method for identifying, analysing and classifying parts of an existing road network according to their potential for safety development and accident cost savings. The RSR is a valuable tool for policymakers, professionals, even people ignorant of road safety issues to realize the safety level of a certain road section. SafetyNet in [17] proposes the high quality data and skilled teams as prerequisites for effective RSR of a road section.

The Directive also mentions in [5] the need of implementing a cost benefit analysis during the Road Safety Impact Assessment. The purpose of carrying out cost-benefit analysis is primarily to ensure that an adequate return in terms of benefits results from committing expenditure. Robinson et al. introduces in [18] an additional purpose; to ensure that the investment option adopted gives the highest return in relation to the standards adopted and the timing of the investment. For economic appraisal, the assessment is made in terms of the net contribution that the investment will make to the country’s economy as a whole. Thus, the analysis differs from that which would be undertaken by private companies in appraising commercial ventures in that it attempts to evaluate economic costs and benefits rather than financial ones as Robinson et al. mentions in [18].

Within a cost-benefit analysis, the relevant safety upgrading costs concern the installation of countermeasures on a specific road network. On the other hand, there has been much discussion in the economic literature concerning the benefits of preventing an accident or the valuation of the human life. For the purpose of a cost-benefit analysis the value of a life is the level of investment that can be justified for the saving of one’s life. It is the valuation of a change in risk such that a life will be saved, rather than the valuation of the worth of a life of a specific individual. Two main methods have been used to value the benefit of prevention of a road crash fatality according to McMahon et al. in [19]:

- The human capital method: This approach consists of valuing death in accordance with the economic impact. The main component in this approach is the discounted present value of the victim’s future output forgone due to death. This approach has clear disadvantages, as it focuses only on the economic effects of the loss of life and does not account for the value and enjoyment of life forgone.
- The willingness-to-pay method: This method consists of estimating the value that individuals attach to safety improvement by estimating the amount of money that individuals would be prepared to pay to reduce the risk of loss of life. This method accords well with the fundamental principle of social cost-benefit analysis as McMahon et al. maintains in [19].

Aim of this paper is to present the iRAP Methodology, as a valuable tool for Road Safety Impact Assessment, Inspection (RSI) and Ranking (RSR). It will also demonstrate the results of the iRAP’s application on the Greek Trans-European Network, concluding to an analysis that should be taken into account when designing road maintenance or rehabilitation investment plans.

3 METHODOLOGY

3.1 Introduction

The main objective of the iRAP method is the improvement of the road users' safety by proposing cost-effective investment plans. The most crucial point in the iRAP is that engineers and planners in developed countries, for over twenty years, have adopted an underlying philosophy of designing a forgiving road system to minimize the chances of injuries when road users make mistakes that result in crashes as Hills et al. mentions in [20]. The method indicates that the severity of a road accident can be reduced through the intervention at the sequence of events happening during this accident. As it is known, an injury accident results from a chain of events, starting with an initial event, probably resulting from several factors, which leads to a dangerous situation. The basic idea is to intervene at any point of this chain, in order to reduce the kinetic energy of all road users, who are involved, in the accident to a tolerable level. Lynam in [21] supports that such an intervention will not reduce the number of accidents, but the severity of injury.

The initial step for the implementation of the iRAP method is the inspection and record of the infrastructure elements of a road network, which relate to the road safety. The record leads to the quantification of the safety that a road section provides to its users by awarding safety scores (Star Rating Scores). The Star Rating Scores express the safety capacity of a road section in a 5-Star scale. This quantification aims at identifying the most appropriate countermeasures, which will increase the infrastructure's road safety score. The Safer Roads Investment Plan (SRIP) includes all the countermeasures proved able to provide the greater safety capacity and maximize the benefit over spent cost of the planned investments. Thus, the SRIPs are considered as a valuable tool for the authorities, stakeholders and investors in order to decide for the most cost-effective and efficient road infrastructure investments.

3.2 Measuring the road infrastructure safety

The assessment of the road safety requires the RSI of the road elements and the assignment of a safety score to them. The inspection is conducted by visual observation and record of the road infrastructure elements which are related -directly or not- to road safety and have a proven influence on the likelihood of an accident or its severity. The iRAP uses two types of inspection; the drive-through and the video-based inspection. During the first one, the record of the infrastructure's elements is performed manually, with the help of specialized software, where as during the second, a specially equipped vehicle is used, so as the recorded video to be used for a virtual drive-through of the network and an automated identification of the infrastructure's elements.

Following the RSI, the Road Protection Score (RPS) is calculated. The RPS is a unit-less indicator, which depicts the infrastructure's safety capacity for each road user type and it is calculated for 100m road sections. Road user types are considered the car occupants, the motorcyclists, the bicyclists and the pedestrians, who may be involved in road accidents. For each road user type and for each 100m road section the respective RPS is calculated as follows:

$$RPS_{n,u}=\sum_{c} RPS_{n,u,c}=\sum_{c} L_{n,u,c} * S_{n,u,c} * OS_{n,u,c} * EFI_{n,u,c} * MT_{n,u,c} \qquad (1)$$

where "n" is the number of 100m road section, "u" the type of road user and "c" the crash type that the road user type "u" may be involved in. The following variables are taken into consideration: L: the Likelihood that the "i" crash may be initiated, S: the Severity of the "i" crash, OS: the degree to which risk changes in relation to the Operating Speed for the specific "i" crash type, EFL: the degree to which a person's risk of being involved in the "i" type of crash is a function of another person's use of the road (External Flow Influence), MT: the potential that an errant vehicle will cross a median (Median Traversability).

3.2 The Star Rating process

The aim of the Star Rating process is the award of the "n" 100m road sections with Stars, depicting the safety offered to each of the "u" road users' types. The Star Rating system uses the typical international practice of recognising the best performing category as 5-star and the worst as 1-star (5-star scale), so that a 5-star road means that the probability of a crash occurrence, which may lead to death or serious injury is very low. The Star Rate is determined by assigning each RPS calculated to the Star Rating bands. The thresholds of each band are different for each road user and were set following significant sensitivity testing to determine how RPS varies with changes in road infrastructure elements. The assignment procedure leads to the development of a risk-worm chart, which depicts the variation of the RPS score in relation to the position (distance from the beginning) on the road under consideration. The final output of the Star Rating is the Star Rating Maps, in which the "n" road sections are shown with different colour, depending on their Star award (5-star green and 1-star black).

3.3 Developing the Safer Road Investment Plans (SRIPs)

The development of the most appropriate SRIP presupposes the assessment of the number of fatalities and serious injuries that could be prevented for each 100m road section on an annual basis when a set of countermeasures is applied. The number of fatalities is calculated as follows:

$$F_n = \sum_{u} \sum_{c} F_{n,u,c} \tag{2}$$

where "n" is the number of the 100m road section, "u" the type of road user, "c" the crash type that the road user "u" may be involved in and F the number of fatalities that can be prevented on a time period of 20 years, given that a specific set of countermeasures is applied.

The F number is related to four main factors: (1) the safety score of the specific road section, (2) the "u" road users flow, (3) the fatality growth, which indicates the underlying trend in road fatalities and (4) the calibration factor, which inserts the actual number of fatalities that occur in the specific road section. The calculation of this factor presupposes the existence of similar crash data.

The assessment of the number of serious injuries that could be prevented for a 100m road section is a function of the $F_{n,u,c}$ value and the ratio of the actual number of serious injuries to the actual number of fatalities to the relevant number of fatalities. In case of lack of appropriate data, the competent Authorities should estimate this actual number as previously, or as the ratio of 10 serious injuries to 1 death, which is proposed by McMahon et al. in [19].

The next step in establishing the SRIPs is the identification of the most appropriate countermeasures. Countermeasures are the engineering improvements that the road authorities should take so as to reduce the fatalities and serious injuries rates. Each countermeasure is characterized by its trigger sets and its effectiveness for each of the 100m road sections. Each trigger set describes all the cases in which this certain countermeasure can be used. The effectiveness is calculated according to the number of fatalities and serious injuries that can be prevented in this section and the RPS of this section before and after the application of the countermeasure. It is important to mention that in the case that multiple countermeasures act on a certain road section, the total effectiveness is not the simple sum of each countermeasure's effectiveness. Instead, a reduction factor should act, which calibrates the total effectiveness.

The procedure of selecting the most appropriate countermeasures is the basis for the techno-economic analysis of the investment plan and aims at the calculation of the Benefit-Cost ratio (BCR) for each countermeasure. The economic benefit is considered as the benefit of preventing a death or a serious injury. The calculations are conducted following the assumptions that the cost of a human life is 70 times the GDP per capita, the cost of a serious injury is the 25% of the cost of a human life and the ratio of 10 serious injuries for 1 death, if more accurate information is not available. In Greece, according to research studies, the cost of a human life is estimated to 1.6 million Euros [22]. The countermeasure cost includes all the construction costs, the maintenance costs over a 20 year period and/or probable reconstruction costs. All the benefits/costs should reflect the actual local prices, taking into account the economic life of each countermeasure and the discount rate. The outcome of this procedure is the BCR calculation for each countermeasure applied to a specific road section.

The SRIP is conducted for a period of 20 years and shows the list of the most cost effective improvements that are able to reduce the crash risk for all road user types. In that way, the SRIP enables the road authorities to set the priorities properly when developing infrastructure‘s maintenance and/or rehabilitation plans.

4 RESULTS - STAR RATING THE GREEK TEN-T NETWORK

4.1 The inspected road network

The current paper presents the results of the Star Rating analysis for two of the most dangerous National roads in Crete, the largest Greek island and a very popular tourist destination. These results are only a part of the analysis of almost 16,000Km of the TEN-T road network in 14 countries in South East Europe, which was performed within the framework of the SENSoR Project, as cited in [23]. While this paper focuses on a specific part of the inspected network in Greece, for demonstration purposes, the results for the entire Greek TEN-T network (3,600Km) are publicly available on the project's website.

According to the official national statistics, more than 200 deaths and 300 serious injuries were recorded in Crete in the period 2010-2012, as a result of 456 fatal and serious road accidents, which mainly occurred on the National Roads NR90 and NR97 that are part of the TEN-T Comprehensive Network of Greece. NR90 is the basic road axis of the island, from Kissamos to Sitia, having a total length of 300 km. NR97 is the basic perpendicular road axis of the island, from Heraklion to Agioi Deka, having a total length of 40km. The largest portion of the aforementioned network is single carriageway. Physical separation of opposing traffic flows, i.e. metal or New Jersey median barriers separating the traffic lanes are only used for a length of approx. 32 km, where as for the rest only centreline markings are used. Moreover, no pedestrian facilities exist on the entire network, even in the cases that the road passes through residential areas, while hazardous objects at a distance of 0-1 m from the side line of the carriageway were recorded in a length of 224 km (62%). These objects include deep canals, steep slopes, trees and poles of a diameter greater than 10cm and so on. However, the most common hazardous objects are safety barriers with unsafe start or end points.

Traffic volume varies from 5,000 to 45,000 AADT, depending on the distance of the road section under consideration from the main cities. The analysis of the operating speed data has led to the conclusion that the 85% of vehicles exceed the speed limits by more than 10 – 30 km/hr. The highest V85 speeds are recorded on the divided road sections. Moreover, the highest difference between the speed limit and the V85 is recorded at the intersections. The average speed on the roads in question is approximately the speed limit.

4.2 Star Rating results

The road inspection vehicle used was equipped with high-resolution cameras (three cameras in the front capturing the 180° driver's view front). Digital images of minimum resolution 1280x960 pixels were collected in 10m intervals while driving at the normal speed. Georeferenced data have been provided for each digital image, including the distance along the road (from the determined start point), longitude and latitude, date and time. After the completion of the road inspection phase, the process of coding of video material took place. Coding represents the process of determining road attributes, at each 100 meters of the inspected road. Road characteristics are grouped into more than 30 attributes. Each attribute has its own set of categories. When the coding process was completed, a detailed road condition report was made. This detailed condition report represents the basis for the star rating assessment, as well as the proposals for the engineering countermeasures required for the improvement of the existing state of the inspected road.

The following map (Fig. 1) illustrates the results of the Star Rating process.

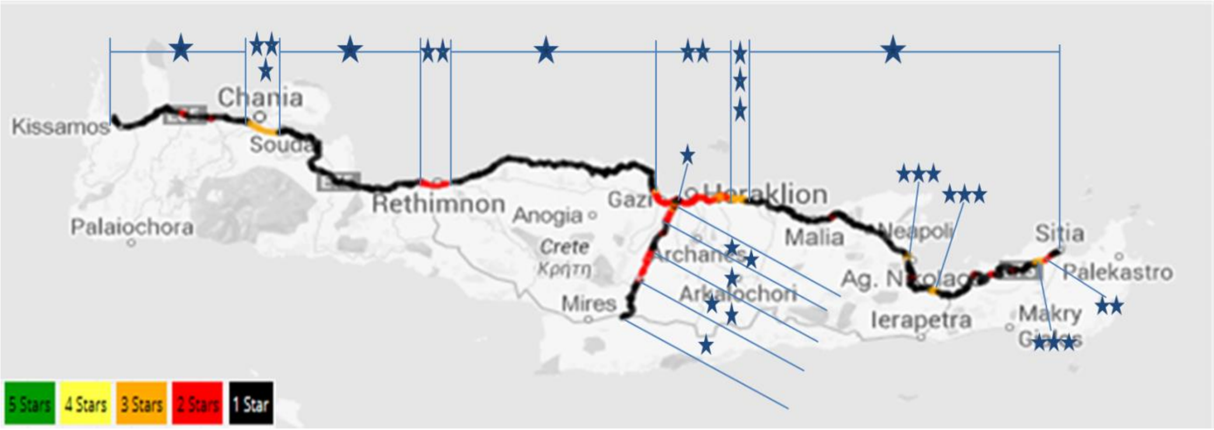

Fig. 1: Star Rating Results for NR90 and NR97 in Crete Island

The analysis shows that the major part (67%) of the network offers the lowest safety (1 Star) to the road users, the 17% is characterized by 2 Stars, the 13% by 3 Stars and only 2% and 1% is characterized by 4 and 5 Stars respectively. The risk-worm chart as depicted in Fig. 2 presents the variation of the RPS score in relation with the position (distance from the beginning) for an indicative road section between the cities of Malia and Agios Nikolaos. The improvement of the infrastructure's safety performance can be achieved by focusing on the high peak points of the chart, where specific engineering countermeasures should be implemented. The selection of the most appropriate countermeasures as well as the estimation of their effect on the improvement of the infrastructure's safety capacity is the core part of the Safer Road Investment Plan's development.

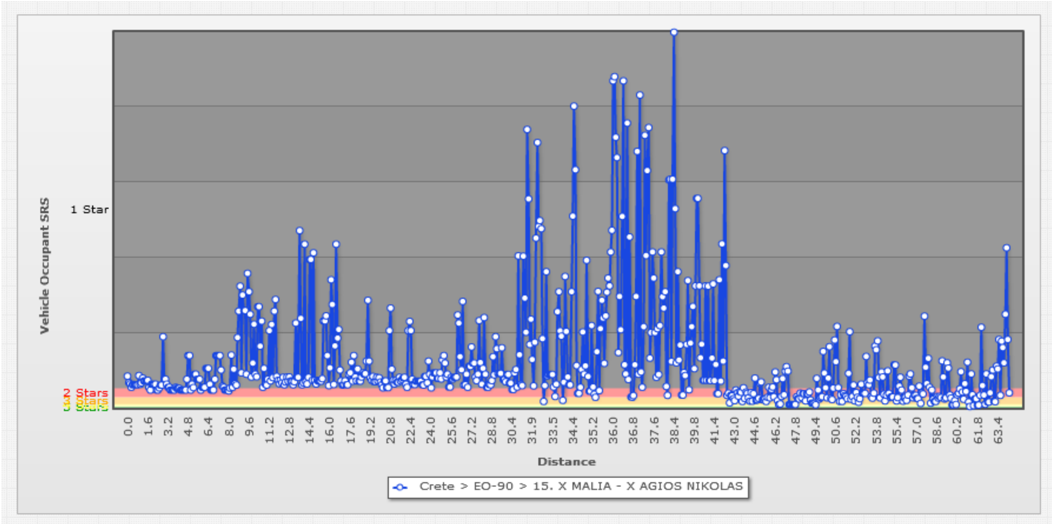

Fig. 2: Risk-worm chart

4.3 Safer Road Investment Plan

In the current paragraph, a detailed example is given for the presentation of the Safer Road Investment Plan (SRIP) for the road section between the cities of Malia and Agios Nikolaos.

As depicted in Figure 2, several peak values of the RPS score occurred at specific points, due to specific road safety hazards (i.e. destroyed or missing barriers, hazardous barrier ends, sharp curves, faded horizontal signing, grade intersections).

The ViDA Software analysis provided specific countermeasures for the improvement of the safety capacity. The proposed countermeasures come out of an extensive list that has been structured according to international research. After having excluded the possibility of the installation of a median barrier, due to the road width and terrain restrictions, Table 1 presents the proposed countermeasures, the road length (in Kms) to which they should be applied, the Fatalities and Serious Injured (FSI) that may be saved over a period of 20 years, the Present Value (PV) of the benefits over the period of 20 years, the estimated cost and cost/FSI Saved as well as the Benefit to Cost Ratio (BCR) for each countermeasure.

Tab. 1: Proposed countermeasures

Countermeasure	Length (km)	FSI saved	PV (€)	Estimated Cost	Cost per FSI saved	BCR
Improve curve delineation	2.2	2	995,442	43,000	756	23
Roadside barriers - passenger side	17.6	16	7,649,259	978,000	2,235	8
Roadside barriers - driver side	16.7	12	5,548,929	907,500	2,859	6
Road surface rehabilitation	14.6	6	2,764,715	457,900	2,896	6
Total	**-**	**36**	**16,958,345**	**2,386,400**	**-**	**16.6**

The implementation of the above mentioned engineering improvements would lead to a saving of 36 Fatalities and Serious Injuries and have a BCR of 16.6. These improvements would lead to an upgrade of the safety ranking (Star Rates) as illustrated in the following Fig. 3.

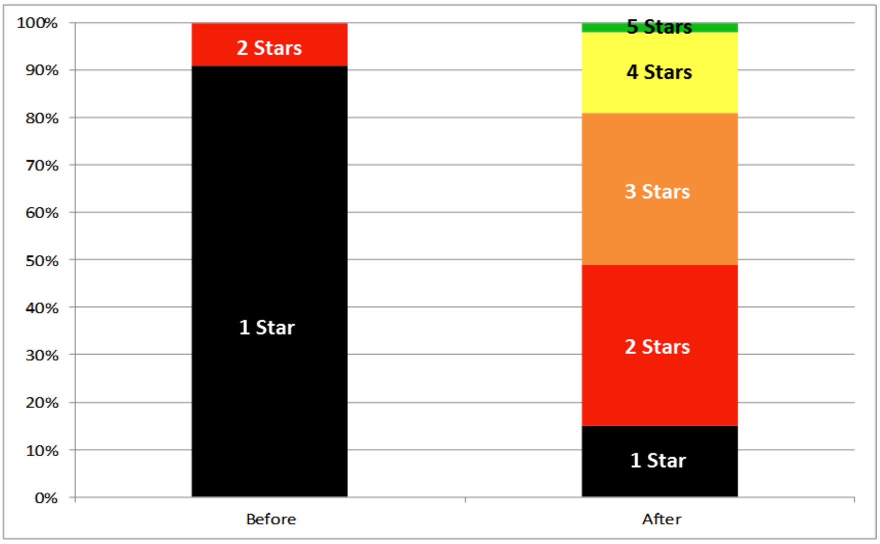

Fig. 3: Star rating upgrading through the implementation of countermeasures

Similar results are available for the entire road network examined and offer to the Road Authorities a sound basis for investments' planning that takes into account the safety level of the roads under consideration and the elimination of the traffic accidents' consequences.

5 CONCLUSIONS

Aim of the paper was to present the iRAP Methodology as well as the results of its application for the safety assessment of the Greek TEN-T Network through a comprehensive case study to two of the most dangerous National roads in Crete Island. It also illustrated the way that these results should be taken into account when designing road maintenance or rehabilitation investment plans. The application of the iRAP method resulted in a reliable Road Safety Inspection (RSI), Ranking (RSR) and Road Safety Impact Assessment for these roads. It showed that the major part (84%) of the specific network offers the lowest safety (1 and 2 Stars). Besides, using the ViDA Software analysis, specific investment plans were proposed, in order to improve the road safety while maximizing the benefit over spent cost.

This integrated approach "from measurement to action" makes iRAP a valuable tool for Road Authorities by enabling them to perform rapid and reliable inspections of the road network, to prepare valuable reports and finally to determine the most effective actions for the elimination of the traffic accidents' consequences.

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